SCHOOL OF PUBLIC HEALTH

COLLEGE OF HEALTH SCIENCES,

UNIVERSITY OF GHANA

LEGON

DIURNAL RHYTHMS OF AMBIENT AIR POLLUTION DUE TO VEHICULAR TRAFFIC IN ACCRA

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THIS DISSERTATION IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER OF PUBLIC HEALTH DEGREE.

JULY 2016

DECLARATION

I hereby declare that apart from references to past and current literature duly cited in this dissertation, the entire research work presented was done by me as a student of the Department of Biological, Environmental and Occupational Health Sciences; School of Public Health, University of Ghana.

It has neither in whole nor in part been submitted for the award of any degree elsewhere.

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DEDICATION

This thesis is dedicated to God Almighty, to my late dad – Williams Sandow, my mum – Elizabeth Sandow, and my brothers – Zibrim, Eddy, Abewini and Fidelis.

ACKNOWLEDGEMENT

I wish to thank Dr John Arko-Mensah, Prof. Julius Fobil and Dr. Judith Koryo Stephens for their advice and immense support during the course of this study. Further appreciation goes to Prince of the Ecological Laboratory at the Department of Geography and Resource Development. This study was funded by the West Africa-Michigan Collaborative Health Alliance for Reshaping Training, Education and Research in Global Environmental and Occupational Health (WEST AFRICA-MICHIGAN CHARTER II).

ABSTRACT

Background: Air pollution has become one of the most serious environmental concerns in cities throughout the world – especially in developing countries. Increase in human and vehicular population has left many streets of developing countries with high levels of congestion and an indiscriminate release of vehicular exhaust emissions polluting ambient air flow and exposing populations to severe health outcomes.

Objective: The aim of this study was to determine the diurnal rhythms of ambient air pollution due to vehicular traffic in Accra.

Methods: The study was a quantitative cross-sectional study which was conducted on five (5) routes. The routes included four (4) major intersections at the Accra-Madina-Adenta route, Kaneshie-Mallam-Kasoa route, Achimota-Pokuase-Ofankor route and the Accra-Tema motorway. The fifth route was on Legon campus specifically on the Limann-Jean Nelson Aka route. Aeroqual 500 series monitors (Aeroqual Limited., Auckland, New Zealand) was used to sample air pollutants; VOCs, CO, SO_2 and NO_2 at specific spots on the respective routes. A GPS was also used to pick the coordinates of each spot on the five routes. GIS version 10 was used to develop maps for the routes. The study was conducted in eight (8) days within a period of 10 hours on each route. Statistical analyses was done with STATA software version 10 (StataCorps LP, Chicago, USA).

Results: Overall, except for NO_2, which had a mean concentration of, (0.10 ppm), the mean concentrations of air pollutants; VOCs (0.16 ppm), CO (2.46 ppm), SO_2 (0.12 ppm) were higher than the acceptable reference values set by the WHO in its air quality guidelines; VOCs (0.02 ppm), CO (0.09), SO_2 (0.175 ppm), NO_2 (0.10 ppm).

Conclusion: Except for NO_2, the average concentrations of air pollutants (VOCs, CO and SO_2) were higher than WHO acceptable levels or standards, which could negatively impact on human health.

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ACRONYMS AND ABBREVIATIONS

ALA	American Lung Association
AMA	Accra Metropolitan Assembly
BTEX	Benzene, Toulene, Ethyl and Xylene
CARB	California Air Resource Based
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COHb	Carboxyhaemoglobin
DANIDA	Danish International Development Agency
DEC	Department of Environmental Conservation
DEP	Diesel Exhaust Particulates
DVLA	Driver and Vehicle Licensing Authority
EGR	Exhaust Gas Recirculation
ELF	Epithelial Lining Fluid
EPA	Environmental Protection Agency
GDI	Gasoline Direct Injection
GHG	Green House Gas
GIS	Geographic Information System
GPS	Global Positioning System
HC	Hydrocarbons
ISTC	International Safety Training Council
Mg/m^3	milligrams per cubic meters
MIC	Methyl Isocyanate
MMT	Metro Mass Transit
Mn	Magnesium
NIOSH	National Institute for Occupational Safety and Health
NOX	Nitrogen Oxides
O_3	Ozone
PAHs	Polycyclic Aromatic Hydrocarbons
PAN	Peroxyacetyl Nitrade
Pb	Lead
PM_{10}	Particulate Matter 10

$PM_{2.5}$	Particulate Matter 2.5
ppb	parts per billion
ppm	parts per million
SSA	Sub-Saharan Africa
UN	United Nations
UNEP	United Nations Environmental Program
UNFPA	United Nations Populations Fund
USAID	United States Agency for International Development
VOCs	Volatile Organic Compounds
WHO	World Health Organization

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Air pollution has become one of the most serious environmental concerns in cities throughout the world – especially in developing countries (AIGBOBO, 2014; Faiz & Sturm, 2002). The United Nations (UN) estimates that more than half of the world's 7 billion human population lives in urban areas and occupies just about 3% of the earth's land mass (Mage et al., 1996). By the year 2030, the world's urban population is expected to increase to almost 65% and a large amount of the new urban dwellers will be in slums and squatter settlements with poor air quality in low-income countries. Sub-Saharan Africa (SSA) is one of the poorest regions in the world. With an urban population growth rate of more than 2% annually, SSA has the fastest urbanization rate in the world (UNFPA, 2007). According to an extensive report by Un-habitat (2010), the urban population of African cities is projected to triple by 2050 to about 1.23 billion people. Many of the large SSA cities have experienced rapid urbanization, industrialization and motorization over the last decade. The shape of cities in these developing countries, and how it will affect the well-being of future urban residents and the global environment, will depend greatly on decisions made now in preparation for this growth (UNFPA, 2007).

Low income levels and lack of economic resources to deal with problems arising from rapid urbanization in countries in SSA have made some cities from this region the most polluted in the world. Road users and also residents in city centers within the immediate vicinity of the traffic arteries are dangerously exposed to pollutants in vehicular exhaust fumes (Kebin, 2010; Kim et al., 2004). Rundell, Caviston, Hollenbach, and Murphy (2006) observed that a reduction of vehicular usage is a prerequisite for the reduction of ambient air concentrations. At intersections, and other disturbance points in the traffic flow, the transient driving patterns, that is, the decelerations and accelerations of vehicles, give substantial additional amounts of emitted exhaust pollution. Kinney et al. (2011), recommend that it is necessary to pay attention to the infrastructural design aspects, when looking for ways of reducing traffic related emissions. Gordian, Haneuse, and Wakefield (2006)also contended that a choice of the optimal design solution for a given intersection with a given flow intensity and flow distribution could be crucial for the surrounding air quality situation. Methods for quantifying the amount of emitted air pollution on the real micro level use various parameters such as driving patterns and traffic management conditions as well as vehicle category, engine type and specific emission factors. It is not a surprise, therefore, that recent studies place vehicular emissions among the top ten risks faced by humans.

To mitigate these effects, technological improvements in internal combustion engines such as Gasoline Direct Injection (GDI) and Exhaust Gas Recirculation (EGR) have been implemented during the last decade to reduce gas emissions. These improvements, however, were overwhelmed by the rapid increase in vehicular population worldwide. According to a World Bank statistics, the global vehicle registrations surpassed one-billion in 2010 (Rundell et al., 2006). As a result, global carbon dioxide CO_2 emissions increased by 9% during the last decade, exceeding 400 parts per million (ppm) in 2015. Studies carried out in the USA and Europe have shown that a small percentage of the car fleet (about 5%) accounts for the 40 - 50% of the total air pollution in urban centres (Kurniawan & Schmidt-Ott, 2006; Kai Zhang & Stuart Batterman, 2013). These observations drive governments and local authorities in many countries to constantly monitor vehicular fleet and establish regulations for reducing the number of high-emitting vehicles on the streets.

However monitoring vehicular emissions has been proven to be very expensive. Based on this, Bourgeois et al., (2003) and later Chiesa et al., (2012) proposed networks or arrays of cost-effective fixed monitoring stations to create real-time, high-resolution air pollutant concentration maps. They built and tested a low-cost monitor for measuring the gaseous emissions of passing vehicles at a stationary point at the side of the road. Emission models and emission calculations on the micro level are needed for making possible cost efficient comparisons between the effects of different measures to be taken, especially for evaluating different infrastructural design alternatives, or traffic management options, and the impact on the environment (Sider, Alam, Farrell, Hatzopoulou, & Eluru, 2014).

1.2 Problem Statement

Air is a universal gas that is odourless, colourless and essential for the existence of all life forms on earth. Air quality is very essential for the sustenance of life. Air pollution due to human activities is an abuse to the environment thereby degrading air quality. Air quality in urban areas is significantly being affected by traffic-related pollutants resulting from the increase use of transportation. City air often contains high levels of pollutants that are harmful to human health (AIGBOBO, 2014). The American Lung Association (ALA, 2007) reported that over 3700 premature deaths annually in the United States could be attributed to a 10-parts per billion (ppb) increase in O_3 levels. Worldwide, the World Health Organization (WHO, 2002a) estimated that more than 1 million premature deaths annually could be attributed to urban air pollution in developing countries. The United Nations Population Fund (UNFPA, 2007) predicted that the urban population worldwide would increase from 3.3 billion in 2008 to 5 billion by 2030. The increase in human population will also be accompanied by an increase in vehicular population meaning that there will be an increase in sensitive and vulnerable population groups such as children and the elderly. More importantly, Wang et al. (2009) further revealed that the young, elderly, pregnant women, sufferers from chronic and lung disease, and street hawkers are more vulnerable to urban air pollution due to vehicular traffic. Therefore, cities with serious air pollution problems need to come up with ways to control the problem and reduce the damages. The major problem of the growing increase in urban air pollution due to urban transportation in Accra is attributable to the increase in vehicular volume. Road traffic congestion has become the predominant source of pollution in many major urban centers of the city. Motorization in the Accra Metropolitan Area (AMA) is high by African standards, at 90 vehicles per 1,000 population, as compared to 20-30 vehicles per the same population for Nairobi, Dar es Salaam, and Addis Ababa (GEF, 2007). This is partly because of the high number of taxis, trotros and a small number of okada i.e. motorcycles used for commercial services. Studies (Whitelegg & Haq, 2003; Zachariadis, Ntziachristos, & Samaras, 2001) in Accra have placed vehicular exhaust emissions as the major source of air pollution attributable to the importation of older poorly maintained vehicles beyond the age of ten (10) years, poor vehicle fuel quality and maintenance culture, and a lack of an effective policy in place to manage the transportation industry. Accra is a typical example of a developing city that has recorded a massive increase in vehicular population. This trend is increasing with 90% of the vehicles imported into the country remaining in the cities. Table 1 shows a summary of the number of vehicles registered by the Driver and Vehicle Licensing Authority (DVLA) for Accra alone from 2000 to 2009. Traffic in Accra is characterized by heavy congestion (particularly during the peak periods), heavy dependence on informal private bus services, weak implementation of traffic management measures, inadequate facilities for pedestrians and bicyclists, poor road safety arrangements and high accident rates. Vehicular exhaust emissions have been a significant cause of poor urban air quality over the years in Ghana (EPA, 2002). However, EPA Ghana has operationalized the monitoring of vehicular emissions using stationary monitors fixed at specific sites [Mention name of sites] to determine air quality in Accra. But considering these interventions, one has to admit that the problem is much weightier than the solutions existing currently, and that the interventions must be revised and improve to match the increasing nature of the problem.

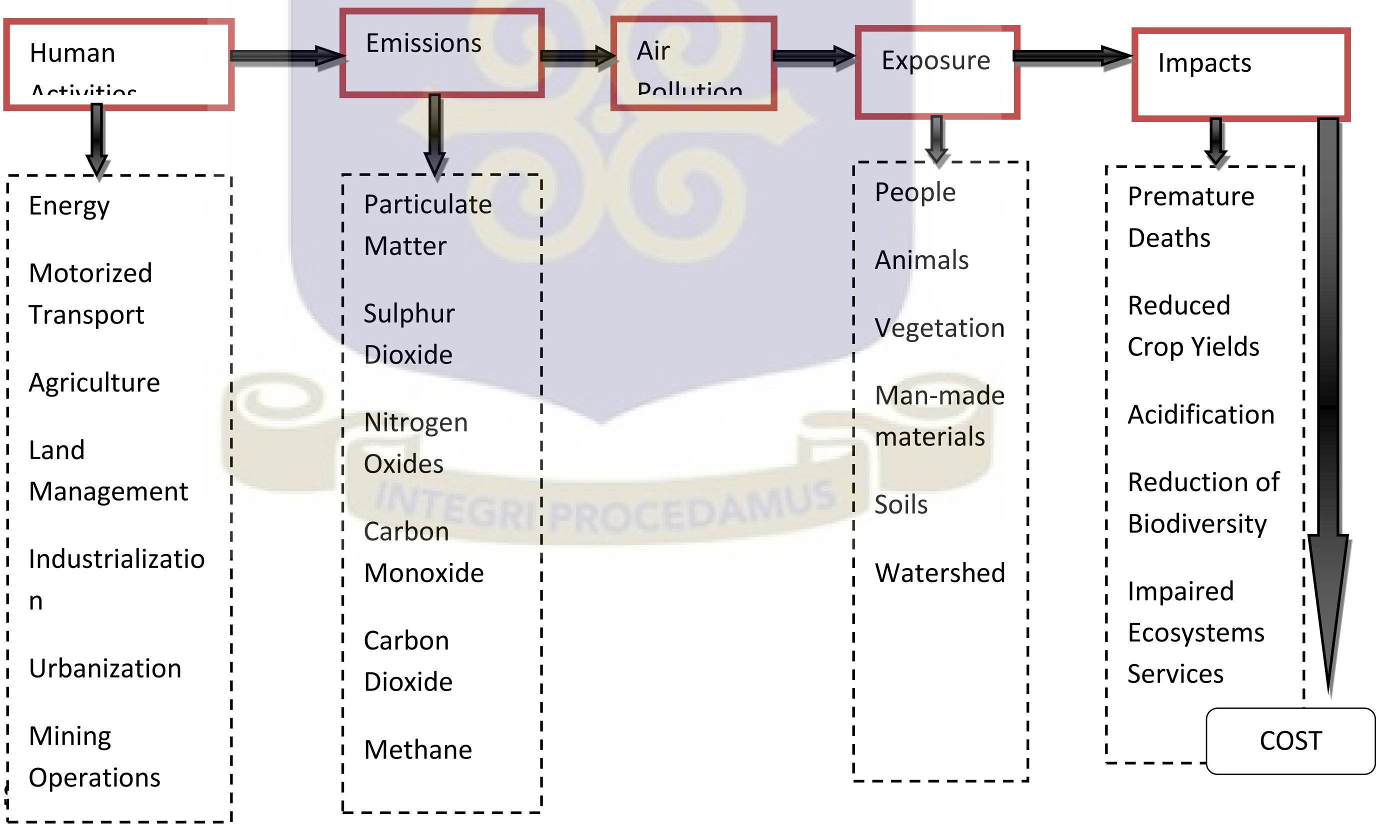
Table 1: Number of Cars Registered between 2000 and 2009

Year	Registered Vehicles (Cumulative)	Year	Registered Vehicles (Cumulative)
2000	511,083	2005	767,067
2001	567,780	2006	841,314
2002	613,153	2007	932,540
2003	643,824	2008	1,033,140
2004	703,372	2009	1,128,138

Source: (DVLA, 2010)

Conceptual Framework

Figure 1: Effects of Vehicular Emissions on Human Development



Source: Fiahagbe (2012)

1.2.1 Summary of Conceptual Framework

Figure 1 above explains that the impact of air pollution in Ghana; emanating from countless sources ranging from the energy sector to mining operations, but significantly impacted upon by human activities. The interaction of man with these independent industries leads to the release of emissions into the atmosphere such as particulate matter, sulphur dioxide, nitrogen dioxide, carbon monoxide etc. The release of emissions into the atmosphere exposes people to premature deaths, affects vegetation by reducing crop yield, man-made materials through acidification. The release of emissions also affects the biodiversity of soils and finally impairs many eco-systems. Fiahagbe suggests from the diagram that suitable interventions that can help address the problems above, all boils down to cost.

1.3 Justification of study

Evidence on the effects of vehicular air pollution is scanty in Accra. The urban transport system in Ghana particularly in Accra, is characterized by the congested central areas of the cities, poor quality of service from public transport operators, high exposure to road accidents, and poor environmental guidelines and standards leading to harmful vehicular emissions in the air and endangering the lives of road users each day (Armah, 2010). This is seen in long commuting times and journey delays, lengthy waiting times for public transport both at and between terminals, high accident rates, and localized poor air quality. Nevertheless this situation is not restricted to Ghana. In addition to the afore-mentioned characteristics, poor vehicle condition and poor infrastructure for non-motorized modes epitomizes Dar-es-Salaam and Hanoi (Armah, 2010).

Rapid urbanization is one of the reasons for the poor state of public transportation in the aforementioned cities. As population continues to increase and as the city continues to sprawl, more people live and work in the city and make more trips within the urban area, often over longer distances. Consequently, the limited capacity of existing transport infrastructure is stretched to the limit and thus, it has become a constraint to cope with the public demand for travel. This study was therefore undertaken in Accra to generate empirical data as contribution to the limited information on vehicular emissions: sulphur dioxide (SO2), nitrogen dioxide (NO2), carbon monoxide (CO), and volatile organic compounds (VOCs) in the largest urban area in Ghana.

1.4 Objectives

1.4.1 General Objective

The general objective of this study was to investigate the diurnal rhythms of ambient air pollution due to vehicular traffic in Accra

1.4.2 Specific Objectives

The specific objectives of the study include the following;

1. Locate areas of heavy vehicular traffic intersection points in Accra for characterization of exhaust emissions.
2. Measure the concentrations of carbon monoxide (CO), volatile organic compounds (VOCs), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2).
3. Compare the concentrations of air pollutants across the different routes
4. Determine the effects of meteorological factors on air pollutants

1.4.3 Expected Outcome

The expected outcome of this study include:

1. Characterization of vehicular emissions according to traffic intersection points.
2. Estimation of concentrations of vehicular emissions on select routes.
3. Comparison of concentrations of emissions across the different routes
4. Determine the effects of meteorological factors on vehicular emissions.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Air is part of the Earth's atmosphere, and one of its most important natural resources. Air is shared and used by all humans, animals and plants to sustain life. Near major industrial centres and in big cities, the air often is of unsatisfactory quality. Air quality degradation is not new – since the middle of the 19th century, the atmosphere of the major British cities was regularly polluted by coal smoke in winter, giving rise to an infamous mixture smoke known as smog, in 1984 the Bhopal gas disaster claimed close to 20,000 lives when 40 tons of Methyl Isocyanate (MIC) gas was released into the air. Today the emphasis has shifted from the pollution problems caused by industry to the ones associated with motor vehicle emissions. Vehicular pollution is a more serious problem in urban environments than in rural settings due to increase in urban mobility demand (Tetteh-Addison, 2012). Urban settings experience air pollution 3 times higher than rural settings, according to projections, the figure will remain largely unchanged by 2030 (Kebin, 2010). In Accra, studies have confirmed that the air is polluted and it has been mainly attributed to vehicular exhaust emissions (Fiahagbe, 2008). Literature related to this study are reviewed under major sub-headings which advances in depth understanding on air pollution due to vehicular traffic.

2.2 Pollution

Seyyednjad, Majdian, Koochak, and Niknejad (2011) defined air pollution as the human introduction into the atmosphere of chemicals, particulate matter, or biological materials that cause harm or discomfort to humans or other living organism, or damage the environment. Pollutants are substances introduced into the environment in an amount sufficient to cause adverse measurable effects on human beings, animals, or materials. Pollutants are referred to as primary pollutants, if they exert the harmful effects in the original form in which they enter the atmosphere. Primary pollutants include CO, CO_2, NO_2, SO_2, most hydrocarbons (HCs) and particulates matter. On the other hand, secondary pollutants are harmful substances formed in the atmosphere when a primary air pollutant reacts with a substance normally found in the atmosphere or with other pollutants, among secondary pollutants are ozone (O_3), hydrogen peroxide, peroxyacetylnitrate (PAN) and peroxybenzoyl nitrate (PBN), HNO_2, SO_3, HNO_3, H_2O_2, NO_3^-, SO_4^{2-} etc. Classification of pollutants can also be according to chemical compositions i.e. organic or inorganic pollutants or according to the state of matter i.e. gaseous or particulate pollutants. Air pollution is basically made up of three components and these are source of pollutants, the transporting medium, which is air and target or receptor which could be man, animal, and structural facility (Abdul Raheem and Adekola, 2011).

2.3 Sources of Air Pollution

In order to better monitor and control air pollution it is essential to accurately identify the emission sources and determine their emissions. As of 1999, the transportation sector, including on-road and non-road vehicles, was estimated by the U.S. Environmental Protection Agency (EPA) to contribute 47% of hydrocarbon (HC) emissions, 55 percent of nitrogen oxides (NOX) emissions, 77 percent of carbon monoxide (CO) emissions, and 25 percent of particulate matter (PM) emissions to the national emission inventory (EPA, 2014).

The presence of airborne pollutants is due to the anthropogenic sources, industrial activities and the effects of natural activities such as volcanoes eruption. These sources emit both primary (directly into the air) and secondary pollutants (formed by chemical reactions within the atmosphere) into the atmosphere (Pooley & Mille, 1999). However, according to Mayer (1999; Pooley & Mille 1999; ADB 2006) most of the airborne particulates are emitted from the combustion engines from vehicles contributing at least 70-75% of the total air pollution. This happened due to the increase of the number of registered road vehicles every year which then become a dominant source of urban air pollution (Brimblecombe, 1999; D'Angiola, Dawidowski, Gomez, and Osses, 2010).

The emission contains carbon monoxide (CO), sulphur dioxide (SO2), Total Suspended Particulates (TSP), Nitrogen Oxides (NOn) and Volatile Organic Compound (VOC) (Mayer, 1999; Percy and Ferretti, 2004) as well as the particulates matter (ADB, 2006) which are released through combustion, fluid leakage, component wear and corrosion metals (Okunola, Uzairu, Ndukwe, and Adewusi, 2008). The common air pollution sources in Nigeria aside traffic emission are; biomass combustion, bush burning, refuse burning, generator emission, gas flaring, industrial emissions and indiscriminate refuse disposal. Table 2 below shows the percentage distribution of principal pollutants from various sources.

Table 2: Sources of the Principal Pollutants in an Average Urban City

Pollutants	CO	NOx	HC
Gasoline vehicles	90%	52%	40%
Domestic	5%	3%	2%
Power stations	1%	26%	<1%
Industry	4%	11%	56%
Others	-	8%	1%

Source: European Fuel Oxygenates Association (2013).

2.4 Overview of Atmospheric Air Pollution in Ghana

In Ghana, and most of the other Sub-Saharan Africa (SSA) countries, there is absence of regular and systematic air quality-monitoring for air quality assessment. As a result, there is a lack of data on the concentrations as well as the characteristics of atmospheric air pollutants. There have been routine monitoring programs in Accra by the Environmental Protection Authority of

Ghana (EPA-Ghana) to measure only particulate matter 10 (PM10). There is no systematic record of PM 2.5 concentrations in Accra, partly because air quality standard for $PM_{2.5}$ has not been established in Ghana. The Environmental Protection Agency of Ghana between March 2005 and December 2008 collaborated with the United States Agency for International Development (USAID), the United States Environmental Protection Agency (USEPA) and the United Nations Environment Programme (UNEP) to set up an urban air quality monitoring network in Accra. The objective of the project was to accurately characterize the seriousness and nature of air pollution problems in Accra and to make recommendations for the development of air quality management strategy for Ghana. Results from the study revealed that vehicular exhaust emissions, is the major contributor to the air quality measured at the monitoring sites.

The EPA in the Ghana State of Environment Report 2004, listed the following as the main issues related to air quality in the country:

- Inefficient utilization of fuels;
- Poorly planned modes of transport;
- Poorly serviced motor vehicles;
- Inefficient cook-stoves and fireplaces;
- Rudimentary kilns and stoves in industries;
- Charcoal production;
- Wide spread bush burning.

2.5 The Transport Sector in Ghana

Ghana's Transport Sector is made up of the following modes: air, inland water, maritime, rail and road transport. The dominant mode is road transportation which accounts for over 95% of all transport services in Ghana. Freight and passenger services are provided largely by private sector owners and operators. Some Government Agencies such as Metro Mass Transit Company (MMT) and International Safety Training Council (ISTC) also provide an extensive network of urban, intra urban, inter-city and rural-urban bus services. Over 80% of the Government's annual budget for the transport sector is channeled into road infrastructure investment. Yet this investment is not able to adequately cater for the transport needs in the country. Economic development has historically been strongly associated with an increase in the demand for transportation. It is believed that the state of a country's transport system is a reflection of its economic growth and development. Car ownership in Accra is increasing at an alarming rate due to economic prosperity. The world vehicle population in 1986 was 500 million but passed the one billion-unit mark in 2010, i.e. just 24 years later. The vehicle/population ratio in Ghana has been growing steadily from 31 vehicles per 1,000 population in 2002, to about 44 vehicles per 1,000 population in 2008. It is estimated that, Accra has the highest number of registered vehicles of 605,739, followed by Tema 256,956 and Kumasi 200,116 as at March 2012. Total number of registered vehicles population in Ghana as at March 2012 stood at approximately 1,425,900 (DVLA, 2012).

Records from the DVLA further indicates that in 2009, 83% of vehicles imported into the country were used cars (second hand), 94% and 97% of older vehicles accounts for freight and traffic movement respectively. This has worsened the ambient air quality particularly in urban and densely populated areas. Increased vehicle population in Ghana, has therefore compromised road safety of travelers and pedestrians, increased traffic congestion, heightened the levels of air pollution in urban centers, and continuously exerts pressure on existing infrastructure due to vehicle population exceeding road capacity. Ghana has indeed made several attempts to reduce vehicular air pollution nevertheless, the country's commitment under the United Nations Framework Convention to minimize emissions is yet to be realized.

Consequently, the Ghana EPA launched a vehicle testing program in 2014 to largely examine the physical conditions of vehicles in order to reduce and phase out grossly polluting vehicles. According to Ghana News Agency (2014), Apex pollution Control Company limited had acquired vehicular test equipment and was tasked with the mandate to initiate a month-long nation-wide trial testing. Despite these among several efforts and attempts, vehicle test exercise is yet to commence in Ghana. In 2005, the vehicular emissions inventory program in collaboration with Danish International Development Agency (DANIDA) Transport Sector Phase II to Ghana was initiated. The main goal of the sub programme was to carry out vehicular emissions (including greenhouse gas emissions) inventory by gathering relevant activity data and on the field emission estimates in the Accra and Kumasi metropolitan areas. The program was intended to ensure that all motor vehicles and motorized equipment in the country and those imported are less pollutant or falls within acceptable emission standards. But since the initiation of the program, emission levels in the country increased linearly from 32,222.78 in 2007 to 52,666.17 in 2006, an estimated rise of 16.67 per cent per annum depending on the commensurate increase in fleet numbers and fuel consumption. Again, programs have been outlined and some implemented to control the level of emissions. They are outlined as follows

- Phase out of leaded gasoline (which was achieved in 2007).
- Deregulation of fuel importation - oil marketing companies can import high quality fuel
- Procurement of crude oil with low sulphur content
- Restriction on Age limit of vehicles imported into the country
- Mainstreaming of environmental issues by ensuring that Strategic Environmental Assessments (SEA) are undertaken for all Transport Sector
- Policies, Plans and Programmes
- Enactment of the Centre for Urban Transportation Bill

Whilst commending the steps taken by the Ghana EPA to reduce vehicular emissions, the World Health Organization (WHO) reports that urban air pollution is responsible for 6500 premature deaths every year in Ghana caused by outdoor air pollution (WHO, 2016). The situation is worsened by the fact that acute respiratory illness caused by air pollution is one of the top 10 causes of outpatient hospital visits in the country.

2.6 Pollutants from Vehicular Traffic

Transportation involves the combustion of fossil fuels to produce energy translated into motion. Pollution is created from incomplete carbon reactions, unburned hydrocarbons or other elements present in the fuel or air during combustion. The principal pollutants from the transport sector responsible for adverse health effects include lead, various types of particulate matter, ozone (formed from atmospheric reactions of oxides of nitrogen and volatile organic compounds), various toxic VOCs, nitrogen dioxide, carbon monoxide, ammonia and sulphur dioxide (Gorham, 2002). According to Ajayi and Dosunmu (2002), the exhaust, the crankcase, the fuel tank and the carburettor are the sources of unburned hydrocarbon (HC). However, the proportion of these various pollutants attributable to the transport sector varies significantly across different cities. Vehicle emissions contribute to the formation of smog which is a mixture of fog and smoke or other airborne pollutants such as exhaust fumes. This can lead to high levels of primary pollutants including nitrogen dioxide (NO_2), carbon monoxide (CO) and particulate matter ($PM_{2.5}$). Extensive studies link smog to a variety of respiratory and cardiovascular symptoms and illnesses.

The effects of vehicular emissions have global implications whilst its health impact varies across continents. K. Zhang and S. Batterman (2013) identified four factors contributing to increased vehicular emissions. They are culture, poor maintenance of vehicles, importation of over used cars and automobile overdependence. They further argued that because all the factors stated above are highly representative to developing countries, the harmful effects of vehicular emissions are likely to have huge implications on the region coupled with the fact that developing countries are confronted with a paucity of standards and guidelines for most of the pollutants present in the air.

2.7 Carbon Monoxide (CO)

The principal source of atmospheric carbon monoxide accounting for nearly 90% is exhaust from gasoline engines, with bonfires, forest fires and waste treatment and disposal processes contributing a large part of the remaining 10% (Kebin, 2010). Carbon monoxide is one of the most dangerous pollutants to human health because it causes a reduction in the oxygen carrying capacity of the blood, resulting in headaches, fatigue, respiratory problems, and in some cases even death. Since the gas is odourless, tasteless and colorless, there is no warning to the exposed person. Carbon monoxide is harmful when breathed because it displaces oxygen in the blood and deprives the heart, brain, and other vital organs of oxygen. Large amounts of CO can lead to loss of consciousness and suffocation without warning. Besides tightness across the chest, initial symptoms of CO poisoning may include headache, fatigue, dizziness, drowsiness, or nausea. Sudden chest pain may occur in people with angina.

According to (Paul, 2008), the annual global emissions of CO into the atmosphere is estimated to be as high as 2,600 million tones, of which about 60% are from human activities and about 40% from natural processes. Anthropogenic emissions of carbon monoxide originate mainly from incomplete combustion of carbonaceous materials. Lipfert and Wyzga (2008), observed that the largest proportion of these emissions is produced as exhausts from internal combustion engines, especially by motor vehicles with petrol engines. Global background concentrations of CO range between 0.06 and 0.14 mg/m^3 (0.05– 0.12 ppm). Approximately 80 to 90% of the absorbed CO binds to haemoglobin to form carboxyhaemoglobin (COHb), which is a specific biomarker of exposure in blood. The affinity of haemoglobin for carbon monoxide is 200–250 times that for oxygen. The toxic effects of carbon monoxide become evident in organs and tissues with high oxygen consumption such as the brain, the heart, exercising skeletal muscle and the developing fetus.

2.8 Nitrogen Oxides (NOx)

Nitrogen oxides are a mixture of gases composed of nitrogen and oxygen. Two of the most toxicologically significant nitrogen oxides are nitric oxide and nitrogen dioxide; both are nonflammable and colorless to brown at room temperature (Brauer et al., 2002). Nitric oxide is a sharp sweet-smelling gas at room temperature, whereas nitrogen dioxide has a strong, harsh odor and is a liquid at room temperature, becoming a reddish-brown gas. Nitrogen dioxide reacts with sunlight, which leads to the formation of ozone and smog conditions in the air we breathe (Vahlsing & Smith, 2011).

The general population is primarily exposed to nitrogen oxides by breathing in air. People who live near combustion sources such as coal burning power plants or areas with heavy motor vehicle use may be exposed to higher levels of nitrogen oxides. Households that burn a lot of wood or use kerosene heaters and gas stoves tend to have higher levels of nitrogen oxides in them when compared to houses without these appliances. (Rietbergen-McCracken & Abaza, 2013), observed that low levels of nitrogen oxides in the air can irritate the eyes, nose, throat, and lungs, possibly causing cough, shortness of breath, tiredness, and nausea.

Depending upon the concentration and duration of exposure, toxic reactions to NO_2 can range from mere mucosal irritation to chemical pneumonitis, acute pulmonary edema or death. There is a latent period from 3 to 30 hours from the time of initial exposure to the onset of potentially fatal pulmonary symptoms (Thiemann, 2005). Gaseous NO_2 diffuses into the epithelial lining fluid (ELF) of the respiratory epithelium and dissolves, and chemically reacts with antioxidant and lipid molecules in the ELF; NO_2's health effects are caused by the reaction products or their metabolites, which are reactive nitrogen species and reactive oxygen species that can drive bronchoconstriction, inflammation, reduced immune response, and may have effects on the heart. Acute harm due to NO_2 exposure is only likely to arise in occupational settings. Direct exposure to the skin can cause irritations and burns. Only very high concentrations of the gaseous form cause immediate distress: 10–20 ppm can cause mild irritation of the nose and throat, 25–50 ppm can cause edema leading to bronchitis or pneumonia, and levels above 100 ppm can cause death due to asphyxiation from fluid in the lungs (NIOSH, 2014). There are often no symptoms at the time of exposure other than transient cough, fatigue or nausea, but over hour's inflammation in the lungs causes' edema. For skin or eye exposure, the affected area is flushed with saline. For inhalation, oxygen is administered, bronchodilators may be administered, and if there are signs of methemoglobinemia, a condition that arises when nitrogen-based compounds affect the hemoglobin in red blood cells, methylene blue may be administered. For the public, chronic exposure to NO_2 can cause respiratory effects including airway inflammation in healthy people and increased respiratory symptoms in people with asthma. NO_2 creates ozone which causes eye irritation and exacerbates respiratory conditions, leading to increased visits to emergency departments and hospital admissions for respiratory issues, especially asthma. The U.S. EPA has set safety levels for environmental exposure to NO_2 at 100 ppb, averaged over one hour, and 53 ppb, averaged annually. As of February 2016, no area of the US was out of compliance with these limits and concentrations ranged between 10–20 ppb, and annual average ambient NO_2 concentrations, as measured at area-wide monitors, have decreased by more than 40% since 1980 (US EPA, 2016).

However, NO_2 concentrations in vehicles and near roadways are appreciably higher than those measured at monitors in the current network. In fact, in-vehicle concentrations can be 2–3 times higher than measured at nearby area-wide monitors. Near-roadway concentrations of NO_2 have been measured to be approximately 30 to 100% higher than concentrations away from roadways. Individuals who spend time on or near major roadways can experience short-term NO_2 exposures considerably higher than measured by the current network. Approximately 16% of U.S. housing units are located within 300 feet (91 m) of a major highway, railroad, or airport (Han & Naeher, 2006). This population likely includes a higher proportion of non-white and economically-disadvantaged people. Studies show a connection between breathing elevated short-term NO_2 concentrations, and increased visits to emergency departments and hospital admissions for respiratory issues, especially asthma. NO_2 exposure concentrations near roadways are of particular concern for susceptible individuals, including asthmatics, children, and the elderly (Haynes, 2011).

2.9 Sulphur Dioxide (SO_2)

Sulphur oxides, primarily sulphur dioxide and lesser quantities of sulphur trioxide are gases formed by the oxidation of sulphur contaminants in fuel on combustion. Sulphur dioxide is a potent respiratory irritant, and has been associated with increased hospital admissions for respiratory and cardiovascular disease (Bascom et al., 1996), as well as mortality (Katsouyanni et al., 1997). Asthmatics are a particularly susceptible group. Studies in New Zealand have shown that sulphur dioxide concentrations are relatively high, and motor vehicles are major contributors to ambient sulphur dioxide, the measured levels in Auckland (for example) have increased in recent years, after many years of decline, as a result of the increasing number of diesel vehicles (and the relatively high sulphur content of diesel in New Zealand). There appears to be a threshold concentration for adverse effects in asthmatics from short term exposures to sulphur dioxide at a concentration of 570 µg m^3, for 15 minutes (Streeton, 1997). Ambient air guidelines/standards are based on this figure, for example the guidelines for New Zealand are 350 µg m^3, 1-hour average, and 120 µg m^3, 24-hour average.

2.10 Volatile Organic Compounds (VOCs)

The term volatile organic compounds (VOCs) encompass thousands of individual chemicals. Common sources of VOCs include: biogenic sources such as odorous plants, industrial sources from refineries and coal power plants and traffic from vehicle exhaust. Although these sources emit many common VOCs, certain VOCs have been used as tracers for a given source type (Baldasano, Delgado, and Calbó 1998). VOCs of particular interest include Benzene, toluene, ethyl benzene and xylene (BTEX). The health effects of benzene is better understood than toluene, ethyl benzene and xylene but studies have yet to find levels of exposure to benzene (US HHS, 2010). Epidemiological studies have found that low-level exposures to benzene are associated with an elevated risk of leukemia (Glass et al. 2003; Bollati et al. 2007).Glass and colleagues further found that chronic exposure to benzene increased the risk of leukemia in Australian refinery workers at exposure levels as low as 1 part per million (ppm) in a year.

Chronic benzene inhalation has been associated with low blood count, bone marrow aplastia, aplastic anemia (a precursor to fibrosis), damage to the immune system, cytopenia, non-Hodgkin lymphoma, acute myelogenous leukemia, and acute non-lymphocytic leukemia (Glass et al. 2003; Bulka et al. 2013) Acute exposure to high concentrations of benzene can cause death from central nervous system depression (Avis and Hutton 1993 U.S.; HHS 2007a). Short exposures to concentrated benzene and BTX (100% benzene and 100% benzene, toluene, and xylenes) among refinery workers increased the risk of leukemia greater than the risk of experiencing the same total exposure at a lower concentration and over a greater amount of time (Glass et al. 2003). Several researchers conclude that even a small exposure to benzene could increase health risks and therefore no safe level of benzene exposure exists (Glass et al. 2003) and (Bollati et al. 2007).

According to Onursal and Gautam (1997) volatile organic compounds (VOCs) are a range of hydrocarbons, the most important of which are benzene, toluene, and xylene, 1,3-butadiene, polycyclic aromatic hydrocarbons (PAHs), formaldehyde and acetaldehyde. The potential health impacts of these include carcinogenic and non-carcinogenic effects. Benzene and PAHs are definitely carcinogenic, 1,3-butadiene and formaldehyde are probably carcinogenic, and acetaldehyde is possibly carcinogenic. Non-carcinogenic effects of toluene and xylene include damage to the central nervous system and skin irritation. Heavier volatile organic (VOCs) compounds are also responsible for much of the odour associated with diesel exhaust emissions. Motor vehicles are the predominant sources of volatile organic compounds in urban areas (Onursal & Gautam, 1997). Benzene, toluene, xylene, and 1,3-butadiene are all largely associated with petrol vehicle emissions. The first three result from the benzene and aromatics contents of petrol, and butadiene results from the olefins content. Evaporative emissions, as well as exhaust emissions, can also be significant, especially for benzene. Motor vehicles are major sources of formaldehyde and acetaldehyde. These carbonyls are very reactive and are important in atmospheric reactions, being products of most photochemical reactions. PAHs arise from the incomplete combustion of fuels, including diesel.

2.11 Particulate Matter

Aerosol particulate matter (PM) is defined is the sum of all solid and liquid particles suspended in air, many of which are hazardous. This complex mixture contains for instance dust, pollen, soot, smoke, and liquid droplets. Technically, the term aerosol refers to both the particles and the gas in which it is suspended. However, it is common practice in literature to use aerosol to refer only to the particles or particulate component inside the atmosphere (Friend et al., 2012; Kulkarni, Baron, & Willeke, 2011; Vallero, 2014). Ambient air particulate pollutants are currently under intensive epidemiological and toxicological investigation. Particulate matter can be seen in two constituents that is aerodynamic diameter equal to or less than 10 or 2.5. The health impact of Particulate Matter is indeed enormous and for that matter detrimental to human health, more attention is paid on the exposure of especially $PM_{2.5}$ as increasing evidence links $PM_{2.5}$ to various respiratory and cardiac effects, and its cardiopulmonary impacts (Goldberg et al., 2001; Janssen, Schwartz, Zanobetti, & Suh, 2002). Natural sources of particulate matter include windblown dust, harmattan dust, natural vegetation (plant fragments, microorganism, pollen, etc.), wildfires, and sea spray. Crustal material, biogenic matter and sea-salt comprise the majority of natural aerosols. Anthropogenic particulates sources are primarily found in industrial locations.

Anthropogenic aerosols are composed of primary emitted soot (elemental carbon), heavy metals, secondary formed carbonaceous material (organic carbon) and inorganic matter (nitrates, sulphates, ammonium and water). Anthropogenic sources of particulate matter and its precursor gases include vehicular emissions, industrial emissions, cooking, heating, agriculture, wood burning, power plants, heavy duty diesel engine, construction and demolition, and dust from disturbed land. They arise mostly from the combustion of fossil fuels, tire and brake wear, and re-suspended dust (Buzorius, Hämeri, Pekkanen, & Kulmala, 1999; EPA, 2004; Ricci, Catalano, & Kelsh, 1996). Heavy metals (e.g. V, Cr, Mn, Co, Ni, Cu, Zn, As, Cd, Ba and Pb) originate from a variety of industrial processes such as incineration, manufacturing, and smelting.

2.12 Determination of Vehicular Emissions

Pollutant emission levels from in-service vehicles vary depending on vehicle characteristics, operating conditions, level of maintenance, fuel characteristics, and ambient conditions such as temperature, humidity, and altitude (Mayer, 2000). The *emission factor* is defined as the estimated average emission rate for a given pollutant for a given class of vehicles. Estimates of vehicle emissions are obtained by multiplying an estimate of the distance traveled by a given class of vehicles by an appropriate emission factor. Because of the many variables that influence vehicle emissions, computer models have been developed that estimate emission factors under any combination of conditions. Two of the most advanced models are the U.S. EPA's MOBILE series (the current version is MOBILE5a), and the EMission FACtors (EMFAC) model developed by the California Air Resources Based (CARB). Both models use statistical relationships based on thousands of emission tests performed on both new and used vehicles. In addition to standard testing conditions, many of these vehicles have been tested at other temperatures, with different grades of fuel, and under different driving cycles (EPA, 2014). Relationships have been developed for vehicles at varying emission control levels, ranging from no control to projections of in-use performance of future low-emission vehicle fleets. Although accurate emission factors and an understanding of the conditions that affect them are obviously important for air quality planning and management, data for in-service vehicles are surprisingly poor.

Table 3: Ambient Air Quality Standards

Pollutants	**Limits +(hours)**	**WHO Guideline Value in ppm**	**Ghana EPA Value in ug/m^3**
Carbon monoxide	1 hour	-----	20 ug/m3
(CO)	24 hours	0.09	35 ug/m3
Sulphur dioxide	1 hour	0.175	10 ug/m3
(SO2)	24 hours	-----	--
Nitrogen dioxide	1 hour	0.10	--
(NO2)	24 hours	-------	50ug/m^3
Volatile Organic	1 hour	0.02	---
Compounds	24 hours	------	15ug/m^3
(VOCs)			

Source (Ghana Environmental Protection Agency, 2012) and (WHO, 2012)

2.13 Relationship between Meteorological Parameters and Emissions

Ambient temperature and humidity are known to have significant impact on most pollutant processes for on-road vehicles. The effects of humidity and temperature on air pollutants has been known for many years. At higher relative humidity, the concentrations of air pollutants such as oxides of nitrogen (NO_2), sulphur oxides (SO_2), hydrocarbons (HC), particulate matter with aerodynamic diameter less than 2.5 ($PM_{2.5}$) has been found at lower concentrations (Lindhjem, Chan, Pollack, & Kite, 2004). Temperature is another meteorological factor that has the capacity to increase or decrease the concentrations of air pollutants under certain conditions. Nam (2008)observed that during cold starts under high temperatures lower emissions were usually recorded below 0.025 ppm for NO_2 and CO. Consequently, findings from Gingrich, Callahan, and Dodge (2003) have also shown that emissions usually increase significantly above 2.25 ppm under high temperatures. This apparent anomalous effect is attributable to complete fleet penetration emissions during hot running of gasoline vehicular engines. As established by Gingrich and colleagues, at higher temperatures beyond 29.37 ^{o}C, emissions obtain higher values. Temperature and humidity affect emissions mainly through three mechanisms: 1) direct effect via temperature adjustment on emission rates; 2) direct effect via humidity correction factor for NOx; 3) indirect effect via air conditioning adjustment. Temperature and relative humidity are used to populate heat index which in turn is used to calculate the fraction of vehicle fleet with air conditioning turned on. As indicated by Choi, Beardsley, Brzezinski, Koupal, and Warila (2011) current analysis examines relationships among meteorological parameters and emissions for: gasoline and diesel for all source types and road types. Although a strong association exists between temperature and relative humidity, efforts are being made to examine each input parameters in isolation. Emissions considered include hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NOx), and total particulate matter ($PM_{2.5}$). For CO, NOx, and $PM_{2.5}$, emissions include cold start emissions and hot stabilized running emissions.

2.14 Adverse Health Effects Associated with Elevated Concentrations of Transport-Related Pollutants

Studies have found that ambient air pollutants are associated with adverse effects on human health. These pollutants can initiate or trigger the occurrence of diseases or as seen in several studies become the outcome of several health conditions. Health conditions or outcomes associated with higher exposures to air pollutants include hypertension, stroke, respiratory diseases and mortality (Allen et al., 2009; Khanna, 2011). Afroz, Hassan, and Ibrahim (2003) subsequently found that the total number of patients affected by respiratory diseases such as asthma and bronchitis increased significantly between 1983 and 1997in Malaysia and this was attributable to exposures to NO_2, SO_2, CO and O_3. Researchers have also found an association between mortality and indicators of traffic-related air pollution in the Netherlands in a full cohort study. It was found that 489 (11%) of 4492 people died during the follow up due to cardiopulmonary disorders. Cardiopulmonary mortality was associated with living near a major road. In fact, the relative risk for living near a major road was 1·41 (0·94–2·12) for total deaths (Hoek, Brunekreef, Goldbohm, Fischer, & van den Brandt, 2002).

As spelled out from above, several air pollutants are associated with detrimental health impacts nevertheless, the ones that have a significant disease burden on populations include particulate matter with aerodynamic diameters less than 2.5 and 10 ($PM_{2.5}$ and PM_{10}). $PM_{2.5}$ and PM_{10} are tiny particles that cannot be seen with the naked eyes. Various studies have shown that affected lung with PM_{10} and other microscopic particles will cause chronic asthma, acute respiratory illness and cardiopulmonary diseases (Ackplakorn et al., 2003; Aditama, 2000; Agarwal, Jayaraman, Anand, & Marimuthu, 2006). The life expectancy could also be reduced in the long-term exposure especially to the elderly and children (Cui et al., 2003; Dai, Song, Gao, & Chen, 2004).

In addition epidemiological studies have shown that a rise in 10 μg/m^3 of PM10 could increase mortality case up to 1% (Hewitt, Stewart, Donovan, & MacKenzie, 2005; Svartengren, Strand, Bylin, Jarup, & Pershagen, 2000). As a whole, air pollution is an episode that causes disruption in daily living, physical discomfort, and illness and reduces life expectancy. Nitrogen oxides and sulfur oxides, for example, are associated with immune system impairment, exacerbation of asthma and chronic respiratory diseases, reduced lung function, and cardiovascular disease (Schwela, 2000) Exposure to carbon monoxide can result in fatigue, headaches, dizziness, loss of consciousness, and even death at very high concentrations (Schwela, 2000). Particulates are especially dangerous because they have been implicated in the development of lung cancer and higher rates of mortality (Schwela, 2000) Lead is similarly dangerous as poisoning causes irreversible neurobehavioral consequences, such as decreased intelligent quotient (IQ) and attention deficits, and death at high levels of poisoning (Schwela, 2000). In addition to these pollutants, vehicle emissions contain volatile organic compounds (VOCs), a class of petroleum combustion by-products which includes many known and probable carcinogens and reproductive toxicants.

VOCs are also hazardous because they can react with sunlight to form ozone, which exacerbates asthma and has other adverse respiratory effects (WHO, 2002b). Studies conducted in Ethiopia, Mozambique, and Kenya found significantly higher prevalence of asthma in urban school children exposed to traffic pollution compared to rural children (Mavale-Manuel et al., 2004; Odhiambo et al., 1998; Yemaneberhan et al., 1997). In a small city in Ethiopia, individuals living closer to roads experienced more wheeze at levels comparable to those observed in developed countries with twice the traffic volume, resulting from the high proportion of super emitters (BRUNEKREEF et al., 2005; Venn, Yemaneberhan, Lewis, Parry, & Britton, 2005). In Ghana, street hawkers are most exposed to vehicular emissions because they spend long hours beyond the time weighted average offering goods and service for sale with the purposes of earning a living (AIGBOBO, 2014)

As usual, developing countries in Asia and Africa are at high risk to exposure of this traffic-related pollution. Research conducted in Ethiopia, Mozambique, Kenya and Republic of Benin, show that there is a high level of DNA damage in urban residents and higher prevalence of asthma in urban school children exposed to traffic pollution compared to rural children (Fanou et al., 2005). The African continent may be highly heated if priority is not given in understanding the scale of this problem and its control. A number of epidemiological studies have similarly linked exposure to vehicle emissions with adverse health outcomes. For example, in the US, chronic exposure to vehicle emissions over 10 years decreased lung function among tunnel officers (Ayres et al., 1973).

A comparison of the prevalence of chronic bronchitis and asthma among street cleaners, a high exposure group, and cemetery workers, who acted as controls, found that exposure to vehicle pollutants in concentrations lower than WHO-recommended guidelines resulted in a significant increase in respiratory effects (Raaschou-Nielsen, Nielsen, & Gehl, 1995; Rudell et al., 1996). Moreover, a significant relationship between residence proximity to high traffic roads and prevalence of asthma and cardiovascular disease in children has been documented (Araujo et al., 2008), in addition to a strong relationship between proximity to congested roads and respiratory morbidity in infants. There is mixed evidence for a relationship between exposure and low birth weight, preterm birth and birth defects (Šrám, Binková, Dejmek, & Bobak, 2005). Clearly, the public health impacts of exposure to traffic pollution are serious and diverse.

Table 4: Summary of Health Effects of Vehicular Emissions

Health Effects	Source
1. Increased morbidity and mortality risk due to respiratory and cardiopulmonary causes	(WHO, 2002b)
2. Hypertension, and stroke 3. Cardiopulmonary mortality	Surachi & Khanna 2011
4. Decreased IQ, attention deficient and death Coronary heart disease	(Schwela, 2000)
5. Lung cancer	(Raaschou-Nielsen et al., 1995)
6. Persistent wheezing, lower peak expiratory flow and sensitization to pollen	(Afroz et al., 2003)
7. Chronic bronchitis, lung cancer, asthma and atherosclerosis	(Araujo et al., 2008)
8. Mutation of genetic material of cells, and chromosomal and DNA damage, reduced lung function	(Schwela, 2000)
9. Bronchitis and asthma	(Afroz et al., 2003)
10. Chronic asthma and cardiopulmonary diseases	(Aditama, 2000; Allen et al., 2009)
11. Bronchoconstriction symptoms 12. Low birth weight	(Rudell et al., 1996; Šrám et al., 2005)

2.14 Role of Vegetation in Pollutant Removal

Urban forest consists of multiple species of vegetation which are intentionally planted or naturally grown within the urban areas. It contains a diverse mix of plant species which are arranged in heterogeneous or homogenous patterns (McPherson et al., 1997). The urban forest plays multiple roles both in human and ecosystem services (Wolf, 2006). Urban forest helps in maintaining the oxygen released through photosynthesis and absorbing carbon dioxide through carbon sequestration which helps in improving the air quality of the urban areas (Johnson, Jamriska, Morawska, & Ferreira, 2000; McPherson & Simpson, 1999; Yang, McBride, Zhou, & Sun, 2005)

The trees cool down the cities by shading and evapo-transpiration as well as reducing the urban heat island intensity (Yang et al., 2005). Nowak, Crane, and Stevens (2006)found that the trees canopy and transpiration process may alleviate the temperature of a city besides controlling the **wind speed,** relative humidity and heat storage efficiency. In order to mitigate this problem, urban forest strategy and implementation should be planned accordingly.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Introduction

The study area and the methodology of the study are described here. A detailed description of the study design using a diagram that depicts sampling points of vehicular emissions along selected routes of the study is provided. Also the individual maps for the respective routes on which the study was conducted has been presented.

3.2 Study Location

Accra (5o 33' N, 0o 13' W), the capital city of Ghana is one of the fastest-growing cities in sub-Sahara Africa (Møller-Jensen *et al*., 2005; CIA, 2011). With an estimated population growth rate of about 4% per annum, Accra has an estimated population of about 4 million (GSS, 2015). The Accra Metropolitan Area (AMA) with a population density of 112 per kilometre squared, has almost 42% of the total population of the Greater Accra Region. Four (4) major routes known to have high vehicular traffic; Kaneshie-Mallam-Kasoa route (KMK), Achimota-Ofankor-Pokuase route (AOP), Accra-Madina-Adenta (AMA) route, the Accra-Tema motorway (AT) and a route on the University of Ghana campus (spanning from the Limann hall through Jean Nelson Aka in Accra) were selected for this study. Study routes were selected such that they lie on a nearly straight line from the coast to the northern boundaries of the AMA, and they have varying daily vehicular pressure traversing the routes as previously described (Agyei-Mensah & Owusu 2009). The four routes were selected because they are densely populated by automobiles with an estimated 1.3 million cars ploughing these routes in and out of Accra each day (Armah, Yawson, & Pappoe, 2010). Pictorially, the routes each lie within a straight line. For each of these routes, KMK lies towards Accra East, AOP lies towards

Accra north, AMA is located in a straight line towards Accra South and AT is located towards Accra West.

3.3 Study Design

The study adopted a cross-sectional quantitative study to investigate air pollution in Accra. In essence, the study was conducted on five routes in the Accra Metropolis. Four busy routes that records heavy traffic due to vehicular movements were used namely; Zongo junction located on the Accra-Madina-Adenta route, Bar yard intersection which is located on the Kaneshie-Mallam-Kasoa route, Achimota roundabout located on the Achimota-Pokuase-Ofankor route and the Tema B1 toll booth on the Tema motorway. The fifth route was on the University of Ghana campus i.e. the Limann-Jean Nelson Aka route. Specific points were marked on each of the routes where monitors were placed on stands to enable an effective monitoring of emissions. However, the number of points used on each of the routes were not equal considering the nature of the route. A total of seventeen (17) spots were used on the Zongo junction, Bar yard intersection and Achimota roundabout. A total of eleven (11) spots were used on the Tema motorway because the route had no intersection but recorded heavy vehicular traffic. Five (5) points were used on the Limann-Jean Nelson Aka route, a route characterized by low vehicular volumes which also served as a control route. The measurements were carried out from the 23rd of June 2016 to 1st July 2016. Monitoring sites within the routes were selected as follows:

1. Emission monitoring at Bar Yard intersection, Achimota intersection and Zongo junction: this intersection had four cross-roads connecting to the intersection and an epicenter. A total of seventeen (17) points were used on this route. Using the labels on the cardinal points, four spots each were measured towards north, south, east and west of the intersection whilst considering the epicenter as the first point. A period of two

days was used to complete the exercise whilst 10 hours was used each day until the process was over. The same procedure described above for Bar yard intersection was used for the Achimota roundabout and Zongo junction. The method adopted allowed for the determination of the dispersion of air pollutants along the different routes given their unique features.

2. Considering the variations and different characteristics on the routes adopted eleven points was used at the Tema route to examine the daily patterns and concentrations of emissions considering the road facing north and south of the route.

3. Emission modelling was done on Legon campus specifically on the route that links Limann hall to the Jean Nelson Aka hall on the University of Ghana campus. This route was designated as the control route to the rest of the other busy routes selected.

Figure 2: A Diagram Showing Sampling Points of Air Pollutants

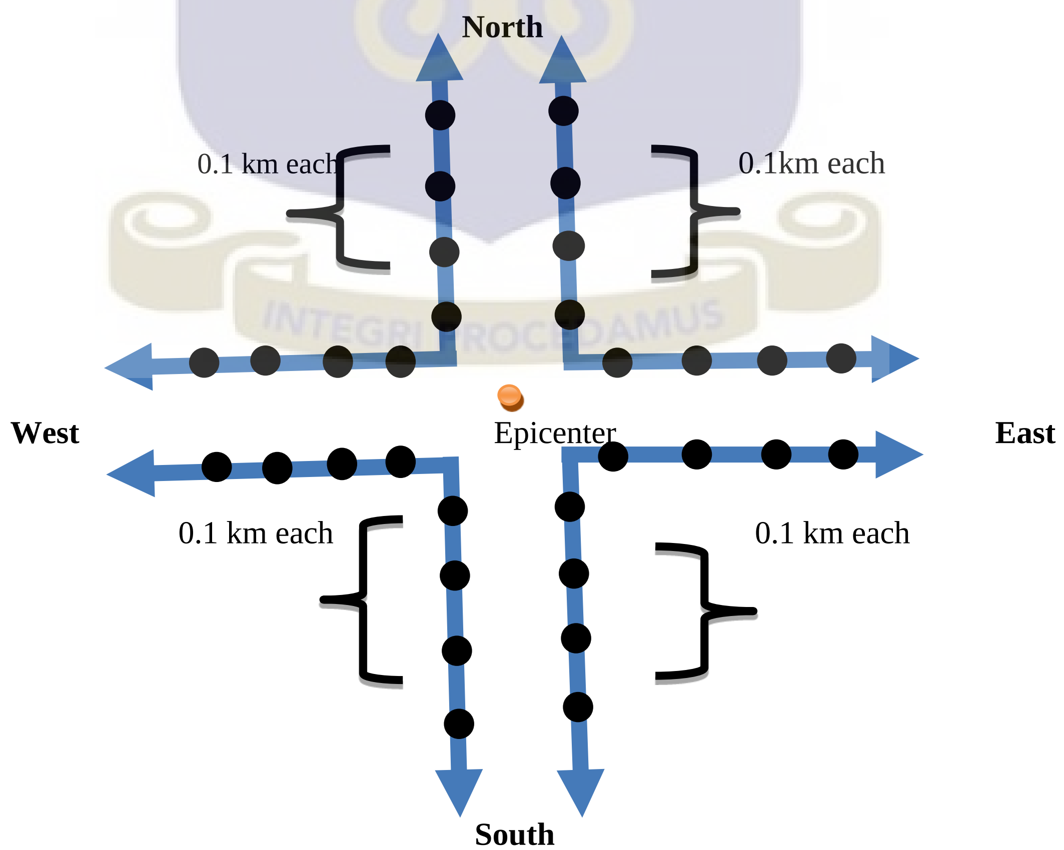


Figure 2 above is a directional guide for sampling and modeling air pollutants on selected routes. Specifically, the routes included four (4) major trunk routes that span busy traffic intersections and one (1) route on Legon campus to serve as a control. A Global Positioning System (GPS) was used to pick the coordinates on specific points on each of the select routes. As shown in Figure 2 above, sampling of emissions was done at the epicenter on each route before proceeding on the other four points towards north, south, west and east sections of the route. A total of seventeen (17) points was adopted for emission modelling except Tema motorway, where emissions were monitored towards north and south because there was no intersection on the motorway. A total of eleven (11) sampling points was used at the Tema route. Using a control route on Legon campus, the concentration of emissions was taken on a straight route beginning from the Liman Hall junction to the Jean Nelson Aka hall. On each of the four spots identified and marked for data collection, two (2) Aeroqual mobile equipment were placed on a stand about 0.5 meters elevation above ground level and the equipment was programed to log data for every 1 min over a total time interval of 30 min preset to sample air pollutants. Sampling of emissions was done in eight (8) days.

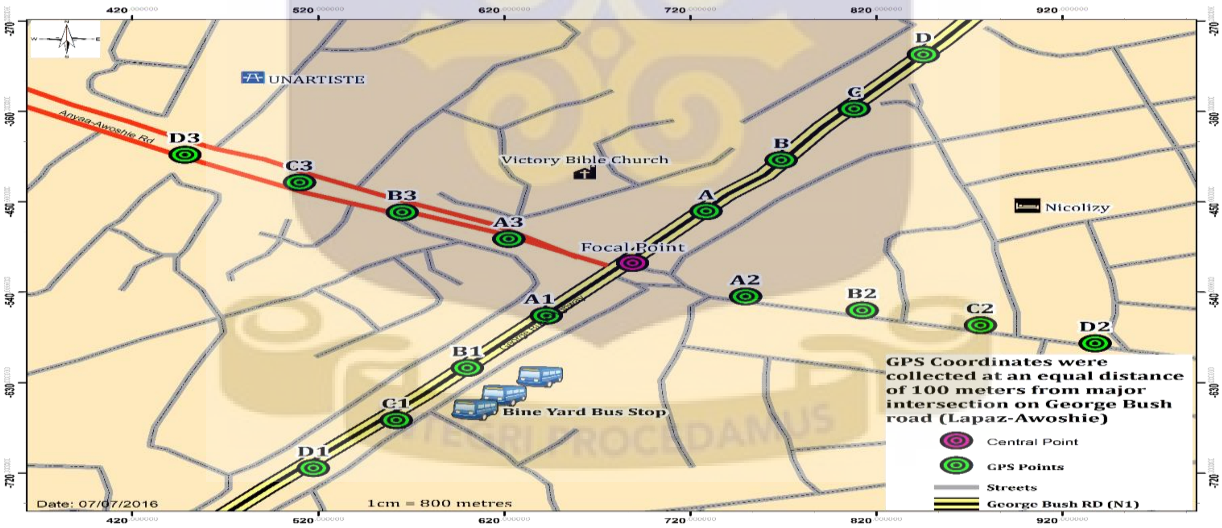
3.3 Sampling Procedure of Vehicular Emissions

The nature of the study required the knowledge and application of Geographic Information Systems (GIS). Usually, GIS application helps to present landscape features, such as roads, buildings, streets, et cetera in terms of their geographic positions. This therefore enhances digital representations of various features and their attributes as they are on the ground. The operational procedure involved in the data collection consisted of two additional android applications, namely GPS Distance meter android version 4.0 and GPS Coordinates application **3.2**. These android applications were also used in order to obtain accurate spatial data (i.e. geographic referenced data). GPS Distance Meter application android version **4.0** consists of digital Mechanical Odometer which indicates the distance walked from one point to the other. The application was set to measure distance in 'Meters', through internet connection and Global Positioning System (GPS). The GPS technology was used in taking precise spatial reference data (i.e. latitudes / longitudes coordinates) from each distance measured. And each GPS coordinate was collected from every 100 meters distance walk along the targeted roads of study as illustrated in the respective maps in **3.3.1** to **3.3.5.** Base map for each of the locations developed was captured from Google Map. This was done to identify notable natural and cultural (man-made) features in all the areas where the respective coordinates were collected, to be incorporated in the designed maps. Finally, GIS application version 10.0 was used in developing referenced maps. In this application, the ArcCatalog and ArcMap were respectively used in the creation of shape files, digitizing and designing the maps.

3.3.1 Vehicular Exhaust Emissions at Kanashie-Mallam-Kasoa Route

Sampling of air emissions took place at the Bar yard intersection; the intersection is characterized with high vehicular volumes and human activity during traffic peak hours as compared to the rest of the intersections. Air pollutants were sampled using Aeroqual 500 series monitors (Aeroqual Limited., Auckland, New Zealand) fitted with sensor heads of CO, NO_2, SO_2 and VOCs. Sampling of air pollutants was done over a period of ten (10) hours; with the first two (2) hours between 6am to 8am dedicated to identifying specific spots on which the equipment was placed to monitor emissions. Using the positions on the cardinal points, four (4) points were taking north towards Lapaz and another four (4) points towards south leading to Kasoa. The rest of the points were taken west and east towards Ablekuma and Odorkor respectively. But emissions were taken simultaneously as the points were being determined for the entire route. All the gases for the respective air pollutants were taken at the epicenter, CO and VOCs were first used to sample air pollutants for a period of 30 minutes, after the time had elapsed, the sensor heads were removed and replaced with SO_2 and NO_2 sensor heads for which air pollutants were also sampled for the same time period. From the epicenter, the aeroqual equipment was hibernated and taken to point 1 facing north of the road. With SO_2 and NO_2 sensor heads still fixed on the aeroqual equipment, emissions were taken from point 1 to points 4 for a period of 30 minutes on each point. SO_2 and NO_2 sensors were removed at point 4 and replaced with CO and VOCs. Air pollutants were then sampled for CO and VOCs from point 4 back to point 1. After monitoring air pollutants towards north of the route, the process was continued towards south of the route at point 1 for CO and VOCs gases monitored to point 4. Again CO and VOCs sensor heads were swapped with SO_2 and NO_2 sensors and emissions were sampled from point 4 to point 1. Emissions were sampled for all the four gases on north and south of the route in one day. Air pollutants were sampled on the west and east part of the route on a different day using the same process described above.

Figure 3: A Map showing Air Sampling Points at Bar Yard Intersection

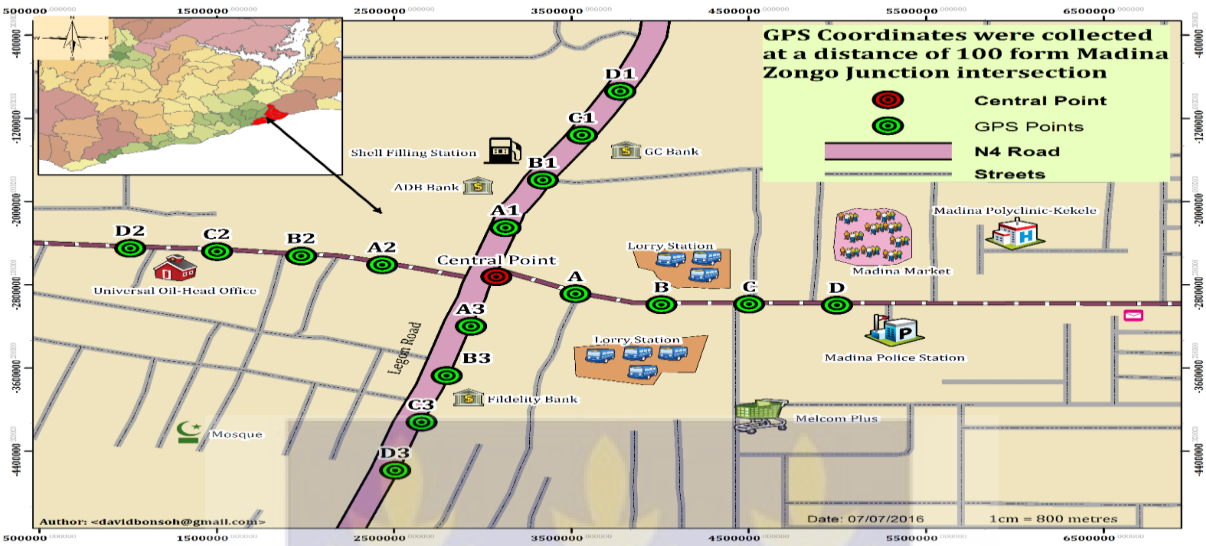


Source: (Author's Construction, 2016)

3.3.2 Sampling of Air Emissions at Accra-Madina-Adenta Route

Similarly as described in **3.3.1**, a period of two days was also used to sample vehicular emissions on this route at the Zongo junction which records heavy vehicular movements coupled with increased human activity which very often leads to the generation of dust. The route is a major cross road that lies north towards Accra, south towards Adenta, east towards Ashribotwe (on the Madina market road) and West towards Abogba. In one day the study attempted to sample air pollutants for CO and VOCs on the four cross roads of the intersection whilst considering SO_2 and NO_2 for another day. The first point for CO and VOCs was taken at the epicenter of the road, and on each side of the cross roads four (4) points each were marked considering an equidistance of 100 m between the four points and labelled as point 1, 2, 3 and 4. A total period 30 min was used for each point, the equipment was also hibernated each time movements were made from one point to the other to continue emission monitoring. The equipment was placed on a stand at 0.5 m elevation above the ground. After the epicenter, emission monitoring was done towards north of the road which lies vertical from the epicenter facing Accra whilst the equipment was taken to the hibernation mode. Moving from a 100 m from the epicenter and on the middle lane of the road, the equipment was placed opposite each other and close on the edges of the lane which allowed for effective sampling of emissions. The procedure adopted for emission sampling towards the north of the road was also used for each of the independent roads selected towards south, west and east. But whilst sampling air pollutants towards East of the intersection and at point 2, the battery of monitor 2 run out 15 min after air samples were taken; from this time forward, only CO was sampled at point 2, point 3 and point 4. Upon reaching point 4, VOC sensor head was inserted into monitor 1 and emission reading was taken from point 4, point 3 and point 2 for VOC. Emission monitoring on the four spots identified on the west lane of the route could not be completed as planned except that only VOC gases were recorded at point 1 on this direction after which the battery for monitor 1 also rundown. Another day was allocated for the completion of the exercise on all the points for CO and VOCs on the west lane. SO_2 and NO_2 were also sampled on a different day but also from morning to evening following the same procedure used to sample CO and VOCs.

Figure 4: A Map showing Air Sampling Points at Zongo Junction, Madina

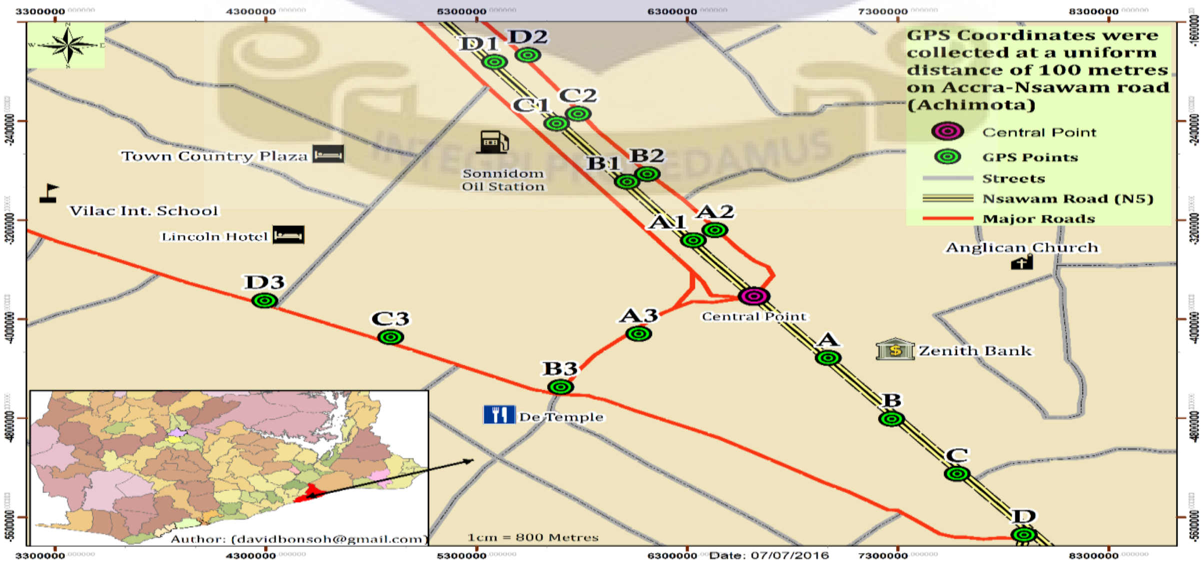


Source: (Author's Construction, 2016)

3.3.3 Achimota-Ofankor-Pokuase Route

The procedure described in **3.3.1** and **3.3.2** was applied on this route. Emissions were first taken at the epicenter identified at the Achimota roundabout and about 2 meters away from the four cross roads. Air pollutants were taken north towards Accra, south towards Pokuase, west towards Chantan and East towards Mile 7.

Figure 5: A Map Showing Sampling Points at Achimota Roundabout



Source: (Authors Construction, 2016)

3.3.4 Tema Motor Way

At the Tema motorway, emissions were taken for only north and south of the route because the route have no intersection. Air pollutants were sampled using the Tema toll both (B1 tollbooth). The four (4) gases for the respective air pollutants were sampled at the epicenter. After sampling emissions at the epicenter, measurements for air pollutants were taken towards north and south. The lack of an intersection on the route required that the number of points be increased from 4 to 5 since the emissions were only measured in two directions. Therefore unlike the other routes described earlier in **3.3.1** to **3.3.3,** air samples were taken on five spots on the Tema motorway to allow for a fair comparison between the other routes in terms of the levels of dispersion of vehicular emissions.

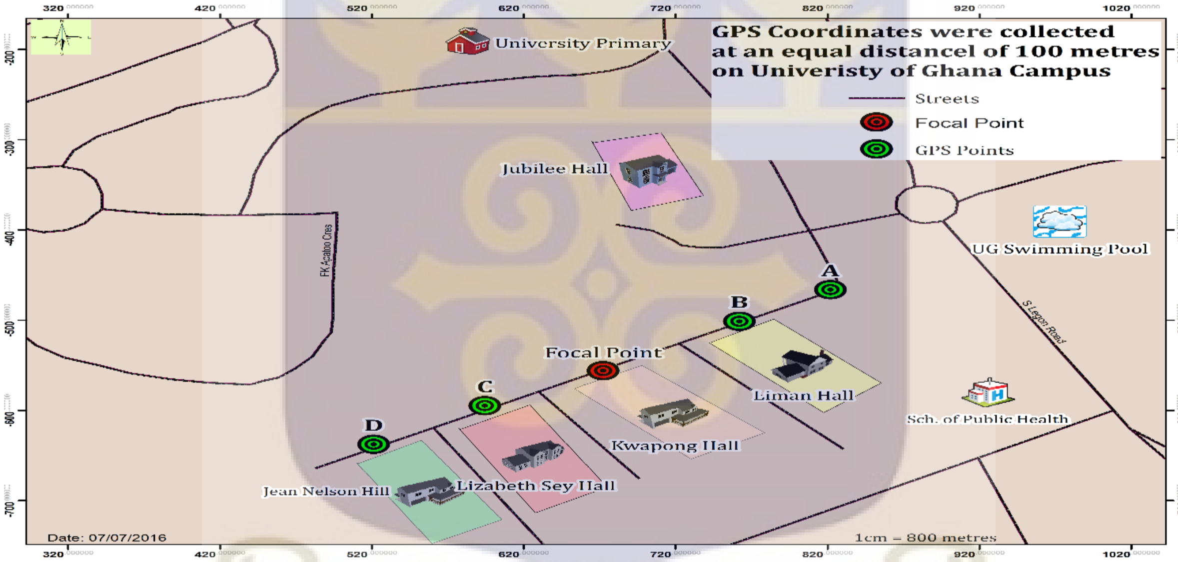
Figure 6: A Map Showing Sampling Points at the Accra-Tema Motorway

Source: (Authors Construction, 2016)

3.3.5 Limann-Jean Nelson Aka Route

The Limann route stretching along the Jean Nelson Aka hall on the University of Ghana campus was used the final route for sampling vehicular emissions. The route records low vehicular activities, at least for the period the study was conducted. This was done to determine the level of concentration of air pollutants within less busy routes and to compare this between very busy routes. Using this route also helped to verify whether high concentrations of air pollutants on major trunk routes is only attributable to vehicular emissions. Emission monitoring was done on four (4) vertical spots with point one located with at Limann hall, point two (2) was located about 3 m behind Kwapong hall, the third point was at Elizabeth Sey hall and the final point was located at Jean Nealson Aka hall. CO and VOCs were measured first on the four spots from point 1 to point 4 whilst readings for SO2 and NO2 were done from point 4 to point 1.

Figure 7: A Map Showing Sampling Points on Legon Campus



Source: (Authors Construction, 2016)

3.4 Data Collection Techniques

Data on air pollution was collected considering specific air pollutants. Parameters measured included gases such as CO, NO_2, VOC, SO_2 as well as temperature and relative humidity. Two (2) Aeroqual series 500 (Aeroqual Limited., Auckland, New Zealand) were used. The equipment comes with a monitor and a sensor head specific for each air pollutant. This particular instrument was chosen for its simplicity and reliability in operation, ease of handling, and rapidity in obtaining the gas concentration directly. The Aerpqual device is able to measure specific air pollutants targeted in addition to meteorological factors such as temperature and humidity. The measurement units were in milligram per cubic meter (mg/m^3). The sensor head was warmed up for 3m to burn off any contaminants prior to usage. The monitors were also put in Stand By mode when they were not being used or when movements were made from one point to the other to sample air pollutants, putting the monitor on Stand By mode was crucial to the extent that it kept the sensors heated and also prevented the build-up of contaminants. For each point considered for the measurement of air pollutants, the equipment was placed on a 0.5 m stand above ground level for a period of 30 m. The sensors were turned to face the direction of emissions emanating from vehicular movements and as the vehicles sped through the routes, the concentrations of the pollutants were recorded for every 1 minute. The operating parameters for the sensors are as follows; CO (detection range 0 – 100 ppm; resolution 0.05 ppm; temperature 0 - 40 ^oC; relative humidity 5 to 95%), SO2 (detection range 0– 10 ppm; resolution 0.2 ppm; temperature -20 - 40 ^oC; relative humidity 5 to 95%), NO2 (detection range 0 – 200 ppb; resolution 1 ppb; temperature 0 - 40 ^oC; relative humidity 30 to 70%) and VOCs (detection range 0 – 0.010 ppm; resolution 0.001 ppm; temperature -5 to 40 ^oC; relative humidity 5 - 95 %). The instrument was also capable of collecting meteorological data such as temperature and relative humidity.

Figure 8: Aeroqual Monitors used to Log Air Pollutants during Field Work

3.5 Study Variables

The variables of the study included carbon monoxide (CO), sulphur dioxide (SO2), nitrogen dioxide (NO2) and volatile organic compounds (VOCs), relative humidity (RH), and temperature.

3.6 Quality Control

Collection of data required the usage of experienced research assistants with a high familiarity with the equipment prescribed for the sampling of air pollutants, to ensure that data was taken as planned. The Aeroqual equipment (Aeroqual Limited., Auckland, New Zealand) was charged overnight prior to usage the next day. The equipment was also calibrated to log data for every one minute and labelled as monitor one and two. Monitor 1 was used for CO and VOC sensor heads whilst Monitor 2 was used SO_2 and NO_2 heads. Chargers for the equipment was also taken to the field so that when the battery of any of the equipment went down for some reasons unaccounted for, they were charged for a period of one hour and returned to the field for the continual sampling of air pollutants. During the period for which the data was collected, a stop watch was used to count upward from zero to 30 minutes after which the sampling was stopped. Additionally the logged data on the equipment was also logged to a laptop after each day's activity. The transferred data was further copied into excel and organized according to the locations where the data first taken.

3.7 Data Processing and Analysis

A thorough descriptive analysis of the data was conducted to measure the concentration of CO, VOCs, NO_2 and SO_2 to this end also, a descriptive test was done to define the averages of the meteorological parameters. As a result, statistical tests was done to compare the mean concentration across the different routes using a multivariate analysis of variance (Mannova). Moreover a multiple comparison test was also conducted in order to ascertain a statistically significant mean differences across the various routes with respect to the underlying pollutants.

Furthermore a correlation analysis was conducted to measure the association between the atmospheric air pollutants and meteorological parameters. Finally a multiple linear regression was fitted to assess to the effects of meteorological factors on air pollutant concentrations.

3.8 Pre-Test

A pre-test was done to give an appropriate estimation of the period of time likely to be used for the study especially on each of the selected routes and to identify the challenges that the study confronted with. The Okponglo intersection was used for the pre-test. An initial 0.5 km between four equidistant points was adopted for the study, but the 0.5km was converted into its equivalent in meters (500 m) because the odometer device that was used to calculate the distance trekked records in meters; following this procedure four points were marked towards north facing Adenta, south towards Accra, east towards Legon and west towards the University of Ghana. In the process of the field work it was realized that the 500 m equidistance was far apart from points where there were heavy vehicular activities and also the dispersion of emissions as they were being released from vehicles could be far away from the points determined. Therefore a 0.1km (100 m) was adopted for the study. The equidistance of 100m used drew the points closer to locations with high vehicular volumes. An etrex GPS device was to be used to pick the coordinates for the points and mark specific points for the monitoring of emissions but the device was cumbersome to use and could not also be used to measure the 0.1 km between points, alternatively, a GPS Distance meter android version 4.0 and GPS Coordinates application 3.2 was used instead. Consequently, a control route was adopted to give justification that vehicular emissions were higher in areas with frequent vehicular activities than areas with relatively lower vehicular emissions. Therefore, the Limann route heading towards Jean Nelson Aka hall was used as a control route.

CHAPTER FOUR

4.0 RESULTS

4.1 Introduction

The study used Aeroqual 500 series (Aeroqual Limited., Auckland, New Zealand) for continuous measurements of air pollutants; volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2), as well as meteorological parameters; temperature and relative humidity (RH). Aeroqual 500 has an internal sampler that records vehicular exhaust concentrations in micrograms per meters cube (ug/mg^3) from moving vehicles within the respective routes considered. The monitors were programmed to read concentrations from vehicular emissions for 30 minutes on specific points. The equipment had a data logger with which concentrations were logged and read directly from the sampler for every 1 minute over a period of 30 minutes at the specific monitoring sites. Logged data were transferred to Microsoft Excel version 13 (Microsoft Corporation, Washington, USA) for organization and analysis. The data was further used to run desired statistical tests to indicate the concentrations of vehicular emissions across the routes considered using Stata version 10 (Stata Corporation LP, Chicago, USA). Concentrations in milligrams per meters cube were converted to parts per million (ppm) for an appropriate comparison with WHO air quality guidelines.

4.2 The Mean Concentrations of the Air Pollutants Measured; NO_2, SO_2, CO and VOC.

Table 5: Concentrations of Air Pollutants across the Different Routes

	Concentrations of Air Pollutants in parts per million (ppm)							
Vehicular route	VOCs Mean	P-Value	CO Mean	P-Value	SO_2 Mean	P-Value	NO_2 Mean	P-Value
Kaneshie-Mallam-Kasoa	0.133		1.955		0.140		0.088	
Accra-Madina-Adenta	0.183		2.981		0.140		0.105	
Achimota-Ofankor-Pokuase	0.131	<0.001	3.596	<0.001	0.117	<0.001	0.102	<0.001
Accra-Tema	0.188		1.491		0.089		0.099	
Legon campus	0.208		0.260		0.014		0.097	

There were significant differences between the mean levels of air pollutants across different routes. Except for VOC, levels of CO, NO_2 and SO_2 were highest on the Accra-Madina-Adenta route. Concentrations of VOCs were highest on Legon campus (0.208 ppm) as measured on the Limann-Jean Nelson Aka route, and lowest on the Achimota-Ofankor-Adenta route. In contrast to VOC levels, Legon campus recorded the lowest levels of CO, NO_2 and SO_2. In general, conncentrations of SO_2 and NO_2 were lower on all the routes, compared to CO and VOC. With regard to SO2, the Kaneshie-Mallam-Kasoa and the Accra-Madina-Adenta routes recorded higher concentrations (0.140 ppm) Accra-Tema motorway, Achimota-Pokuase-Ofankor and Legon campus.

4.3. The Relationship between Emission Parameters and Meteorological Factors.

Table 6: Relationship between Emission Parameters and Meteorological Factors

	Relative Humidity				Temperature			
Dependent Variable	Coeff	Std err	95% CI	p-value	Coeff	Std err	95% CI	p-value
VOC	0.006	0.001	0.004,0.009	<0.001	0.014	0.003	0.007, 0.022	<0.001
CO	-0.163	0.050	-0.261, -0.064	0.007	-0.458	0.169	-0.789, -0.126	0.007
SO_2	-0.005	0.001	-0.007, -0.002	<0.001	0.000	0.003	-0.007, 0.008	0.844
NO_2	0.000	0.000	-0.000, 0.001	0.187	0.002	0.001	-0.000, 0.004	0.072

There were strong associations between meteorological factors and levels of air pollutants at ($p< 0.001$). Table 6 shows a positive association between relative humidity (RH) and VOCs. It was observed that a unit change in RH increased the concentrations of VOCs by 0.006 ppm at constant temperature. Although there were associations between RH and NO_2, a unit change in RH almost had no significant effect on NO_2 at constant temperature as presented in Table 6. In contrast to VOC and NO_2, a negative association was found between RH and CO or SO_2.. A unit change in RH decreased the concentrations of CO and SO_2 respectively whilst temperature was constant. (Table 6). A significant association was found between temperature and VOCs. There was however no significant associations between temperature, SO_2 and NO_2 as shown by the P-values

CHAPTER FIVE

5.0 DISCUSSION

5.1 Introduction

This work investigated the concentrations of ambient air pollutants across five routes; specifically on four busy intersections that record heavy vehicular traffic and one route characterized with low vehicular volumes. To my knowledge, this is one of the first studies to investigate the diurnal rhythms of urban air pollution due to vehicular traffic especially along busy intersections in Accra.

A few studies have been conducted in Ghana on ambient air pollution with specific focus on the sources of air pollutants and ambient concentrations, and have been compared to established guidelines or standards ((Arku et al., 2008; Dionisio et al., 2010; Ofosu, Hopke, Aboh, & Bamford, 2012; Rooney et al., 2012). Although none of these studies assessed the level of concentrations of air pollution from vehicular exhaust as this study has done, there are relevant similarities worth noting. The studies above found that the concentrations of air pollutants were very high at the respective locations considered. For example with regard to particulate matter, Dionisio et al. (2010) found that PM 2.5 and PM 10 were as high as 200 and 400ug/m^3 at some segments of their study area and concluded that biomass fuels, transportation and unpaved roads may be important determinants of local PM variations in Accra neighborhoods.

On the other hand, other studies performed in Accra recorded lower concentrations of certain air pollutants, compared to acceptable levels or standards. Arku et al. (2008) found that SO_2 concentrations were lower than the US-EPA National Ambient Air Quality Standards (NAAQS) (annual average <0.03ppm; daily average < 14 ppm). In the same study, it was further established that the mean NO_2 concentrations was also lower than the NAAQS (annual average < 0.053 ppm). In an attempt to explain the reasons accounting for the lower concentrations of the two pollutants (SO_2 and NO_2) Arku and co-workers postulated that vehicle fuels used in Ghana as of the time of study had low levels of SO_2 and NO_2. Although findings from this study showed low levels of NO_2 compared to WHO standards (average 24 hours < 0.10 ppm), the mean concentration of SO_2 was higher when compared to WHO standards (24 hour average > 0.175), which contradicts the findings by Arku (2008). One possible explanation for the current elevated levels in SO_2 could be as a result of higher levels of SO_2 in imported fuel. On the other hand, it is possible that the quality of petroleum products, or culture of vehicle maintenance have decreased over the years. Kojima and Lovei (2001) also attributed the high concentrations of some air pollutants to intentional adulteration and contamination of petroleum products in an attempt to maximize profits. High ambient concentrations of SO_2 as found in this study could have several negative health consequences. Several studies have drawn an association between SO_2 and negative health outcomes. For example, Bascom et al. (1996) and Katsouyanni et al. (1997) observed SO_2 to be a potent respiratory irritant, and associated with increased hospital admissions for respiratory and cardiovascular diseases. Wang et al. (2009) also observed that SO_2 is a precursor to respiratory diseases among the young and the elderly in Beijing (China) and proposed adherence to personal protective equipment to limit the exposure of SO_2 exhaust emissions. Several categories of people are exposed to emissions from vehicular traffic, including street hawkers (traffic vendors), shop attendants (with about 2m proximity to road traffic) ,motor traffic police, passengers in other vehicles, people resident in houses along these routes are constantly exposed to air pollutants.

Carbon monoxide (CO), which is a product of incomplete burning of various fuels, including coal, wood, charcoal, oil, kerosene, propane, and natural gas, is another important air pollutant, with deleterious health effects. Overall, CO had the highest concentrations (24 hours average

> 2.46 ppm), with a huge margin exceeding WHO standards (0.02 ppm). Also, a comparative analyses of CO concentrations on the five (5) routes studied showed Accra-Madina-Adenta recorded the highest concentration (3.596 ppm), whereas Legon campus had the lowest CO concentration (0.260 ppm). Carbon monoxide is associated with several negative health outcomes, including decreased intelligent quotient, persistent wheezing, lower peak expiratory flow and sensitization to pollen, chronic bronchitis, lung cancer, asthma and atherosclerosis (Schwela, 2000; Nording et al., 2008, Allen et al., 2009).

Surprisingly, the control route, the Limann-Jean Nelson Aka route on Legon campus which usually have the least volume of vehicular traffic recorded the highest concentrations of Volatile organic compounds (VOCs), levels of which were also higher than the WHO standard (> 0.208 ppm). The Legon route was used as a control to justify whether vehicular emissions were exclusively due to vehicular traffic especially among busy routes. It has been shown that VOCs are usually very high on traffic congested roads compared to less busy routes ((Riediker, Williams, Devlin, Griggs, & Bromberg, 2003). High VOCs levels have been suggested as posing a health threat to commuters and traffic-exposed workers (Duffy and Nelson (1997). The higher VOC levels on relatively less busy routes could have been contributed by other factors such as pesticides, wood preservatives, aerosol sprays, cleansers and disinfectants, paints, building materials, furnishings and butimen (Onursal and Gautam (1997), factors that abound on Legon campus due to high population density. It was observed during the study that weedicides were frequently used on the Limann – Jean Nelson Aka route to stop the growth of weeds. There was also massive construction activities going on especially the renovation of some halls, which required painting. That notwithstanding, a small dose exposure of VOCs can be detrimental to the health of populations. Glass et al. (2003) concluded that even a small exposure to benzene could increase health risks and therefore no safe level of benzene exposure exists. Glass further found that short exposures to concentrated VOCs specifically benzene and

BTX (100% benzene and 100% benzene, toluene, and xylenes) among refinery workers increased the risk of leukemia.

Ambient conditions have greater impacts on vehicular emissions. Higher humidity results in lower NO_2, SO_2 and CO levels (Lindhjem et al., 2004). Results obtained in this study were consistent with this finding in that a unit change in relative humidity led to a decrease in concentrations of CO (-0.163 ppm) and SO_2 (-0.005) whilst there was almost no significant change in NO_2 (0.000 ppm). Higher temperatures are also associated with higher emissions above 2.25 ppm (Gingrich et al., 2003). Except CO concentrations, temperature increased the levels of VOCs, SO_2 and NO_2 but not as high as 2.25 ppm as revealed by this study. During cold starts under high temperatures, lower emissions are usually recorded below 0.025 ppm for NO_2 and CO (Nam, 2008). This observation was in consonance with the values obtained from this study; none of the air pollutants recorded were higher than 0.025 ppm when temperature was regressed with air pollutants. Lindhjem et al. (2004) also observed that under hot stabilized running engines emission factors were higher at high temperatures between 25.2 ^{o}C and 28.62 ^{o}C, the average concentration in temperature of this study was 29.25 ^{o}C above the maximum 28.62 ^{o}C proposed by Lindhjem in his study and this could have contributed to a significant association between temperature and VOCs ($P<0.001$). The impact of temperature and relative humidity on air pollution is of environmental relevance (Choi et al., 2011).

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study revealed that the average concentrations of air pollutants investigated on the selected routes were higher than the WHO required standards except for NO_2. In effect, elevated levels of VOCs, CO and SO_2 recorded could have negative health implications as several adverse health effects have been associated with long time exposures, especially in vulnerable groups such as children, pregnant women and the aged.

6.2 Recommendations

The recommendations derived from the study are as follows;

- Public education and awareness on the dangers and control of gaseous pollutants must be given to individuals by government and other mandated agencies responsible.
- The management of the university (UG) must put certain measures in line so as to reduce the production of volatile organic compounds.
- Regulate the importation of over used-vehicles (second hand vehicles) by imposing high taxes
- Establishment of a modern mechanic workshop at the DVLA to examine and certify vehicles that are worthy for road usage.
- Effective on-road monitoring by the Ghana Environmental Agency of vehicles that emit high emissions for caution and sanctions.
- Development of standards for every air pollutant especially for volatile organic compounds to enable researchers to determine their threshold effects and to enhance robust comparison between other countries.

- Subsequent research should be based on determining the impact of wind speed and wind direction on the impact of the concentration on vehicular activities.
- Government and other stakeholders must improve on air travels and build rail roads to ease the burden on vehicular transportation sector in the country.
- The Ghana Health Service (GHS) should sponsor and collaborate with academic and research institutions that into air pollution and adopt strategies to avert its impact on the environment and humans.
- Town and country planning should enforce a sustainable and cost effective development of human settlements in accordance with sound environmental and planning principles.

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