

THE UNIVERSITY OF NAIROBI



**ASSESSMENT OF LEVELS OF SELECTED AIR POLLUTANTS IN ATHI RIVER,
KENYA.**

BY

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156/67355/2013.

**A THESIS SUBMITTED IN PARTIAL FULFILMENT FOR THE AWARD OF THE
DEGREE OF MASTER OF SCIENCE IN ENVIRONMENTAL CHEMISTRY OF
THE UNIVERSITY OF NAIROBI**

SEPTEMBER, 2017.

DECLARATION

I hereby declare that this thesis is my original work and has not been presented elsewhere for examination, award of a degree or publication. Where other people's work has been used, this has been acknowledged and referenced in accordance with the University of Nairobi's requirements.

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ABSTRACT

Air pollution has increased in developing countries due to industrialization, economic development, urbanization and population growth. The discharge of harmful chemicals and increased combustion of fossil fuels, affects both the physical environment and the public health. Air pollution effects are both acute and chronic on human health, ranging from minor upper respiratory irritation to chronic respiratory and heart disease, lung cancer, acute respiratory infections in children and chronic bronchitis in adults

A study on air quality assessment was therefore carried out at three different industrial sites and one non- industrial site in Athi River, Kenya. The levels of air pollutants that were determined were sulphur dioxide, nitrogen dioxide, suspended particulate matter and carbon dioxide. The air samples were collected by scrubbing them through appropriate trapping solutions and subsequently analyzed in the laboratory using colorimetric methods for sulphur dioxide and nitrogen dioxide. The levels of suspended particulate matter and carbon dioxide were determined using the filtration technique and the titrimetric method. Temperature, relative humidity, wind speed and wind direction were also measured during the sampling exercise.

The mean concentrations of sulphur dioxide at the various sites during rainy season were: Shalom Hospital ($602 \mu\text{g}/\text{m}^3$); Vannilaz Restaurant ($793 \mu\text{g}/\text{m}^3$); Redeemed Gospel Church ($861 \mu\text{g}/\text{m}^3$) and Sabaki residential Estate ($370 \mu\text{g}/\text{m}^3$). These levels exceeded the WHO guideline value of $500 \mu\text{g}/\text{m}^3$ for 10 minutes exposure except for Sabaki Residential Estate. Nitrogen dioxide levels were $111 \mu\text{g}/\text{m}^3$ (Sabaki residential Estate), $157 \mu\text{g}/\text{m}^3$ (Redeemed Gospel Church), $159 \mu\text{g}/\text{m}^3$ (Shalom Hospital) and $175 \mu\text{g}/\text{m}^3$ (Vannilaz Restaurant). Nitrogen dioxide concentrations exceeded the WHO guidelines of $120 \mu\text{g}/\text{m}^3$ for 8 hours exposure time, in all the sites except in Sabaki residential Estate ($111\mu\text{g}/\text{m}^3$). The elevated levels of SO_2 and NO_2 were associated with heavy vehicular traffic and industrial activities from cement manufacturing plants. The suspended particulate matter (SPM) results were; Shalom Hospital ($3210 \mu\text{g}/\text{m}^3$); Vanillas Restaurant ($3710 \mu\text{g}/\text{m}^3$); Redeemed Gospel Church ($2370 \mu\text{g}/\text{m}^3$) and Sabaki residential Estate ($1680 \mu\text{g}/\text{m}^3$). These values far exceeded the short term WHO guidelines of a 24 hour maximum limit of $150\text{-}230 \mu\text{g}/\text{m}^3$ for suspended particulate matter due to vehicular movement, quarrying, excavation activities in the area, resuspension of dust by wind, crushing mills, packing processes and biomass burning. The average concentrations of carbon dioxide were $1614 \text{ mg}/\text{m}^3$ (Sabaki residential Estate), $247 \text{ mg}/\text{m}^3$ (Shalom Hospital), $460 \text{ mg}/\text{m}^3$

(Vannilaz Restaurant) and 596 mg/m³ (Redeemed Gospel Church). These values were below the average calculated value of CO₂ at 691 mg/m³ in Athi River Town except at Sabaki Residential Estate. However, CO₂ values were below the Occupational Health and Safety Administration (OSHA) permissible exposure limit for CO₂ of 5,000 ppm equivalent to 9,000 mg/m³ for an 8-hour in a workday.

Mean concentrations of sulphur dioxide during the dry season for Shalom Hospital, Vanillaz Restaurant, Redeemed Gospel church and Sabaki residential Estate were 863, 875, 862 and 664 µg/m³ respectively; Nitrogen dioxide were 139, 147, 136 and 94 µg/m³ respectively. Carbon dioxide gave 863, 709, 769 and 1548 mg/m³ respectively, while suspended particulate matter gave 3890, 3710, 4390 and 1690 µg/m³ respectively. In dry season, sulphur dioxide exceeded WHO value in all the four sites; nitrogen dioxide exceeded WHO guideline in all the sites except in Sabaki Estate; suspended particulate matter values exceeded WHO value in all the four sites and carbon dioxide values exceeded OSHA and the calculated mean values in all the four sites.

DEDICATION

This thesis is dedicated to my family and all those who contributed towards the success of the study.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my deepest praise to God who has given me strength, faith and determination to complete this research and also for all his blessings and kindness. I wish to express my sincere gratitude and regards to my supervisors; Prof. Amir Yusuf, Dr. John Onyatta and Mr. Godfrey Wafula for their valued academic guidance and suggestions. Without their encouragement and guidance this research would not have materialized. They guided and made me to understand the minute details of each and every step for the successful completion of this study. I am privileged to offer my sincere thanks and owe an enormous deal of gratitude to Mr. Godfrey Wafula for his support, constructive criticism and genuine guidance during my sampling and laboratory analysis and for working closely with me during my research. I acknowledge and thank my lecturers in the Department of Chemistry for their academic advice and the laboratory technologists who cooperated and made my work easier during chemical analysis. I would like to thank my colleagues for their constant help and support at various stages of my research. The generous support of all the members of staff of the Department of Chemistry is also greatly appreciated.

On a personal note, I know that this work could not have been completed without the tremendous support of my family. They have been a great source of strength and support for me through each step of the journey and I thank them for their constant encouragement, optimism and belief in me. My gratitude to them is beyond measure for they ensured that I had the best opportunities possible and they have constantly believed in me and encouraged me to dream big and to pursue those dreams.

TABLE OF CONTENTS

| | |
|--|----------|
| DECLARATION..... | i |
| ABSTRACT..... | ii |
| DEDICATION..... | iv |
| ACKNOWLEDGEMENTS | v |
| TABLE OF CONTENTS | vi |
| LIST OF FIGURES | xii |
| APPENDICES LIST..... | xiii |
| CHAPTER ONE | 1 |
| INTRODUCTION..... | 1 |
| <i>1.1 Air pollution</i> | <i>1</i> |
| <i>1.2 Statement of the Problem.....</i> | <i>2</i> |
| <i>1.3 Objectives of the Study.....</i> | <i>3</i> |
| 1.3.1 General objective | 3 |
| 1.3.2 Specific objectives were; | 3 |
| <i>1.4 Justification and Significance of the Study</i> | <i>4</i> |
| CHAPTER TWO | 5 |
| 2.0 LITERATURE REVIEW | 5 |
| <i>2.1 Air pollution</i> | <i>5</i> |
| <i>2.2 Cement production in Kenya</i> | <i>7</i> |
| <i>2.3 Air pollutants.....</i> | <i>8</i> |
| 2.3.1 Suspended particulate matter..... | 8 |
| 2.3.2. Sulphur dioxide..... | 9 |
| 2.3.3 Nitrogen dioxide..... | 11 |
| 2.3.4 Carbon dioxide..... | 12 |

| | |
|---|-----------|
| 2.4 Sources of air pollution..... | 13 |
| 2.4.1 Vehicular emissions..... | 13 |
| 2.4.2. Industrial wastes | 13 |
| 2.4.3 Domestic burning..... | 14 |
| 2.5 Meteorological parameters and air pollution..... | 14 |
| 2.6 Environmental impacts of air pollution | 15 |
| 2.6.1 Acid rain | 15 |
| 2.6.2 Eutrophication | 16 |
| 2.6.3 Haze..... | 16 |
| 2.6.4 Ozone depletion..... | 17 |
| 2.6.5 Global climate change | 17 |
| 2.7 Health effects of air pollution..... | 17 |
| 2.8 Air pollution control technologies and equipment..... | 19 |
| 2.8.1 Bag filters..... | 19 |
| 2.8.2 Catalytic combustion | 20 |
| 2.8.3 Electrostatic precipitation | 21 |
| 2.8.4 Absorption (wet scrubbing) | 22 |
| 2.9 Principles of the Instrumentation Method Used In Chemical Analysis of Air Pollutants | 23 |
| 2.9.1 Ultraviolet –Visible spectrophotometer | 23 |
| 2.9.2 Single-beam device | 23 |
| 2.9.3 Dual-beam instrument | 24 |
| 2.9.4 The working principle of Ultraviolet –Visible spectrophotometry | 25 |
| 2.9.5 The basic parts of a spectrophotometer..... | 25 |

| | |
|---|----|
| 2.9.5.1 Light source | 25 |
| 2.9.5.2 Sample holder | 26 |
| 2.9.5.3 Diffraction grating or monochromator..... | 26 |
| 2.9.5.4 Detector..... | 26 |
| 2.10 The principle of chemical analysis of pollutants | 27 |
| 2.10.1 Sulphur dioxide | 27 |
| 2.10.2 Nitrogen dioxide..... | 28 |
| 2.10.3 Carbon dioxide..... | 28 |
| 2.10.4 Suspended particulate matter..... | 29 |
| 2.11 Air Pollution Studies in Kenya | 29 |
| CHAPTER THREE | 31 |
| 3.0 MATERIALS AND METHODS..... | 31 |
| 3.1 STUDY AREA..... | 31 |
| 3.1.1 Athi River | 31 |
| 3.2 Sampling sites | 32 |
| 3.2.1 Site A: Shalom Hospital | 32 |
| 3.2.2 Site B: Vannilaz club | 33 |
| 3.2.3 Site C: Redeemed Gospel Church | 33 |
| 3.2.4 Site D: Sabaki residential Estate..... | 33 |
| 3.3. Sampling requirements and sampling..... | 33 |
| 3.3.1 Field Apparatus | 33 |
| 3.3.2 Field working solutions..... | 34 |
| 3.3.3 Sampling procedures | 34 |
| 3.4 Chemical analysis procedures..... | 35 |
| 3.4.1 Reagents for sulphur dioxide | 35 |

| | |
|--|-----------|
| 3.4.2 Standard solutions for sulphur dioxide | 36 |
| 3.4.3 Experimental procedure for sulphur dioxide..... | 36 |
| 3.4.4 Reagents for nitrogen dioxide | 37 |
| 3.4.5 Standard solutions for nitrogen dioxide | 37 |
| 3.4.6 Experimental procedures for nitrogen dioxide..... | 38 |
| 3.4.7 Reagents for carbon dioxide | 38 |
| 3.4.8 Experimental procedure for carbon dioxide..... | 38 |
| 3.4.9 Experimental procedures for suspended particulate matter | 39 |
| CHAPTER FOUR..... | 40 |
| 4.0 RESULTS AND DISCUSSIONS..... | 40 |
| <i>4.1 Average Levels of the Analyzed Air Pollutants.....</i> | <i>40</i> |
| <i>4.2 Study Site A (Shalom Hospital).....</i> | <i>44</i> |
| 4.2.1 Sulphur dioxide..... | 44 |
| 4.2.2 Nitrogen dioxide..... | 44 |
| 4.2.3 Carbon dioxide | 45 |
| 4.2.4 Suspended particulate matter..... | 45 |
| <i>4.3 Site B (Vannilaz club)</i> | <i>46</i> |
| 4.3.1 Sulphur dioxide..... | 46 |
| 4.3.2 Nitrogen dioxide..... | 46 |
| 4.3.3 Carbon dioxide | 46 |
| 4.3.4 Suspended particulate matter..... | 46 |
| <i>4.4 Site C (Redeemed Gospel Church- Athi River).....</i> | <i>47</i> |
| 4.4.1 Sulphur dioxide..... | 47 |
| 4.4.2 Nitrogen dioxide..... | 47 |
| 4.4.3 Carbon dioxide | 47 |

| | |
|--|----|
| 4.4.4 Suspended particulate matter..... | 47 |
| 4.5 Site D (Sabaki Residential Estate)..... | 48 |
| 4.5.1 Sulphur dioxide..... | 48 |
| 4.5.2 Nitrogen dioxide..... | 48 |
| 4.5.3 Carbon dioxide..... | 48 |
| 4.5.4 Suspended particulate matter..... | 48 |
| 4.6 The meteorological parameters results..... | 49 |
| 4.6.3 Wind speed..... | 51 |
| 4.6.4 Relative humidity..... | 51 |
| 4.6.5 Wind direction..... | 51 |
| 4.6.7 Temperature..... | 52 |
| 4.7 Epidemiological effects of pollution..... | 52 |
| 5.0 CONCLUSIONS AND RECOMMENDATIONS..... | 53 |
| 5.1 CONCLUSIONS..... | 53 |
| 5.2 RECOMENDATIONS..... | 54 |
| REFERENCES..... | 55 |
| APPENDICES..... | 67 |
| Appendix 1: A Typical Calibration Graph for Sulphur Dioxide..... | 67 |
| Appendix 1.1 Sulphur dioxide concentration versus absorbance of standards..... | 67 |
| Appendix 2.1: Nitrogen dioxide concentration versus absorbance of standards..... | 68 |
| Appendix 3: Sulphur Dioxide Levels at Site A During Rainy Season..... | 69 |

LIST OF TABLES

| | |
|---|----|
| Table 3.1: The trapping solutions for the various pollutants. | 34 |
| Table 4.1: The average levels of pollutants analyzed at the four sites during the wet season..... | 40 |
| Table 4.2: The average levels of pollutants analyzed at the four sites during the dry season | 41 |
| Table 4.3: Median and range levels of pollutants analyzed at the four sites during the dry season. | 42 |
| Table 4.4: Median and range levels of pollutants analyzed at the four sites during the wet season. | 43 |
| Table 4.5: Mean relative humidity, wind direction, wind speed and temperature during wet season | 49 |
| Table 4.6.: Mean relative humidity, wind direction, wind speed and temperature during dry season..... | 50 |

LIST OF FIGURES

| | |
|--|----|
| Figure 2.1: Schematic diagram of a bag filter..... | 20 |
| Figure 2.2: Packaged micro combustor | 21 |
| Figure 2.3: Schematic diagram of electrostatic precipitator | 22 |
| Figure 2.4: Packed tower for gas absorption. | 23 |
| Figure 2.5: Schematic diagram of a single beam ultra violet-Visible spectrophotometer..... | 24 |
| Figure 2.6: Schematic diagram of a double beam Ultra violet-Visible spectrophotometer..... | 25 |
| Figure 3.1: Athi River, Study site | 32 |
| Figure 3.2 : Air sampling train..... | 35 |

APPENDICES LIST

| | |
|--|----|
| Appendix 1: Typical Calibration Graph for Sulphur Dioxide..... | 67 |
| Appendix 2: Typical Calibration Graph for Nitrogen Dioxide..... | 68 |
| Appendix 3: Sulphur Dioxide Levels at Site A During the Rainy Season | 69 |
| Appendix 4: Sulphur Dioxide Levels at Site B During the Rainy Season | 70 |
| Appendix 5: Sulphur Dioxide Levels at Site C During the Rainy Season | 71 |
| Appendix 6: Sulphur Dioxide Levels at Site D During the Rainy Season | 72 |
| Appendix 7: Nitrogen Dioxide Levels at Site A During the Rainy Season | 73 |
| Appendix 8: Nitrogen Dioxide Levels at Site B During the Rainy Season | 74 |
| Appendix 9: Nitrogen Dioxide Levels at Site C During the Rainy Season | 75 |
| Appendix 10: Nitrogen Dioxide Levels at Site D During the Rainy Season | 76 |
| Appendix 11: Carbon Dioxide Levels at Site A During the Rainy Season | 77 |
| Appendix 12: Carbon Dioxide Levels at Site B During the Rainy Season | 78 |
| Appendix 13: Carbon Dioxide Levels at Site C During the Rainy Season | 79 |
| Appendix 14: Carbon Dioxide Levels at Site D During the Rainy Season | 80 |
| Appendix 15: Suspended Particulate Matter Levels at Site A During the Rainy Season | 81 |
| Appendix 16: Suspended Particulate Matter Levels at Site B During the Rainy Season | 82 |
| Appendix 17: Suspended Particulate Matter Levels at Site C During the Rainy Season | 83 |
| Appendix 18: Suspended Particulate Matter Levels at Site D During the Rainy Season | 84 |
| Appendix 19: Meteorological Parameters Results at Site A During the Rainy Season | 85 |
| Appendix 20: Meteorological Parameters Results at Site B During the Rainy Season | 85 |
| Appendix 21: Meteorological Parameters Results at Site C During the Rainy Season | 86 |
| Appendix 22: Meteorological Parameters Results at Site D During the Rainy Season | 86 |
| Appendix 23: Sulphur Dioxide Levels at Site A During the Dry Season | 87 |
| Appendix 24: Sulphur Dioxide Levels at Site B During the Dry Season | 88 |
| Appendix 25: Sulphur Dioxide Levels at Site C During the Dry Season | 89 |
| Appendix 26: Sulphur Dioxide Levels at Site D During the Dry Season | 90 |
| Appendix 27: Carbon Dioxide Levels at Site A During the Dry Season | 91 |
| Appendix 28: Carbon Dioxide Levels at Site B During the Dry Season | 92 |
| Appendix 29: Carbon Dioxide Levels at Site C During the Dry Season | 93 |
| Appendix 30: Carbon Dioxide Levels at Site D During the Dry Season | 94 |

| | |
|---|-----|
| Appendix 31: Nitrogen Dioxide Levels at Site A During Dry Season | 95 |
| Appendix 32: Nitrogen Dioxide Levels at Site B During Dry Season | 96 |
| Appendix 33: Nitrogen Dioxide Levels at Site C During Dry Season | 97 |
| Appendix 34: Nitrogen Dioxide Levels at Site D During Dry Season | 98 |
| Appendix 35: Suspended Particulate Matter Levels at Site A During Dry Season | 99 |
| Appendix 36: Suspended Particulate Matter Levels at Site B During Dry Season | 100 |
| Appendix 37: Suspended Particulate Matter Levels at Site C During Dry Season | 101 |
| Appendix 38: Suspended Particulate Matter Levels at Site D During Dry Season | 102 |
| Appendix 39: Meteorological Parameters Results at Site A During Dry Season Sampling | 103 |
| Appendix 40: Meteorological Parameters Results at Site B During Dry Season Sampling | 103 |
| Appendix 41: Meteorological Parameters Results at Site C During Dry Season Sampling | 104 |
| Appendix 42: Meteorological Parameters Results at Site D During Dry Season Sampling | 104 |

LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|-----------------|--|
| µg | - micro gram |
| CDF | -Constituency Development Fund |
| CO ₂ | - Carbon dioxide |
| EQN | -Equation |
| ESP | - Electrostatic precipitation |
| KNBS | -Kenya National Bureau of Statistics |
| NIOSH | -National Institute for Occupational Safety and Health |
| NO ₂ | - Nitrogen dioxide |
| NO _x | . Oxides of nitrogen (nitrous oxide N ₂ O, nitrogen dioxide NO ₂ and nitric oxide NO). |
| OSHA | -Occupational Safety and Health Administration |
| SO ₂ | - Sulphur dioxide |
| SPM | - Suspended particulate matter |
| TCM | -Tetrachloromercurate |
| UNEP | - United National Environment Program |
| USEPA | - United States Environmental Protection Agency. |
| UV | -Ultra violet |
| VOCs | - Volatile organic compounds |
| WHO | - World Health Organization |

CHAPTER ONE

INTRODUCTION

1.1 Air pollution

Air pollution is the presence of any gaseous, solid or liquid substance in the atmosphere in such concentration that could exceed the established standards thus becoming harmful to the health of living organisms as well as destruction to infrastructures. Air pollution includes noise and radioactive radiation (Alias *et al.*, 2007). Air pollution sources are categorized into two; either as anthropogenic (caused by human activities like coal combustion, industries and exhaust fumes) or biogenic (caused by dust storms and volcanic eruptions). Air pollution causes harmful alteration in the process of biological, physical and chemical interaction hence leading to the interruption of normal functioning of living organisms. Due to its detrimental effects on human health and the environment as a whole, air pollution continues to receive a lot of attention worldwide.

Considering that air is one of the basic needs of life process, continuous contamination through pollution attributed to anthropogenic and natural activities, scientists are faced with the challenge of minimizing these effects. The transportation industry as well as manufacturing industries contribute the higher proportion of pollutants in the atmosphere. Estimated air pollution from vehicles is 60%, followed by industries at 20-30% in urban centers. In Kenya, car imports increased by 50% between the years 1992-1999 (Maina, 2004). Cement industry is among the industries that significantly pollute the air due to the release of toxic fumes, gases, smoke and dusts into the atmosphere (Park and Park, 1985). Cement is produced from raw materials such as limestone, chalk, clay and sand. The raw materials are ground and homogenized, then calcination process follows (Eqn 1.1) by burning resulting calcium oxide together with silica, alumina and ferrous oxide at high temperatures to form clinker. The clinker is then milled together with gypsum and pozzolana to produce cement (Karstensen, 2006). During calcination, CO₂ is liberated.



Eqn 1.1: Decomposition of limestone.

Cement industries in Athi River, Kenya are thriving due to the rapid population growth and the availability of raw materials. Demand for cement in Kenya is expected to increase because of the Government's plans to build new housing units and also to meet vision 2030 (GoK, 2007). Unless restricted regulations are enforced by government to ensure compliance with national and international standards upon this industry, the increase of cement plants and their associated pollutions may lead to deterioration of air quality. The emission from cement factories consist of particulate matter, sulphur dioxide, carbon dioxide, heavy metal oxides and nitrogen oxides among other pollutants, generating noticeable clouds of dust which eventually upset the human life, vegetation, soil and the environment as a whole. The rapid increase in urbanization, industrialization and the unexpected resettlement of refugees and foreign workers in towns, have caused a strain on the town services. This has resulted in increased demand for transportation, industrial production and increased energy requirements, giving rise to air pollution. Increased population in urban centers intensifies pollution of air due to the lack of adequate green open spaces in towns and cities (Givoni, 1991).

Motor vehicle emissions also contribute to air pollution in the urban centers (Seinfeld, 1989). Air borne pollution is further enhanced by increased vehicular traffic, poor fuel quality and inadequate maintenance of vehicles. Automobiles emit oxides of nitrogen, sulphur dioxide, carbon dioxide, carbon monoxide and a complex mixture of unburnt hydrocarbons. The release of these pollutants is of great concern and needs to be regulated in urban centers so as to protect the environment.

1.2 Statement of the Problem

Air pollution in industrial areas is on the rise due to industrial growth, high vehicular traffic density and urbanization. It is a major problem because it has adverse effects on human health, materials and the environment. Health effects of industrial pollution have been reported among workers in battery manufacturing and cement production plants in Athi River and Mombasa. This is also true in mineral processing plants in Nairobi and Thika. The effects included asbestosis, occupational asthma and silicosis (Kahenya, 1996). Air pollution contributes to formation of acid rain, affects soil by reducing its fertility, destruction of aquatic ecosystems and death of certain plants. Acid rain further accelerates corrosion of metallic and other building structures which sometimes may be located far away from the pollutant source (Rao *et al.*, 2003).

Human health and the environment at both local and global levels are affected by many forms of atmospheric pollution. These pollutants are emitted from different sources and some of them react together to form new compounds in the air. Most industrialized nations have made important development toward controlling some pollutants in recent years, but air quality is much worse in many developing countries due to weak legislation and lack of enforcement. The existing data show that air quality has deteriorated in Nairobi over the past two years (Murakaru, 1991). The same scenario was experienced in Athi River Town according to Mogere (2002), the study showed increased air pollution which was attributed to industrialization and heavy traffic flow. Hence, there is a great need for continuous monitoring of air quality and establish the extent of human exposure to such risk.

Some of the health effects of sulphur dioxide (SO₂) and nitrogen dioxide (NO₂) pollution are throat and nose irritations (Balmes *et al.*, 1987). Suspended particulate matter (SPM) causes lung inflammation when it penetrates the epithelium of the lung (Ghio and Huang, 2004), and also affects the coagulation of blood. Carbon dioxide causes the greenhouse effect, hence global warming.

1.3 Objectives of the Study

1.3.1 General objective

The general objective was to determine the levels of selected air pollutants in Athi River Town, Kenya

1.3.2 Specific objectives were;

1. To determine the airborne levels of NO₂, SO₂, CO₂, and suspended particulate matter.
2. To determine the effect of meteorological parameters on the levels of NO₂, SO₂, CO₂ and suspended particulate matter.
3. To compare the levels of NO₂, SO₂, CO₂, and suspended particulate matter with respect to WHO air quality standards and OSHA.
4. To determine the possible sources of these pollutants.

1.4 Justification and Significance of the Study

Air pollution monitoring provides a scientific foundation for protecting the environment and the public from adverse effects of air pollutants. These activities enable air quality regulators and policy makers to device cost effective and efficient strategies that minimize air pollution. Since Athi River is one of the cement producing towns in the region, assessment of air pollutants from the factories as well as transport related emissions is of great importance in ensuring that there are no adverse health effects on those living around the factories. Protection of the environment by minimizing or removing pollutants is of importance.

Comprehensive data on air pollution in Athi River Town is very limited. Hence, the significance of this study is to provide more broad information on the levels and the characteristics of the air pollutants.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Air pollution

Air pollution problems dates back to 16th century when the English diarist John Evelyn complained about the horrid smoke which killed bees and flowers (Ashmore, 2013). Also in the early 1800's, main indigenous *Sphagnum* moss species in England was replaced by cotton grass *Eriophorum vaginatum* with the start of industrial revolution due to its sensitivity to pollution since it has no structures of tubes and fibres to hold it up, it grows well in the cool, damp climate (Ashmore, 2013). Air pollution has remained a critical issue to be dealt with as it damages our environment affecting plants and animals.

The policy makers and decision-makers are faced with challenges of trying to make industries to comply with established standards of emitting gases into the atmosphere. Studies indicated that emission from exhaust in the transportation industry (automobiles and airplanes) well as discharge of particulate matter into the atmosphere by manufacturing industries (cement and steel making factories) contributes the higher proportion of air pollution in the world. Excessive emission of carbon dioxide and other gases accelerate respiratory discomfort as well as corrosion of building materials and destruction of ecosystems (Rao *et al.*, 2003). Subsequent centuries have seen the rise in range and quantities of chemicals released into the atmosphere from power generation plants, agriculture, manufacturing industries and domestic use of fossil fuel. Once the gases are discharged into the atmosphere, chemical reaction and transformation continues to take place. The level of reaction depends on the quantity and concentration of other substances that could catalyse the chemical reaction to new compounds, which could be more harmful to the human health and biodiversity. Tropospheric ozone is an example of the reaction that is formed on the ground level; it is formed by the interaction of hydrocarbons (volatile organic compounds, VOCs) with ultraviolet light and nitrogen oxides. The ground level ozone is a component of urban smog. Anthropogenic activities such as vehicular exhaust, industrial emissions and chemical solvents are the major sources of NO_x and VOCs. Quality of air is of importance because it's a necessity in life. People who live within the vicinity of industries that

discharge toxic fumes and chemicals should be concerned, since the pollutants they are exposed to may affect their health (EAP, 2010).

Scientists have categorized air pollution into primary and secondary air pollution. Air pollution is categorized as primary when harmful gases such as hydrogen sulphide (H₂S), sulphur dioxide (SO₂), ammonia (NH₃), carbon dioxide (CO₂) and carbon monoxide (CO) or particulate matter are directly released into the atmosphere from a source. These gases react with oxygen in the atmosphere to form nitrogen dioxide (NO₂), nitric acid (HNO₃), ozone (O₃), sulphuric acid (H₂SO₄), sulphates and nitrates. On the other hand air pollution becomes secondary when the primary air pollution reacts with atmospheric components to form a pollutant (Naik, 2005). For example, inside internal combustion engines, nitrogen gas and oxygen can react to form nitric oxide (NO) (Eqn 2.1), which eventually reacts with oxygen (O₂) in air to form nitrogen dioxide (NO₂) (Eqn.2.2.).



Eqn. 2.1: Formation of nitric oxide.



Eqn.2.2: Formation of nitrogen dioxide.

Sulphur dioxide (SO₂) is one of the major air pollutant released as a by-product of the combustion of fossil fuels (oils, natural gas, coal) which are commonly used domestically and commercially to run machines. Common air pollutant is suspended particulate matter, which is normally found in the atmosphere in the form of liquid or solid particles. These particles are released into the atmosphere by diesel-power machines, volcanic eruptions and cement manufacturing industries. However nitrogen oxides (NO_x) are formed from lightning, fires and motor exhaust (Ahmed, 1999).

2.2 Cement production in Kenya

Cement is one of the basic ingredients of concrete used in modern constructions and structures. It is used as a binder, for bringing together sand and gravel when making concrete (Ian and David, 2002). A number of factories have been put up in Kenya so as to satisfy the ever growing demand. However the rise in the number of cement factories has also resulted in the upsurge of air pollution. Anthropogenic sources of pollution from cement industry are dust from raw mills and cement mills. Nitrogen oxides (NO_x) are generated from drying process, while sulfur oxides (SO_x) are produced from the sulphur compounds in the ores and the combusted fuel. Carbon dioxide (CO_2) is formed from combustion of carbon compounds. Furthermore, it contributes about 5% of the global carbon dioxide (Ian and David, 2002). Carbon dioxide is released during production of clinker, a component of cement. The calcium carbonate (CaCO_3) when heated in a rotary kiln during calcination produces carbon dioxide (Conneely *et al.*, 2001).

Kenya has six cement factories in Athi River Town. The cement companies with their annual production capacity in tonnes in the year 2010 were; East Africa Portland Cement Company (1.35 million), Bamburi Cement Limited (1.4 million), National Cement Company Limited (Devki Group) (1.5 million), Mombasa Cement Limited (1.5 million), Athi River Mining (2.5 million) and Savannah Cement Company (1.5 million). Kenya's national cement production increased to 3.97 million tonnes in 2011 from 3.71 million tonnes in 2010. The increased output was attributed to the construction of new plants and the recent capacity expansions at existing plants. Cement consumption increased to 3.43 million tonnes in 2011 from 3.1 million tonnes in 2010 (International Cement Review, 2010, Kenya National Bureau of Statistics, 2012). Cement production in Kenya has been increasing tremendously with 2014 production at 5.88 million tonnes per year as per the KNBS report. The National Housing policy foresees the construction of 150,000 units per year to bridge the housing deficit and this will increase cement demand. The cement demand is further fueled by the Constituency Development Fund (CDF) projects, the County Government projects and the growing real estate industry. Therefore, Kenya continues to record significant growth in infrastructure-led consumption of cement.

Several studies have reported certain diseases including shortness of breath, sore throat, chest pain, nausea, asthma, bronchitis and lung cancer linking them to air pollution from cement (Jeff and Hans, 2004). The World Health Organization states that 2.4 million people die each

year from causes directly attributable to air pollution (WHO, 2007). One of the critical impacts of cement manufacturing is the dust generated during quarrying, transport, storage, milling and packing (EIPPC, 2001). Mineral dust contains high concentrations of metal ions which affect plants, animals and humans (Branquinho *et al.*, 2008). The usual gaseous emissions from cement manufacturing plants include nitrogen oxides (NO_x), sulphur dioxide (SO₂), carbon oxides (CO and CO₂) and dust (Pregger and Friedrich, 2009). During oxidation of limestone used in clinker preparation, sulphur dioxide is formed from the volatile sulfur (Jeff and Hans, 2004), as shown in Eqn 2.3.



Eqn. 2.3: Formation of sulphur dioxide.

2.3 Air pollutants

2.3.1 Suspended particulate matter

The suspended particulate matter (SPM) are tiny parts of solid or liquid matter suspended in the air. Their sizes are smaller than 100 micrometers and may remain suspended for a few seconds to several months in the air. It is the universal term used for air pollutants that comprise of complex and varying mixtures of particles, with different sizes and composition suspended in the air. They are released by natural and anthropogenic activities (Poschl, 2005). The major components are ammonia, sodium chloride, black carbon, sulphates, nitrates, mineral dust and water. It consists of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air.

Major sources of SPM pollution are manufacturing plants, power plants, waste incinerators, motor vehicles, construction activities, fires, and natural wind-blown dust. The presence of lots of toxic substances carried on the tiny particles in suspended particulate matter is detrimental to human health. SPM is classified into PM₁₀ and PM_{2.5} fractions. PM₁₀ is particulate matter which equates roughly to the mass of particles less than 10 micrometers in diameter or equal to 10 microns. Studies indicated that air pollution in the form of suspended particulate matter are the major causes of respiratory malfunctioning by causing cardiovascular diseases and

worsening heart and lung diseases. Therefore, specific attention on fine particulates has recently been highlighted for adverse health effects (Li and Roth, 1995; Wanyi *et al.*, 2011). Particles with diameter more than 10 microns are not readily inhaled and are removed from the air by sedimentation. PM_{2.5} refers to suspended particulate matter with diameter of 2.5 micrometers or even smaller. They have strong association with observed ill-health. They can cause worse health problem because PM_{2.5} can enter the bronchial respiratory system into the blood. (Venner *et al.*, 2003).

Studies conducted by Samet, *et al.*, (2000) in 20 cities in United States of America indicated that increased cases of cardiovascular conditions and respiratory complications were attributed to accumulation of fine suspended particulate matter in the atmosphere. A case study was conducted as an epidemiological investigation in Utah valley to establish the correlation between human health and the continuous exposure to accumulated fine suspended particulate matter (Ghio and Devlin, 2001). The WHO allowable limit for total SPM is 150- 230µg/m³ for 24 hours.

2.3.2. Sulphur dioxide

Sulphur dioxide (SO₂) is a colorless gas released when fossil fuels containing sulphur is burned. It smells like burnt matches. About 95 % of sulphur is released as sulphur dioxide (SO₂) when coal is combusted (Franco and Diaz, 2009). Impurities within the coal, mostly from pyrite (FeS₂) forms sulphur (Tzimas *et al.*, 2007). The pyrite can be oxidized under high temperatures to form SO₂ (Fleig *et al.*, 2009), as shown in the equations 2.4, 2.5, and 2.6



Eqn. 2.4: Decomposition of pyrite to iron (II) sulphide



Eqn. 2.5: Decomposition of iron (II) sulphide to sulphur



Eqn. 2.6: Synthesis of sulphur dioxide from sulphur

SO₂ can also be oxidized to SO₃ under low temperatures as shown in equation 2.7



Eqn.2.7: Synthesis of sulphur trioxide from sulphur dioxide.

When SO₃ reacts with water it forms sulphuric acid during precipitation (Eqn 2.8); the acids affect the ecosystem, especially when the soils lacks basicity to buffer the acidity effect of the acid precipitation (McGonigle *et al.*, 2004).



Eqn.2.8: Formation of sulphuric acid.

Sulphur dioxide is harmful to plant leaves as it darkens it and also makes the leaves flaccid and finally drop. This is due to the formation of sulphite (SO₃²⁻) and sulphate ions (SO₄²⁻) in the leaf when sulphur dioxide enters through the stomata and reacts with water. The leaf tissue finally dies (Strauss and Mainwaring, 1984). The oxidation of sulphur dioxide (SO₂) to sulphur trioxide (SO₃) in the atmosphere leads to formation of fog due to poor dispersal of pollutants (Lenchev *et al.*, 2008). Sulphur dioxide is also generated during industrial production of iron, steel and crude oil.

Exposure to high levels of sulphur dioxide causes health effects which include respiratory problems, changes in the lung's defenses, and worsening cardiovascular diseases (Nemery *et al.*, 2001). SO₂ in moderate concentrations may result in a fall in lung function for asthmatics. Sulphur dioxide (SO₂) is a major contributor of acidic precipitation since it forms sulphuric acid. Acid is formed when sulphur dioxide combine with moisture in the atmosphere. Sunlight serves as a catalyst for the reactions since it accelerates the reaction processes and subsequent formation of acidic precipitation. Acid rain damages buildings, lakes and plants. Any precipitation with a pH lower than seven can be defined as acid rain (Brimblecombe, 1996).

Acidic precipitation occurs in different forms like wet fog, aqueous rain or dry deposition of acidic particles or gases. Wind strength also plays a crucial role in spreading dry or wet

compounds over large areas. Studies have shown that when marble and limestone comes into contact with nitric, sulphuric as well as sulphurous acid found in the polluted air, they dissolve. Exposure to high levels of sulphur dioxide to plants may cause water stress, decline in photosynthesis and reduced cell wall permeability (Borer *et al.*, 2005). The WHO maximum allowable level of sulphur dioxide is 500 $\mu\text{g}/\text{m}^3$ for average 10 minutes exposure and 350 $\mu\text{g}/\text{m}^3$ for an hour's exposure.

2.3.3 Nitrogen dioxide

The major sources of nitrogen oxides (NO_x) are motor vehicle exhausts and power generation plants. NO_x are made as by-products during combustion processes in the engine at high temperature (Ma, 2010). The majority of NO_x emitted from vehicles is in the form of nitric oxide (NO). About 90% of NO_x are produced when nitric acid is oxidized to NO_2 in the air (Bris *et al.*, 2007). Nitrogen oxides (NO_x), is a universal description of the total number of the NO and NO_2 as well as other oxides of nitrogen. Most airborne NO_x results from by-products of combustion of fossil fuel in electrical utilities and automobiles. In addition, NO_x occurs naturally through lightning and biotic decay processes hence contributing to its accumulation in the atmosphere. Domestic appliance such as stoves and home heaters produce NO_x in indoor settings (USEPA, 2003).

Nitrogen dioxide (NO_2) is one of the many chemical species of air pollutants that affects human health. It is reddish-brown in color, soluble in water and a strong oxidant. NO_x are recognized as indirect greenhouse gases. They affect the net radiation of the sun and are one of the key contributors of ground level ozone, acid rain and smog. High concentrations of NO_x determine ozone (O_3) concentrations in the troposphere because the photolysis of nitrogen dioxide is the only key initiator of the photochemical formation of ozone, whether in polluted or unpolluted atmospheres. NO_x causes acid rain in the form of nitric acid which leaches soil nutrients in soil like nitrates and aluminium ions (Al^{3+}) into nearby waterways which can contribute to eutrophication of water bodies (Driscoll *et al.*, 2010). Soil acidification can lead to changes in plant survival and tends to make certain plant species susceptible to insect infestation and diseases (Driscoll *et al.*, 2010). The Nitrogen dioxide WHO maximum allowable limit for 8-hour average is 120 $\mu\text{g}/\text{m}^3$.

Exposure to nitrogen dioxide can have chronic or acute health effects. Research studies show that exposure to NO₂ in certain concentration might lead to reduced resistance of the lungs to bacterial infection and change in lung structure and metabolism. The nitric acid formed results in the formation of reduced visibility and causes cardiovascular diseases (Alves *et al.*, 2010). Nitrogen dioxide has the ability to absorb visible solar radiation leading to reduced atmospheric visibility.

2.3.4 Carbon dioxide

Since the beginning of industrial revolution, fossil fuel combustion for heating and energy supply has widely spread. This has led to an increase in atmospheric concentration of carbon dioxide (CO₂) by about 20 % since the pre-industrial times. The greenhouse gas carbon dioxide (CO₂) is the main anthropogenic contributor to global warming. In Africa, anthropogenic activities include the use of kerosene, charcoal and firewood in cooking as well as unconventional land use practices (agro waste, clearing of vegetation for agricultural purposes). Statistics indicates that Africa contributes approximately 4% of the global carbon dioxide (Kituyi *et al.*, 2005).

Cement production is also an important source of global carbon dioxide (CO₂) emissions, making up approximately 2.4 percent of global carbon dioxide emissions from industrial and energy sources (Marland *et al.*, 1989). According to Hao *et al.*, (1991), half of the total global large biomass fires occur in Africa. Kenya being one of a developing country has many of its household heating needs dependent on biomass burning. This contributes to the pollution of the environment. WHO has not produced a guideline value for carbon dioxide in ambient air. However, there is an Occupational Health Guideline for carbon dioxide which was set at 5,000 mg/litre (ppm) averaged over eight-hour period. This may be expressed as 9,000 mg/m³. At this elevated level of exposure carbon dioxide may lead to rapid breathing, increased heartbeat, sweating, headache, dizziness, shortness of breath, depression, unconsciousness and death (NIOSH, 1976).

2.4 Sources of air pollution

2.4.1 Vehicular emissions

Population increases in a town when new industries are built and this scenario increases traffic. The impact of transportation on the global environment is substantial. Petrol and diesel engines of motor vehicles emit a wide variety of pollutants, principally oxides of nitrogen (NO_x) and hydrocarbons which impact more on urban air quality (Mage *et al.*, 1996). Vehicular emissions continue to be the major source of air pollutants especially in areas with traffic and industrial activities (Seinfeld, 1989). Motor vehicles emission pollutants harm human health when the toxic gaseous pollutants and fine suspended particles are inhaled. Inhalation of toxic gases and particulates in the air in urban areas is the main cause of respiratory health problems (Pope *et al.*, 2004). Transportation generates major pollutants such as particulate matter, SO₂, NO_x, CO, and CO₂ (Rhys-Tyler *et al.*, 2011; Hoek *et al.*, 2002).

Air quality in motor industry, is affected by factors related to fuel such as fuel type, sulphur, oxygen, benzene and lead content. The rate of vehicle discharge of pollutants also impact on air quality (Samaras and Sorensen, 1999). Pollution from vehicles is caused by incomplete carbon combustion, unburned hydrocarbons and fuel evaporation during hot days. These processes produce pollutants like carbon monoxide, soot, carbon dioxide, different gaseous and liquid vapor hydrocarbons, oxides of sulphur, oxides of nitrogen, sulphate and nitrate particulates, ash and lead compounds. These pollutants affect the environment and public health.

2.4.2. Industrial wastes

There are a number of industries which discharge air pollutants into the atmosphere, contributing to the worsening of air quality. Industrial waste is produced as a by-product during manufacturing process and has occurred since the beginning of industrial revolution (Maczulack, 2010). Petroleum refining is the chief source of SO₂ and NO_x gaseous pollutants. Cement factories emit plenty of dust, which is a potential health hazard. Stone crushers and hot mix plants also create a menace by emitting particulate matter. Particulate pollution has been associated with respiratory illness and acute changes in lung function (Dockery, 1996). Food and fertilizer industries also release gaseous pollutants. Chemical industries that manufacture

sulphuric and nitric acids discharge acidic vapors into the air, causing acid rain which affects both terrestrial plants and aquatic ecosystem. Industrial waste discharged in gaseous form into the environment, impacts negatively on human health and the ecosystem.

2.4.3 Domestic burning

Many households use wood, paraffin, cooking gas and charcoal for cooking and lighting. This domestic burning contributes to the release of SO₂, CO, CO₂, NO_x, methane and volatile organic compounds (VOCs) into the environment. These pollutants affect the environment. The domestic use of biomass fuel, the burning of refuse and plant remains in developing countries contributes to air pollution (Christian *et al.*, 2010). Coal and bio-fuel used for cooking and heating during cold periods also contributes to pollution of the air (Tummon *et al.*, 2010). The most recent national biomass energy study (Republic of Kenya, 2002) reported that biomass energy provides 68% of the national energy requirements an indicator that biomass is extensively used in Kenya. This has greatly contributed to deterioration of air quality.

2.5 Meteorological parameters and air pollution

More often, the study of air pollution is comparable to the study of meteorology of a given area. The amount of pollutants present in the atmosphere is determined by the features and the movements of the air mass into which they are emitted. The atmosphere is always in motion at varying scales; it is never calm (Tyson and Preston-Whyte, 2000). The concentrations of the pollutants accumulate in one location closer to the source if the wind remains still for some time. On the other hand pollutants are distributed over a large area away from the source if the wind becomes turbulent. Also strong winds lift up dust particles from the loose ground and deposit them in the atmosphere. Relative humidity also impact on the concentration of pollutants. Humid environment may wash out pollutants and hence lower their concentration. Temperature, wind direction and speed as well as humidity measurements are important parameters that allow the scientists to monitor air pollution.

Poor air quality has both severe as well as prolonged health effects (Nastos *et al.*, 2010). The ambient concentration of the air pollutants and its exposure time impacts on the severity of air pollution. The local landscape, source emission, and surrounding atmospheric conditions alter the concentrations of air pollutants. Climatic parameters are mostly responsible for causing

variations in the ambient concentrations of air pollutants among the variables (Banerjee *et al.*, 2011).

The atmosphere is a distributing medium of air pollutants. High air pollution is due to low temperatures, low wind speeds and high air pressure which cause air to circulate slowly. During low pressure, the weather is often wet and windy causing pollutants to be dispersed or washed out of the atmosphere by rain. The greater the wind speed the greater the turbulence and more rapid and complete dispersion of contaminants. Winds carry some pollutants far from their sources across national boundaries and even across the oceans. Considering that warm air tend to rise up since it is less denser than the cold air, air pollutants tend to accumulate closer to earth surface due to temperature inversions which limit vertical mixing. This phenomenon is favored by winter and night conditions. Summer conditions weaken the strength of the wind blow thus making the pollutants to stagnate and accumulate in one area for over a long period. Temperature is significant to air pollution, since surface temperature influences the boundary layer base heights (Hewitt and Jackson, 2009). The high surface temperature leads to high mixing depths and low pollution mixing ratio as a result.

2.6 Environmental impacts of air pollution

2.6.1 Acid rain

Air pollution is the chief contributor to acid rain, which has been responsible for considerable damage to fish resources, vegetation and the soil. The indirect effect of acid rain in human is caused by heavy metals such as lead, zinc and mercury that is liberated from soil when the soil is acidified (Tolba, 1983). These mobilized contaminants make their way to ground water that is taken by humans. It also contaminates vegetables and fish consumed by human (Thornton and Plant, 1980).The continuous release of carbon dioxide, nitrogen dioxide and sulphur dioxide into the atmosphere due to burning of fossil fuels leads to the precipitation of harmful carbonic, nitric and sulphuric acids. Acid rain occurs in three different forms such as rain, snow or fog. However, in excess amounts the precipitation occur as dry precipitation i.e. particulates and gas. The gaseous pollutant released is transported over long distance before precipitating to form the rain droplets. Increased amounts of sulphuric, carbonic and nitric acid in the environment makes the water bodies, soil and plants more acidic, thus destroying habitats,

food and water for consumption. Acidification intensifies the rate of decay on sculptures, vehicle bodies, buildings and statues. Acid precipitation causes skin irritation as well as skin cancer (Bobbink *et al.*, 2010).

Acid rain does not only affect the environment and the human health but it corrodes buildings and historical monuments. These effects can be long-lasting leading to eventual losses of these ancient monuments. Deposition of pollutants on surfaces is one of the most critical form of building deterioration (Marioni *et al.*, 2003), which masks structures and historical statues (Gaviño *et al.*, 2004). The specks, together with dry-deposited gases such as sulphur dioxide finally forms a hard, grey - black crust. Particulate matter will be trapped in the crusts, putting pressure on the formed crystal, hence small parts of the stone or the building breaks off. This exposes the material to more ruin by the acid. Latest studies showed that deposition of these pollutants is dangerous because it may lead to greater human exposures therefore increasing risks for human health as it can act as inactive storehouses for air pollutants (Slezakova *et al.*, 2011).

2.6.2 Eutrophication

Release of excess nitrogen oxide into the environment from power plants, motor vehicles and other sources that use fossil fuel, increase the amount of nitrogen compounds reaching the water bodies. High concentration of nutrients in the water bodies, accelerate the growth of algae (aquatic plant), thus leading to algal blooms. The process depletes the supply of oxygen in the water thus affecting the animal and plant species living in the water bodies (Dise *et al.*, 2011). This process is termed eutrophication.

2.6.3 Haze

Excess amount of tiny particles in the air obstructs the penetration of light reaching the earth's surface. Haze affects the clarity, form, texture and colour of the object perceived by human eyes. These tiny particles are released from construction site, industrial facilities and automobiles. In favourable conditions, nitrogen dioxide and sulphur dioxide released into the atmosphere forms particles upon interacting with other substance in the air. Haze adversely affects human sight and respiratory system, thus causing diseases (Brunekreef and Holgate, 2002).

2.6.4 Ozone depletion

Ozone (O₃) is an irritating, pale-blue gas that is explosive and toxic, even at low concentration. The gas is found between upper atmosphere (stratosphere) and ground-level (troposphere) above earth. The ozone layer protects harmful ultraviolet rays from reaching the earth's surface. Home appliance such as fridges, foaming agents, fire extinguishers, pesticides, aerosol propellants and solvents use gases that are known to deplete ozone layer. These include hydro chlorofluorocarbons and chlorofluorocarbons. Thinning the ozone layer increases the amount of UV radiations reaching the earth's surface, thus causing skin cancer, impaired immune system and cataract among the people (Ashmore, 2005). The depletion of the ozone also has negative impacts on the earth, human wellbeing, natural eco-systems and agriculture.

2.6.5 Global climate change

Increased amounts of carbon dioxide, water vapour and methane gases in the atmosphere leads to trapping of sunlight rays reflected from earth's surface thus increasing the surface temperature gradually. The balancing of naturally occurring gases and the gases generated by human activities is delicate, and difficult to maintain considering the increased industrial revolution and emerging technologies worldwide. These gases create greenhouse effect near the earth's surface, which leads to global warming. Increased average earth temperature melts the ice and snow in the high mountains thus increasing sea level and consequently negative effects such as smoothing of coral reefs, human health, agriculture, forestry and wildlife. It is undisputed that the average temperature at the surface of the Earth has increased over the past century by about 1°F (0.6°C), with both the air and the oceans warming (IPCC, 2001). The anthropogenic climate change causes a serious threat to the human health and ecosystems (IPCC, 2007).

2.7 Health effects of air pollution

One of the earliest forms of air pollution that caused health effects even at low ambient levels was particulate pollution. The health effects included sickness and mortality results. The results from several epidemiological studies on long term effects of exposure to particulate matter revealed that, respiratory and cardiovascular deaths is related to an increase of 10 µg/m³ in daily PM₁₀ average concentration (WHO, 2006). Particulate air pollution also led to increased healthcare visits and hospitalization for respiratory and cardiovascular disease. The symptoms

include asthma, cough and irritation of the lower respiratory system (WHO, 2006). In addition, epidemiological studies on PM_{2.5} particulate matter pollution have been associated with increase in respiratory disease (bronchitis), respiratory symptoms in asthmatics, coughing, infections of the lower respiratory tract and damaged lung function (WHO, 2006).

Observable symptoms associated with continuous exposure to air pollutants include impeded lung functioning, cough and chest pain (Gold *et al.*, 1999). Children are the most susceptible segment of the population since their body defense mechanism is under developed. Also, elderly people tend to be affected more by continuous exposure to air pollutants due to deteriorating health and weak body defense mechanism (Gold *et al.*, 1999). Eye (conjunctivitis) and lung cancer is also associated with air pollution. Occupational cement dust exposure has been associated with an increased risk of liver defects, pulmonary disorders, and carcinogenesis. The studies conducted by Schwartz and Dockery (1992) and Dockery *et al.*, (1993) indicated that high accumulation of ambient air pollutants that is common in urban setting are enough to increase the prevalence of neuro behavioral and cardiovascular effect, impeded pulmonary functioning, upsurge morbidity and mortality. In order to evaluate the negative effect of pollutants in the atmosphere to human health in various countries, Kunzli *et al.*, (2000) analyzed outdoor activities associated with air pollution under public health. The research was conducted in three countries: Switzerland, France and Australia. The findings indicated that 6 percent which is more than 40,000 cases annually of the total mortality was attributed to air pollution. Automobiles traffic contributed to approximately half of the total mortality attributed to air pollution. The three countries accounted for 25,000 new cases, 290,000 episodes and 0.5 million chronic bronchitis in adults, bronchitis in children and asthmatic attack respectively (Kunzli *et al.*, 2000).

Nitrogen monoxide is almost rapidly oxidized to nitrogen dioxide. Nitrogen dioxide is much more toxic to humans. It penetrates deep into the lung at much higher concentrations because it is less soluble than sulfur dioxide. From the respiratory tract of humans, approximately 70–90% of nitrogen dioxide inhaled can be absorbed (Tiwary and Colls, 2009). In human studies, nitrogen dioxide has been associated with adverse health effects even at low ambient concentrations. Exposure to high nitrogen dioxide levels from occupational exposure may have adverse effects such as pulmonary edema (Godish, 2004; WHO, 2006).

Short term exposure effects studies on the symptoms and severity of asthma have not led to clear findings though the asthmatics are the most reactive group upon exposure to nitrogen dioxide (WHO, 2006). Increased sulphur dioxide pollution causes irritation in the nose, throat and bronchoconstriction for asthmatic persons (Balmes *et al.*, 1987). In order to accurately evaluate prevailing risks associated with continuous exposure to ambient air pollution, it is important to evaluate the effect of pollutant source on the personal exposure. Scientists have reiterated that it is challenging to obtain accurate and reliable findings since population exposure and assessment of an individual is hard to achieve concurrently (Ghose and Majee, 2001).

2.8 Air pollution control technologies and equipment

2.8.1 Bag filters

Bag filter is used to control air pollution by removing particles out of air or gas released from industries during combustion. Filtration is the key component of bag filters since it involves the isolation of solid elements from the gas through the use of filter media that allows gaseous substance to pass through and capture the solid materials. The bag filter contains fabric bags that serve as collector for the dust. The fabric bags are emptied periodically to allow collected dust to be analyzed and determine their composition. Studies indicated that the use of bag filter to capture dust is very effective since it removes almost all the dust and allow gases to escape. However, the material used to manufacture the filters is sensitive to temperature and humidity (Donovan, 1985). The schematic diagram is shown in figure 2.1.

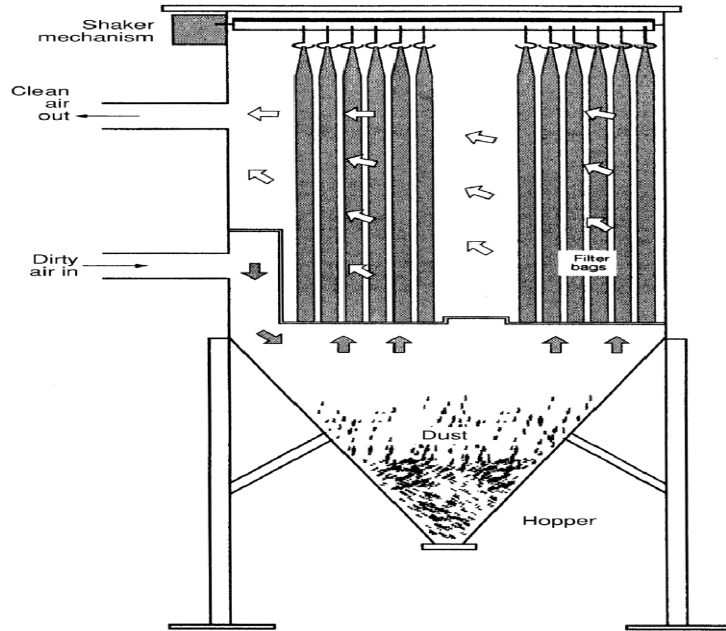


Figure 2.: Schematic diagram of a bag filter (source: Wang *et al.*, 2004)

2.8.2 Catalytic combustion

By use of a catalyst as adsorbers, gaseous pollutants are combusted to less harmful products of water and carbon dioxide (Pfefferle and Pfefferle, 1987). For example catalytic oxidation of carbon monoxide to carbon dioxide (Eqn. 2.9).



Micro combustors have been made to offer higher temperature profiles by utilizing heat produced during combustion hence complete combustion of unburned hydrocarbons, carbon monoxide and soot (Khandelwal *et al.*, 2010). A packaged micro- combustor is as shown in figure 2.2.

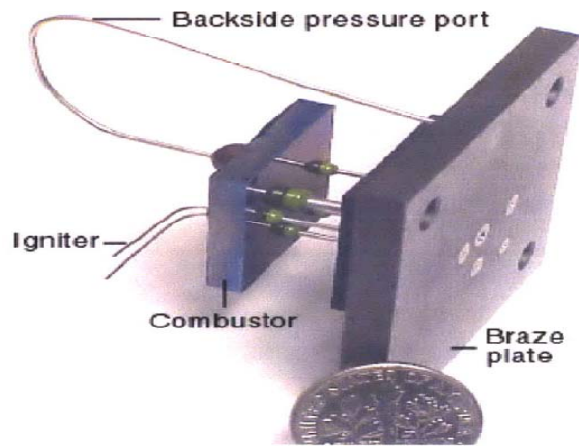


Figure .2: Packaged micro combustor (source: Mehra, 2000)

2.8.3 Electrostatic precipitation

The system is designed in a manner that positively charged electrode attracts charged particulate matter. These particulate matter accumulate in the pipe and have to be removed by hitting the pipe with a hammer to detach the accumulated dust (Karstensen, 2006). Dry electrostatic precipitation is further removed by using rappers that scrap the surface of the pipe through vibration. On the other hand, wet electrostatic precipitation allows the collected particulate matter to be collected through rinsing with water. Studies indicated that the use of electrostatic precipitation is more efficient and effective in collection of particulate matter as compared to other techniques since it traps even the finer particulate matter. In addition, the system generates a collection force that attracts particulate matter in the form of mists, fumes and dry materials. Another advantage of electrostatic precipitation is that its operation costs is minimal and functions in a wider range of temperatures. The major disadvantage is that the acquisition of the equipment is capital intensive, requires fixed operating condition, challenging to monitor particulate matter with high resistivity and installation requires a wider space (Cooper and Alley, 1994). The precipitator diagram is as shown in figure 2.3.

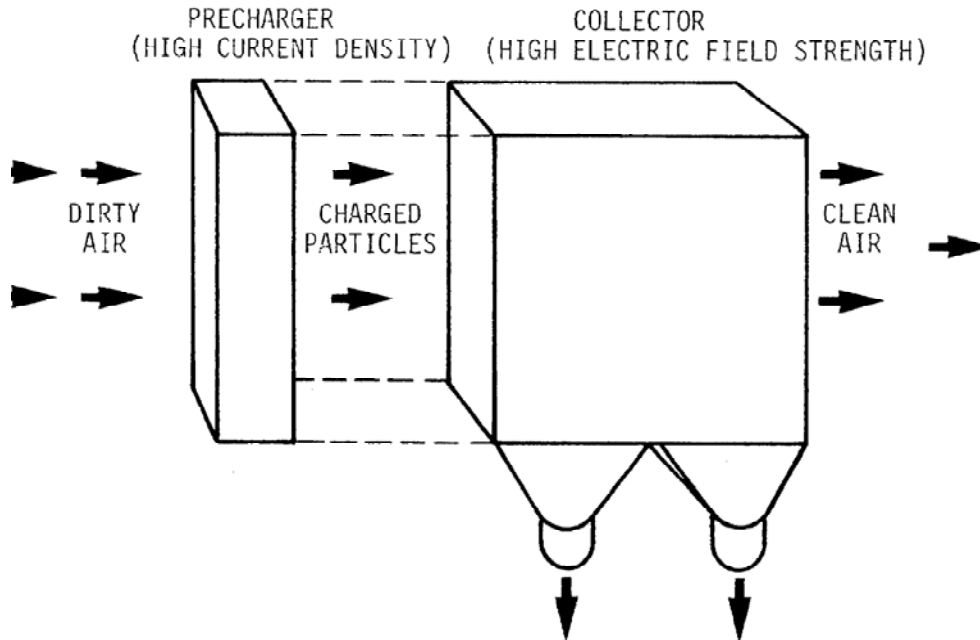


Figure 2.: Schematic diagram of electrostatic precipitator (source: Cowen *et al.*, 1980)

2.8.4 Absorption (wet scrubbing)

The technique in absorption is to pass polluted air through a liquid absorbent containing a scrubber. The liquid cleans the air by absorbing all the toxic substance and allowing clean air to pass through. The most commonly used liquid absorbent in a wet scrubber is water or water-based solution since it has a reactive agent that serves as a neutralizer to acids absorbed. The acidic gas is removed from the stream carrier and neutralized to become relatively low in acidity. As a result, the waste collected after absorption is less harmful and could be released to the treatment plant without causing much corrosion to equipment since the acid has been neutralized to accepted levels. Good examples of equipment that employ the principle of absorption include spray chambers, venture scrubbers, tray or plate columns and packed towers. Packed towers are the most commonly used gas absorbers for pollution control (McInnes *et al.*, 1990). Packed tower absorbers can achieve higher removal efficiencies and handle higher liquid rates. The diagram is as shown in figure 2.4.

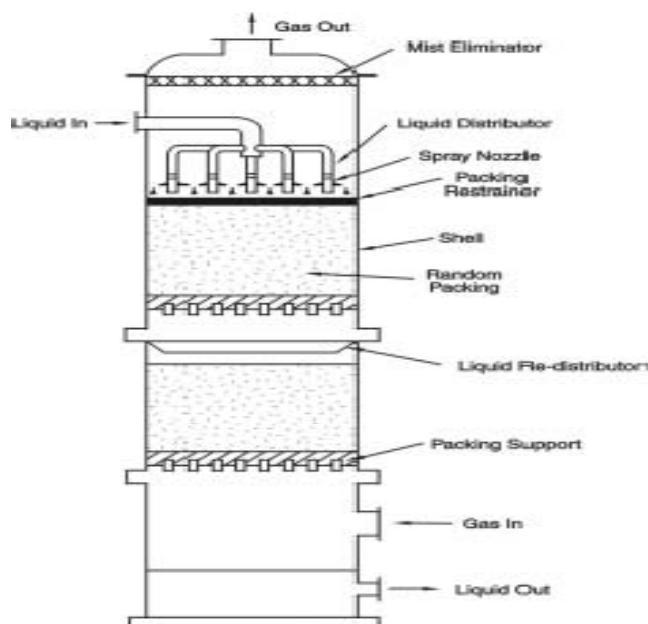


Figure 2.: Packed tower for gas absorption (source: McInnes *et al.*, 1990).

2.9 Principles of the Instrumentation Method Used In Chemical Analysis of Air Pollutants

2.9.1 Ultraviolet –Visible spectrophotometer

Ultra violet-Visible spectroscopy is a technique that relies on radiations generated on a wavelength ranging from 190 nm to 800 nm which fall within the visible range. It deals with transition of atoms /molecules from the ground state to the excited state. The absorption in the visible range directly affects the perceived colors of the chemicals used (Skoog *et al.*, 2007). Due to the fact that molecules and atoms takes in ultraviolet-visible radiation at varied range of wavelength, spectrometry is normally employed to identify substances based on the generated spectra. There are two types of spectrophotometer; single beam and double beam.

2.9.2 Single-beam device

As the name states, the instrument allows all of the light to illuminate through same sample cell. The benchmark light is measured before the first sample is analyzed as shown in figure 2.5. This instrument uses a simple optical system with high output and increased sensitivity hence becoming more effective and efficient. Some devices allows for the measurement of blank and subsequent samples in split of seconds for a single wavelength analysis. Consequently, split of seconds accumulates into several minutes when a full spectrum

of wavelength is utilized in the analysis. These instruments include conventional such as single-beam spectrophotometer. Since errors such as the drifting of a lamp from its desired position occurs this could significantly affects the results. In order to minimize these errors and enhance the results, dual-beam spectrophotometer was designed and developed.

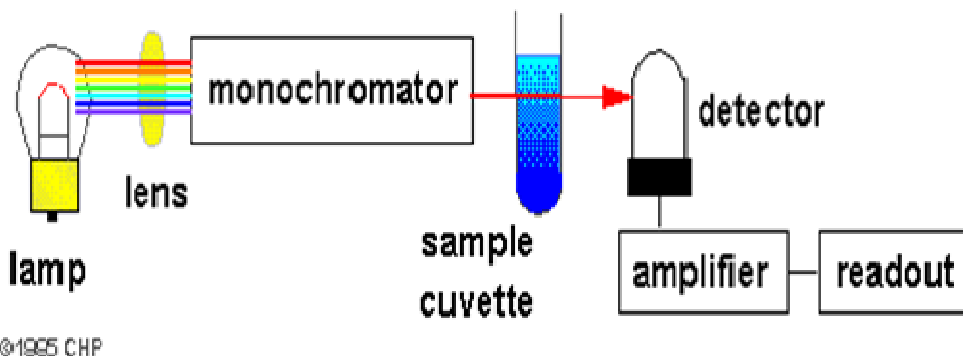


Figure 2.5: Schematic diagram of a single beam ultraviolet-visible spectrophotometer

2.9.3 Dual-beam instrument

As the name suggests the instrument split the illuminated beam into two before it reaches the detector. The split beam allows one light to serve as a reference and the other to be used as a sample. The detector alternately detects beams from the reference and the sample (Christian, 1990). Some double beam Ultraviolet-Visible spectrophotometers carries two photodiodes which are detectors used for measuring reference and sample beam concurrently (See figure 2.6).The double-beam instrument has more advantages than single beam instrument. They include; compensation for variations in the source intensity, variation in intensity as a function of wavelength, drift in the detector and amplifier.

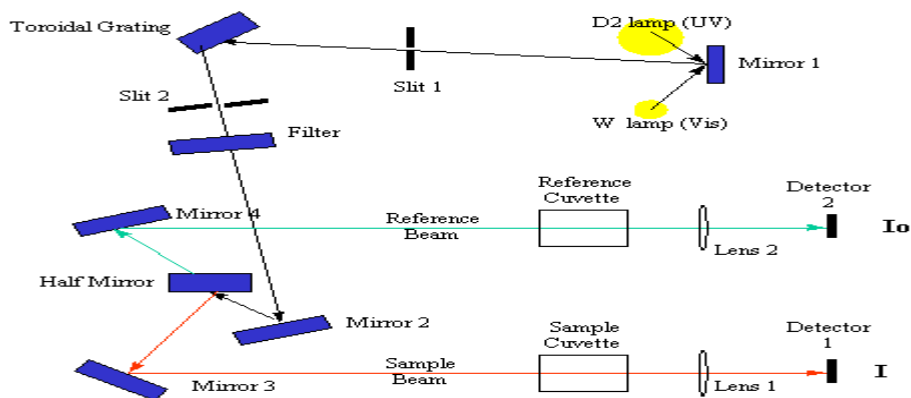


Figure 2.6: Schematic diagram of a double beam Ultraviolet-visible spectrophotometer.

2.9.4 The working principle of Ultraviolet –Visible spectrophotometry

The working principle of the ultraviolet-visible involves the analysis of ultraviolet and visible (UV-Vis) light passed through an absorption spectroscopy. The principle of ultraviolet-visible spectroscopy is based on the ability of a molecule to absorb ultraviolet and visible light. The absorption of light corresponds to the excitation of outer electrons in the molecule. The absorption is due to chromophores (absorbing molecules). The higher the number of molecules absorbed by the light in a given wavelength, the higher the intensity of peak recorded within that spectrum. On the other hand the intensity of the peak is weak when the number of molecules observed by the light is few. This makes the basis of Beer-Lambert's Law which states that the fraction of incident radiation absorbed is proportional to the number of absorbing molecules in its path.

$$A = \epsilon l c \quad (2.10)$$

A = Absorbance = $\log_{10} (I_0/ I)$, where I and I_0 are the intensity of the transmitted and incident light respectively; ϵ is absorptivity or extinction coefficient; l is the path path-length in cm and c is the concentration of the absorbing molecule in moles/litre.

2.9.5 The basic parts of a spectrophotometer

2.9.5.1 Light source

The radiation source used in the visible region is often a tungsten filament (300-2500 nm). The tungsten wire filament which is enclosed in a sealed glass bulb that is either filled with

inert gas or a vacuum is heated to radiance by an electric arc (Willard *et al.*, 1986). Deuterium arc lamp has been used in the ultraviolet region (190-400 nm). More recently light emitting diodes (LED) and xenon arc lamps have also been used in the ultraviolet region. Most spectrophotometers used to measure the UV-visible range contain both types of lamps. In such instruments, either a source selector is used to switch between the lamps as appropriate, or the light from the two sources is mixed to yield a single broadband source.

2.9.5.2 Sample holder

This involves the placement of sample into a transparent cell referred to as cuvette. These are typically rectangular cells that hold the sample with an internal width of 1 cm. The sample holder is transparent in order to allow the light to pass through a specific spectral region. According to Atkins and Julio (2006), quartz glass or high quality fused silica are commonly used since these allow enough light to pass through.

2.9.5.3 Diffraction grating or monochromator

They separate the different wavelengths of light. A monochromator consists of an entrance slit, a dispersion device, and an exit slit. The wave length selectors are filters made up of colored glass that disperses source radiation into its component wavelengths. The entrance slit is the frame holding the filter, which serves to confine the light source to where it is to be used. The exit is a simple fixed mask which blocks the undesired dispersed radiation and confines the transmitted beam of radiation to the dimensions of the sample holder (Pye Unicam, 1985).

2.9.5.4 Detector.

A detector converts a light signal into an electrical signal. Ideally, it should give a linear response over a wide range with low noise and high sensitivity. Spectrophotometers normally contain either a photomultiplier tube detector or a photodiode detector (Pye Unicam, 1985).

2.10 The principle of chemical analysis of pollutants

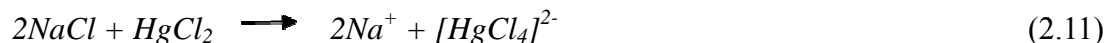
2.10.1 Sulphur dioxide

Potassium tetrachloromercurate (TCM) is a solution that is used to extract sulphur dioxide from the atmosphere. In order to prevent the sample from getting oxidized due to presences of oxygen in the atmosphere, a dichlorosulphitomercurate is used. This solution is resistant to complex oxidation such as oxide of nitrogen as well as ozone. This allows samples to be stored for over a long period of time before being analyzed. The complex is made to react with para rosaniline and methylsulphonic acid. The absorbance of the solution is measured by means of a suitable spectrophotometer.

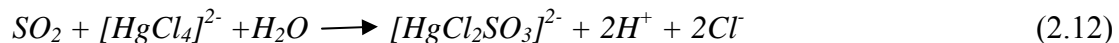
It is a modification of the West-Gaeke procedure which has been used as a reference method for quantitative determination of atmospheric sulphur dioxide. This procedure is recommended by the International Organization for Standardization, because it gives greater sensitivity, reproducibility and observes the Beer's law throughout a larger working range than the former (Mueller *et al.*, 1965; ISO, 1990).

The reactions are as follows (Eqn. 2.11 and 2.12):

1. Tetrachloromercurate II is produced by adding sodium chloride



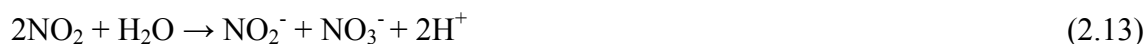
2. Sulphur dioxide is trapped and stabilized forming a complex dichlorosulphitomercurate.



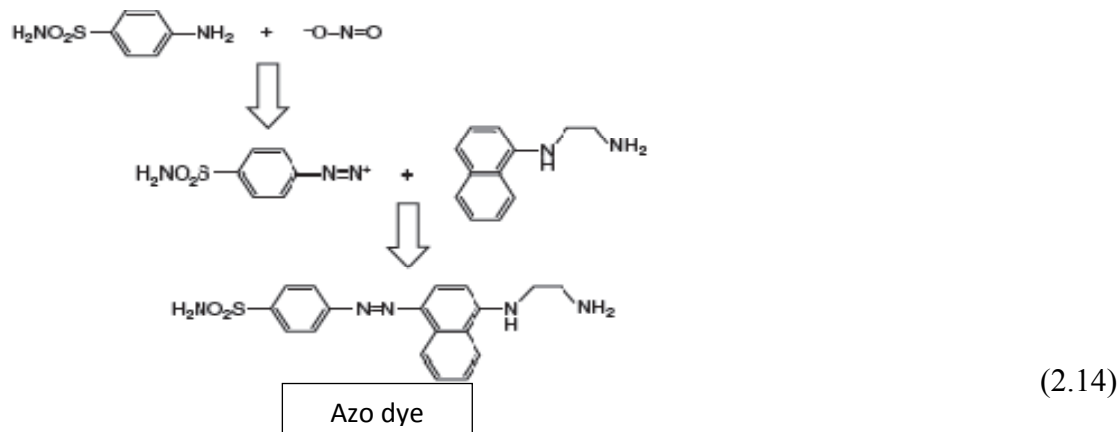
3. The dichlorosulphitomercurate complex reacts with pararosaniline and formaldehyde to form the intensely colored pararosaniline methyl sulphonic acid. The absorbance of the solution is measured by spectrophotometer to determine SO₂ in ambient air.

2.10.2 Nitrogen dioxide

The modified method of Saltzman (1954) was used for the determination of nitrite ion. In aqueous solution, nitrogen dioxide rapidly degrades to nitrate and nitrite (Eqn 2.13). It involves diazotisation of an aromatic amine in acid solution, followed by coupling of the diazo compound to form an intensely colored azo dye. The absorbance of the solution is measured spectrophotometrically at 550 nm. The corresponding concentration of nitrogen dioxide is determined from a calibration graph of absorbance versus concentration prepared using sodium nitrite solutions of known concentrations. The International Standard specifies a modified Griess-Saltzman method for the determination of the concentration of nitrogen dioxide present in ambient air (ISO, 1998). It is based on formation of an azo dye by reaction of NO_2^- with Griess reagent.



Nitrite reacts with sulphanilamide to form a diazonium ion which is then coupled to N-(1-naphthyl) eththylenediamine (NED) to produce a densely colored azo dye, which absorbs strongly at 550 nm. The reaction is shown in equation 2.14.



2.10.3 Carbon dioxide

In order to determine the amount of carbon dioxide dissolved in a sample, the use of titration process was appropriate. Titration is described as an analytical technique which allows

the quantitative determination of a specific substance (analyte) dissolved in a sample. It is based on a complete chemical reaction between the analyte and a reagent (titrant) of known concentration which is added to the sample (Skoog, 2004).

A typical chemical reaction for titrimetric analysis is shown in equation 2.15.



Where **a** is the mole of analyte, **A** contained in the sample that reacts with **t** moles of the titrant **T** in the titrant solution. A typical reaction is shown in Eqn 2.16.



The amount of potassium hydroxide is measured by titration with 0.5 M HCl, as shown in equation 2.17.



2.10.4 Suspended particulate matter

The term mass concentration in the analysis of air pollution serves as a benchmark for measuring industrial emission as well as atmospheric concentration through filtration process. The filtering process allows emitted particulate matter to be trapped and collected and subsequently weighed. This is determined by weighing and calculating the difference in filter weights prior to and after sampling expressed as concentrations in mg/m^3 . This method is well standardized under the ISO 14644-1 and 2 (ISO, 1999).

2.11 Air Pollution Studies in Kenya

Air quality in Nairobi City and its environs has been declining due to lack or inadequate regulations of air pollution in Kenya (Van Vliet and Kinney, 2007). A study by Kinney *et al.*, (2011) on exposure levels to particulate matter ($PM_{2.5}$) along busy highways and roundabouts, found an average of $98 \mu g/m^3$ exposure levels of $PM_{2.5}$. The average level is over WHO daily guideline limit of $25 \mu g/m^3$ (24 hours). Also studies by Gaita *et al.*, (2014) in Nairobi indicated that the major sources of air pollution included combustion, industries, mineral dust and automobiles. Nairobi bus drivers were more than five times exposed to higher concentrations of $PM_{2.5}$ compared to Swedish bus drivers (Lewne *et al.*, 2007).

In sub-urban areas in Kenya, they have experienced emergence of informal settlement schemes. Studies in these settlements revealed that the occupant's burn solid waste in open air and most of the homes used kerosene and charcoal for domestic cooking, leading to indoor air pollution. Particulate matter, chemicals and infectious agents volatilized from open fires may have damaged the respiratory systems of some household members, especially children (UNEP, 2001).

Study by Kinyua *et al.*, (1998) on dust fallouts in offices was higher than the WHO limit of $150\text{-}230\mu\text{g}/\text{m}^3$ (24 hours) in Nairobi. In Kisumu City in Kenya, Awange and Obera (1987) highlighted the emerging threats of motor vehicle pollution. Ngugi (1983) and Karue (1991) studies showed that air quality in Nairobi has been deteriorating. This is further supported by Wafula (1999) where air pollution levels of sulphur dioxide in Thika, Kikuyu and Nairobi industrial area were higher than the WHO limit of $50\mu\text{g}/\text{m}^3$ (annual mean). These high concentrations of air pollution were attributed to industrial activities as well as motor vehicle exhaust, construction work and increasing population.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 STUDY AREA

3.1.1 Athi River

Athi River is located at latitude 1.45° South (1⁰27'27.8"S), longitude 36.98° East (36⁰58'42.6"E) and 1532 meters elevation above the sea level. Athi River Town is in Kenya, in Machakos County, Mavoko constituency. The town hosts Mavoko Municipal Council and headquarters of Mavoko division. The town is dusty and polluted due to many manufacturing industries and tanneries. The area is under semi-arid ecosystem with the main industries being cement manufacturing plants. It is relatively industrialized with six cement factories, which include: Bamburi Cement Company, Mombasa Cement Limited, Athi River Mining, East Africa Portland Cement, National Cement Company and Savannah Cement Company. The area is also a growing residential area due to industrialization, which has created more job opportunities. Figure 3.1.1 is a map which shows the study area. Athi River is approximately 693km² with a population of 139,380 according to the 2009 census. Its annual population growth using statistics from Kenya National Bureau of Statistics (KNBS) is around 2.5%. Its approximate population would be 156,802 in 2016.

The main objective of the research is to determine the air borne levels of sulphur dioxide, nitrogen dioxide, carbon dioxide and suspended particulate matter in Athi River Town and compare these with WHO allowable limit and OSHA.

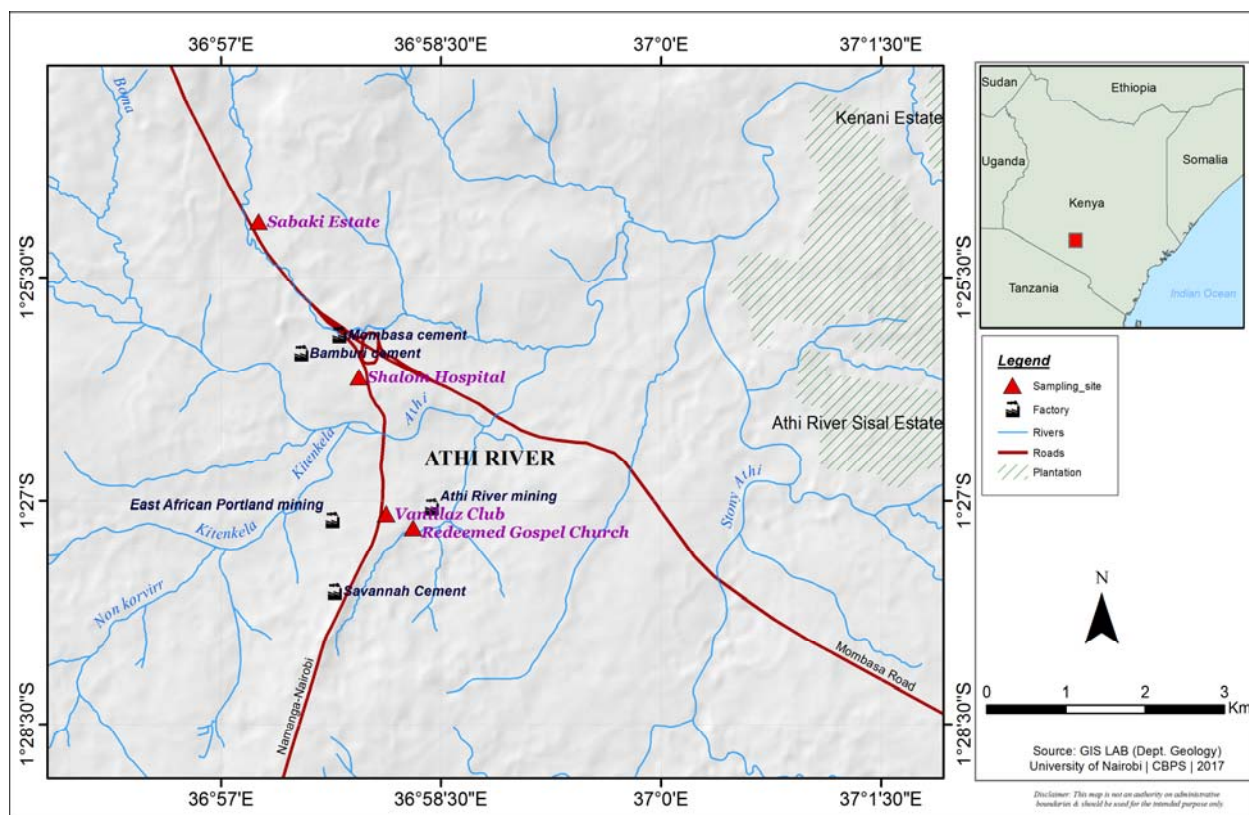


Figure 3.1: Athi River, Study site (Source: GIS LAB, 2017).

3.2 Sampling sites

The monitoring stations chosen were free from any interference from the surrounding that would prevent free air flow from the ambient atmosphere. Sampling was done at 1.5 m height. Four sites were selected. Site A (Shalom Hospital), Site B (Vanillaz club), Site C (Redeemed Gospel Church) and Site D (Sabaki residential Estate) as shown in figure 3.1.

3.2.1 Site A: Shalom Hospital

The site was near Shalom Hospital (see figure 3.1) located at latitude ($1^{\circ}25'05.9''S$) and ($36^{\circ}57'40.1''E$) longitude, situated in an industrial environment with an open terrain. Within the vicinity were Mombasa Cement Company located about 400 meters to the north and Bamburi cement plant about 600 meters west of the study site. There was busy traffic of trucks/ vehicles carrying raw materials as well as finished cement products into and out of cement plant

companies. Also private vehicles frequented the local Bamburi road. There is Mombasa-Namanga road which goes to Tanzania that has heavy vehicular traffic. All these anthropogenic activities could have an effect on pollutant levels.

3.2.2 Site B: Vannilaz club

Site B (Vannilaz club) is located at the junction of Makadara road along Nairobi-Namanga highway at latitude ($1^{\circ}27'10.1''\text{S}$) and ($36^{\circ}57'49.4''\text{E}$) longitude (figure 3.1.) with East Africa Portland Cement Company (EAPCC) factory located south west of the site while Athi River Mining Cement Company (ARM) is located to north east of the site. The site was close to a furniture mart, business premise with a club, restaurant, shops and car wash yard along Nairobi- Namanga road. Biomass was used for heating and cooking at the site.

3.2.3 Site C: Redeemed Gospel Church

The site is located at Redeemed Gospel Church with a primary school within the church compound at latitude ($1^{\circ}27'59.1''\text{S}$) and ($36^{\circ}47'38.8''\text{E}$) longitude. It is along Makadara- Athi River road as shown in figure 3.1. The site is surrounded by Associated Battery Manufacturers and recycling company (ABM), Athi River Mining Cement Company (ARM) and a mining quarry. The factories, ABM and ARM are about 200 meters away from the site while the quarry is adjacent to the church fence about 50 meters from the sampling site.

3.2.4 Site D: Sabaki residential Estate.

The site is a residential Estate about 2 km off Mombasa road (figure 3.1.) located at latitude ($1^{\circ}25'42.3''\text{S}$) and ($36^{\circ}57'55.1''\text{E}$) longitude. It is a non-industrial area with less vehicular traffic and housing construction was the major activity in this place.

3.3. Sampling requirements and sampling

3.3.1 Field Apparatus

A 220/240 volts electric power driven suction pump (manufactured by Charles Austen Pumps Limited, England), fitted with a 10 meter rubber tubing and 70 meter power cable, a portable Tiger generator, an impinger or glass trapper, a wet and dry hygrometer with conversion tables (manufactured by Russell Scientific Instruments Limited, England),

together with a thermometer for temperature monitoring, a filter holding tube with filter papers (Whatman membrane filters 0.2µm pore size) and anemometer for monitoring wind speed.

3.3.2 Field working solutions

0.1M Sodium tetrachloromercurate, triethanol amine, n-butanol, 0.5M potassium hydroxide (KOH), 95% metabisulphite (Na₂S₂O₅), distilled water, 98% mercuric chloride (HgCl₂), 99.9% sodium chloride (NaCl), concentrated hydrochloric acid (37% w/v), formaldehyde (HCHO), sulphamic acid (H₂NSO₃H), para-rosaniline, sodium nitrite (NaNO₂), ammonium hydrogen phosphate, and N-(1-naphthyl)-ethylenediamine dihydrochloride (NEDA).

3.3.3 Sampling procedures

Air samples were scrubbed through appropriate trapping solutions using a portable suction pump of known flow rate according to active sampling method. The impinger was rinsed with distilled water, followed by the appropriate trapping solution of the pollutant to be analyzed. Table 3.1 gives the different trapping solutions for each pollutant.

Table 3.1: Trapping solutions for the various pollutants.

| PARAMETER | TRAPPING SOLUTION |
|-----------------|---|
| SO ₂ | 0.1 M Sodium tetrachloromercurate (TCM) |
| CO ₂ | 0.5 M KOH |
| NO ₂ | Triethanolamine (C ₆ H ₁₅ NO ₃) |

The trapping solution (50 ml) was transferred into an impinger using a graduated pipette. The impinger inlet was connected to 10 m rubber tubing, whereas the impinger outlet was connected to a 30 cm rubber tubing with the suction pump. The 10 meter rubber tubing was then tied to a convenient hook where sampling was desired. For the suspended particulate matter, the impinger was replaced with filter holding tube fitted with filter paper. Sampling at all sites was done for 15 minutes. Air Sampling was done at the specific sites during the day (morning and afternoon) and it covered both the dry and rainy seasons. The meteorological parameters namely

wind speed, wind direction, relative humidity and temperatures were measured during sampling. All samples were transferred and stored in 120 ml plastic bottles, tightly sealed prior to laboratory testing. Filter papers were also stored in sealed plastic bags. The experimental set up is as shown in figure 3.2.

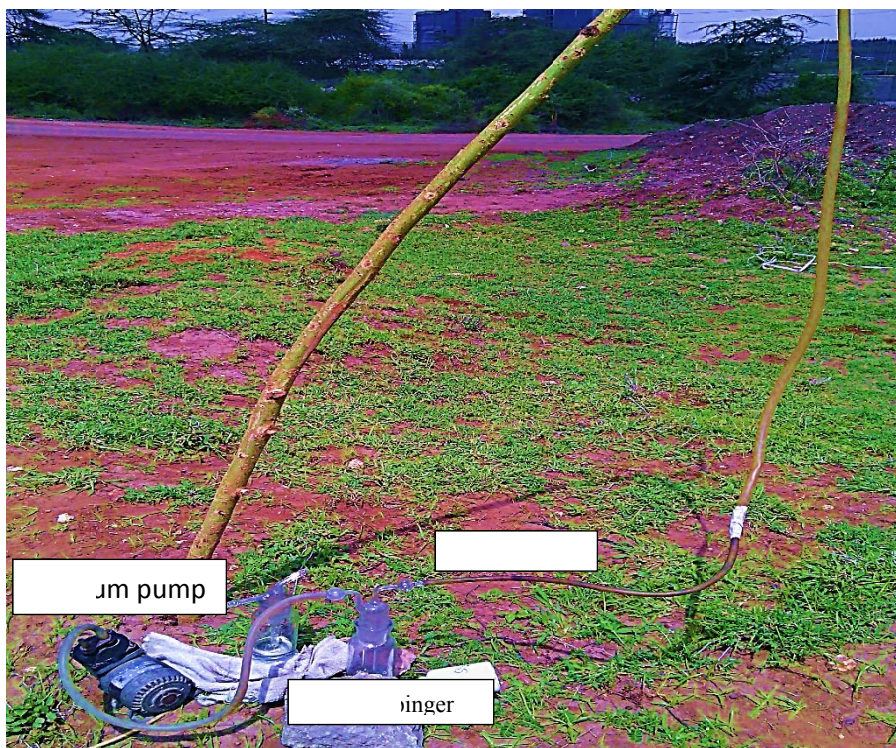


Figure 3.2: Air sampling train

3.4 Chemical analysis procedures

3.4.1 Reagents for sulphur dioxide

- (1) 0.1 molar sodium tetrachloromercurate solutions was prepared by dissolving 27.80g of 98% mercuric chloride (HgCl_2) and 11.70g of 99.9% sodium chloride (NaCl) in 1L volumetric flask and made to volume with distilled water.
- (2) 0.2% formaldehyde solution (HCHO) was prepared by diluting 5.3ml of 38% formalin to one litre with distilled.

- (3) 0.6% (w/w) sulphamic acid ($\text{H}_2\text{NSO}_3\text{H}$) solution which reduces the interfering oxides of nitrogen to nitrogen gas was prepared by dissolving 0.60g of sulphamic acid in 99.4 ml distilled water.
- (4) 0.04% (w/v) para-rosaniline solution was prepared by dissolving 0.04g of para-rosaniline in 6 ml of concentrated hydrochloric acid (HCl) and shaken with 50 ml of distilled water, filtered and diluted to 100 ml. This solution was for color development.

3.4.2 Standard solutions for sulphur dioxide

Stock solution of 1000 ppm SO_2 was prepared by dissolving 0.1484g of 95% sodium metabisulphite ($\text{Na}_2\text{S}_2\text{O}_5$) in distilled water and making it to 100 ml. Sub-stock of 50 ppm was prepared by measuring 5 ml of stock solution (1000 ppm) in 100 ml volumetric flask and diluted to the mark with distilled water. Serial dilutions of SO_2 concentrations were prepared as working solutions in the range of 0 ppm, 1ppm, 2 ppm, 3 ppm to 4 ppm by measuring 1ml, 2ml, 3ml, and 4 ml from the sub-stock of 50 ppm into 50 ml volumetric flask each and diluted with distilled water to the mark. The different concentrations were used for calibration and quantitative determination.

3.4.3 Experimental procedure for sulphur dioxide

10 ml sample was taken from the original 50 ml trapping solution and placed in a 50 ml volumetric flask (dilution factor of 5) and 2 ml of 0.6% sulphamic acid was added. The solution was allowed to react for 10 minutes to destroy nitrite, and then 4 ml of 0.2% formaldehyde and 4 ml of 0.04% pararosaniline solution were added and made to the mark with 0.1M tetrachloromercurate trapping solution. Reference blank solution containing only 0.1M TCM and standards were treated in the same way as samples. Distilled water was used as optical reference. Samples were analyzed using UV-Visible spectrophotometer and the absorbance was then measured at 560nm spectrophotometrically using Shimadzu Uv-1700 pharmaspec spectrophotometer.

A typical calibration graph (Appendix 1) was drawn with slope of 0.326, an intercept of 0.0398 and a Pearson's correlation coefficient of 99.55%. Equation (3.1) describes the linear relationship between absorbance and concentration.

$$A = ax + b \quad (3.1)$$

Straight line equation where; **A** is absorbance, **a** is the slope, **x** the concentration and **b** the intercept.

3.4.4 Reagents for nitrogen dioxide

1. Trapping solution was prepared by measuring 30g (41.33ml) of triethanolamine in 1L of volumetric flask and 6ml of n-butanol added to avoid foaming and diluted to volume with distilled water.
2. Buffer solution was prepared by weighing 200g of ammonium hydrogen phosphate in one litre volumetric flask then dissolved with 250ml of 85% phosphoric acid and made to volume with distilled water.
3. Diazotization reagent was prepared by weighing 10g of sulphamic acid and dissolving in 100ml of acetone in one litre volumetric flask, and then made to volume with distilled water.
4. Saltzman reagent was prepared by measuring 200 mg of N-(1-naphthyl)-ethylenediamine dihydrochloride (NEDA) and dissolved in 250 ml buffer solution in 1 litre volumetric flask. This was diluted to volume with distilled water.
5. Colorimetric solution was prepared just before analysis by mixing equal amounts of diazotization reagent and saltzman reagent.

3.4.5 Standard solutions for nitrogen dioxide

Stock solution of 1000 ppm NO₂ was prepared by dissolving 0.1499g of 100.04% sodium nitrite (NaNO₂) in 100 ml volumetric flask and made to the volume with distilled water. Sub-stock of 50 ppm was prepared by measuring 5 ml of stock solution (1000 ppm) in 100 ml volumetric flask and diluted to the volume with distilled water. Serial dilutions of NO₂ concentrations were prepared (working solutions) in the range of 0.0, 0.2, 0.4, 0.6, 0.8, to 1.0 ppm for calibration and quantitative determination. Working standards were prepared by measuring 0.2, 0.4, 0.6, 0.8, and 1.0 ml from 50 ppm into 50 ml volumetric flasks and made to volume with distilled water.

3.4.6 Experimental procedures for nitrogen dioxide

20 ml of the sample was taken from 50 ml original trapping solution into 50ml volumetric flask (dilution factor 2.5). To this sample, colorimetric solution was added to the mark forming a highly colored azo dye. Reference blank solution containing 20 ml of trapping solution was treated in the same way as the sample. Distilled water was used as optical reference. Samples were analyzed using UV-Visible spectrophotometer and the absorbance was then measured at 550nm spectrophotometrically using Shimadzu Uv-1700 pharmaspec spectrophotometer. Measurements of absorbance for standards 0.2 ppm-1.0 ppm were also done. A typical calibration graph (Appendix 2) was drawn with slope of 0.93, an intercept of – 0.004 and a Pearson's correlation coefficient of 99.58%. The equation $A = ax + b$, describes the linear relationship between absorbance and concentration. **A** is absorbance, **a** is the slope, **x** the concentration and **b** the intercept.

3.4.7 Reagents for carbon dioxide

- (1) 0.5 M KOH was prepared by measuring 28.05g of potassium hydroxide (KOH) in one litre volumetric flask and 100 ml of distilled water added slowly while shaking. The solution was then made to volume with distilled water.
- (2) 0.5 M HCl was prepared as titrant by measuring 41.66ml of 37% HCl into one liter volumetric flask and made to the volume using distilled water.
- (3) Methyl orange indicator; made by weighing 100mg of methyl orange into 100ml volumetric flask and made to volume with distilled water.

3.4.8 Experimental procedure for carbon dioxide

Appropriate volume of air was bubbled through 50 ml trapping solution of 0.5 M KOH for 15 minutes. 10 ml of this trapping reagent was pipetted into 250ml conical flask and 2-3 drops of methyl orange indicator added. The solution was titrated against 0.5 M HCl. The titration was done drop wise until color change occurred from orange to pink at end point. The titre volume was recorded and used to calculate the concentration of carbon dioxide in the air. These are shown in Appendices 11-14 and 27-30.

3.4.9 Experimental procedures for suspended particulate matter

The filter papers were conditioned in an oven at 100 °C and cooled in a desiccator. The filter papers were weighed using an analytical balance and the results recorded. Mass differences of the filter papers prior to analysis and after analysis were calculated taking into account the volume of air during sampling. The concentration was expressed in mg/m³. These are shown in Appendices 15-18 and 35-38. The set-up of the experiment is shown in figure 3.2; where by the filter paper with the holder was placed at the end of the gas inlet tube.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Average Levels of the Analyzed Air Pollutants

The average levels of the pollutants during wet and dry season are given in tables 4.1 and 4.2 respectively. The median and range values are also given in tables 4.3 and 4.4. In table 4.1; Appendices 3-6 were used to calculate SO₂ content mean levels at sites A-D; Appendices 7-10 were used to calculate NO₂ content mean levels at sites A-D; Appendices 11-14 were used to calculate CO₂ content mean levels at sites A-D and Appendices 15-18 were used to calculate SPM content mean levels at sites A-D.

Table 4.1: The average levels of pollutants analyzed at the four sites during the wet season.

| LEVELS OF POLLUTANTS DURING WET SEASON | | | | |
|--|---|---|---|---------------------------------------|
| Site | SO ₂ (µg/m ³) Mean ± SD | NO ₂ (µg/m ³) Mean ± SD | CO ₂ (mg/m ³) Mean ± SD | SPM (mg/m ³) Mean ± SD |
| A | 602 ± 84 | 159 ± 19 | 245 ± 161 | 3.21 ± 1.36 |
| B | 793 ± 62 | 175 ± 5.5 | 460 ± 142 | 3.71 ± 2.08 |
| C | 861 ± 26.4 | 157 ± 10 | 596 ± 181 | 2.37 ± 0.95 |
| D | 370 ± 57 | 111 ± 7 | 1614 ± 227 | 1.68 ± 0.56 |
| WHO Value | 500 µg/m ³ 10 minutes | 120 µg/m ³ 8 hours | | 150-230 µg/m ³ 24 hours |
| OSHA Value | | | 9000 mg/m ³ 8 hour | |

*SD= Standard deviation, Site A is Shalom Hospital, Site B- Vannilas Restaurant, Site C- Redeemed Gospel Church and Site D- Sabaki Residential area.

SO₂ content in air samples at sites A-C were all above the WHO value of 500 µg/m³ at exposure of 10 minutes except for site D (370 µg/m³). The NO₂ levels at sites A-C were higher than the WHO allowable value of 120 µg/m³ at exposure of 8 hours except at site D (111 µg/m³). CO₂ levels at sites A-C were below the levels of CO₂ at 697 mg/m³ (mean level in ambient air), except at site D (1614 mg/m³) which exceeded the limit. However, the CO₂ levels at sites A-D were below the OSHA levels at 9,000 mg/m³. Suspended particulate matter at all sites was much higher than the WHO value of 150-230µg/m³ of 24 hours exposure time as shown in table 4.1.

In table 4.2, Appendices 23-26 were used to calculate SO₂ content mean levels at sites A-D; Appendices 31-34 were used to calculate NO₂ content mean levels at sites A-D; Appendices 27-30 were used to calculate CO₂ content mean levels at sites A-D and Appendices 35-38 were used to calculate SPM content mean levels at sites A-D.

Table 4. 2: The average levels of pollutants analyzed at the four sites during the dry season.

| LEVELS OF POLLUTANTS DURING DRY SEASON LEVELS | | | | |
|---|---|---|---|---------------------------------------|
| Site | SO ₂ (µg/m ³) Mean ± SD | NO ₂ (µg/m ³) Mean ± SD | CO ₂ (mg/m ³) Mean ± SD | SPM (mg/m ³) Mean ± SD |
| A | 863 ± 33 | 139 ± 9 | 863 ± 111 | 3.89 ± 1.09 |
| B | 875 ± 27 | 147 ± 9 | 709 ± 124 | 3.71 ± 2.0 |
| C | 862 ± 44 | 136 ± 11 | 769 ± 80 | 4.39 ± 2.37 |
| D | 664 ± 23 | 94 ± 9 | 1548 ± 163 | 1.69 ± 0.69 |
| WHO Value | 500 µg/m ³ 10 minutes | 120 µg/m ³ 8 hours | | 150-230 µg/m ³ 24 hours |
| OSHA value | | | 900 mg /m ³ 8 hour | |

In table 4.2, SO₂ content in air samples at all sites A-D were all above the WHO value of 500 µg/m³ at exposure of 10 minutes. The NO₂ levels at sites A-C were higher than the WHO allowable value of 120 µg/m³ at exposure of 8 hours, except at site D which was below (94 µg/m³). CO₂ levels at sites A-D were higher than the levels of CO₂ of 697 mg/m³ which is the mean level found in ambient air. Though, all the values in A-D were below the level given by OSHA at 9,000 mg/m³ for an 8 hour exposure in a work day. Suspended particulate matter levels at all sites were much higher than the WHO value of 150-230 µg/m³ of 24 hours exposure time. These values were more than 3-7 times the WHO value.

The data for calculating the median and range in table 4.3 were from appendices used for table 4.2.

Table 4.3: Median And Range Levels of Pollutants Analyzed at the Four Sites during the Dry Season.

| MEDIAN AND RANGE LEVELS OF POLLUTANTS DURING DRY SEASON | | | | | | | | |
|---|--------|-----------|--------|-----------|--------|-----------|--------|-----------|
| Pollutant | Site A | | Site B | | Site C | | Site D | |
| | Median | Range | Median | Range | Median | Range | Median | Range |
| SO ₂ (µg/m ³) | 853 | 828-938 | 883 | 833-925 | 844 | 805-930 | 660 | 631-720 |
| NO ₂ (µg/m ³) | 139 | 123-151 | 149 | 132-162 | 136 | 124-162 | 95 | 84-105 |
| CO ₂ (mg/m ³) | 871 | 743-1078 | 708 | 554-930 | 777 | 636-911 | 1552 | 1270-1761 |
| SPM (mg/m ³) | 3.33 | 1.67-5.00 | 3.25 | 1.55-6.68 | 4.11 | 1.59-8.09 | 1.59 | 1.58-3.29 |

The range and median values for SO₂ content at all sites A-D (table 4.3) were above the WHO mean value of 500µg/m³. The median and range of NO₂ levels at sites A-C were higher than the WHO allowable value of 120 µg/m³ at exposure of 8 hours except at site D. CO₂ levels at the sites A, D were higher than the levels of CO₂ of 697 mg/m³ in ambient air but lower than OSHA level at 9,000 mg/m³ of an 8 hour exposure. Suspended particulate matter at all sites was much higher than the WHO value of 150-230 µg/m³ of 24 hours exposure time. The mean, median and range levels of most pollutants during the dry season all showed high values than the WHO value for the pollutants as shown in table 4.2 and table 4.3.

The data for calculating the median and range in table 4.4 were from appendices used for table 4.1.

Table 4.4: Median and range levels of pollutants analyzed at the four sites during the wet season.

| MEDIAN AND RANGE LEVELS OF POLLUTANTS DURING WET SEASON | | | | | | | | |
|---|--------|-----------|--------|----------|--------|-----------|--------|---------------|
| Pollutant | Site A | | Site B | | Site C | | Site D | |
| | Median | Range | Median | Range | Median | Range | Median | Range |
| SO ₂ (µg/m ³) | 605 | 496-807 | 777 | 708- 914 | 866 | 816-890 | 416 | 266-425 |
| NO ₂ (µg/m ³) | 157 | 131-185 | 174 | 164-183 | 158 | 142-170 | 111 | 99-119 |
| CO ₂ (mg/m ³) | 207 | 79-578 | 470 | 158-639 | 622 | 304-796 | 1709 | 1041- 1893 |
| SPM (mg/m ³) | 3.01 | 1.44-5.76 | 2.89 | 1.41-7.2 | 2.1 | 1.38-4.33 | 1.44 | 1.43-2.91 |

In table 4.4, the median of SO₂ value in air samples at sites A (605µg/m³) and D (416 µg/m³) were lower than the WHO limit while sites B (777 µg/m³) and C (866 µg/m³) were above the WHO value of 500 µg/m³ at exposure of 10 minutes. The median and range of NO₂ levels at sites A-C were higher than the WHO allowable value of 120 µg/m³ at exposure of 8 hours except at site D (111 µg/m³). CO₂ levels at sites A-C were within the levels of CO₂ of 697 mg/m³ except at site D (1709 mg/m³) which exceeded the limit. These values were all below the Occupational Health and Safety Authority of 9,000 mg/m³. Suspended particulate matter at all sites was much higher than the WHO value of 150-230 µg/m³ of 24 hours exposure time.

4.2 Study Site A (Shalom Hospital)

4.2.1 Sulphur dioxide

The levels of SO₂ during the wet and dry season were 602 µg/m³ and 863 µg/m³ respectively. Both values were above the WHO recommended value of 500µg/m³ at exposure time of ten (10) minutes (tables 4.1; 4.2). The high concentration of SO₂ at the site could have been due to the presence of Bamburi Cement and Mombasa Cement which are found in the vicinity. Bamburi Cement is about 500 m to the west while Mombasa Cement is about 500m to the north-west. Clinker raw materials and gypsum contained sulphur which formed SO₂ during combustion and this process could have enhanced the SO₂ level. The presence of Devki steel plant and tannery may have also contributed towards higher levels of this gas. Many of these industries use fuel oil which contains sulphur. Other contributing factors were; high vehicular traffic along Bamburi road and along Mombasa- Namanga highway. The wet season had a lower level (602µg/m³) of SO₂ as compared to dry season (863µg/m³) due to washout of SO₂ by rain water to form acid rain.

4.2.2 Nitrogen dioxide

The overall mean of nitrogen dioxide in both seasons exceeded WHO guidelines of 120 µg/m³ for 8 hour exposure with levels at 139 µg/m³ during dry season and 159 µg/m³ during wet season (tables 4.1 and 4.2). The traffic density in the site may have contributed to the high levels of NO₂. The nitrogen dioxide levels varied with range of 123-151 µg/m³ during dry season and 131-185 µg/m³ during the wet season (tables 4.3 and 4.4). Combustion of fossil fuels (coal and oil) from the industries (Bamburi cement and Mombasa cement) may have contributed to NO₂

pollution. The combustion of fuels at high temperatures in cement kilns also resulted in the release of NO₂ emissions. During the wet season, NO₂ concentration was higher compared to dry season this could be due to low wind speed and maybe consistent wind direction leading to reduced air pollutant dilution.

4.2.3 Carbon dioxide

The CO₂ levels at Athi River during dry season exceeded the calculated world average carbon dioxide level of 697 mg/m³. The mean level was at 863 mg/m³ during the dry season (table 4.1), while during the wet season, the mean concentration was 245 mg/m³. This was still below the permissible exposure limit of OSHA of 9,000 mg/m³. The low concentration was linked to washout of the pollutant during the wet season. The increased value during the dry season could be due to the presence of cement industries in the vicinity like Bamburi and Mombasa Cement plants. They emitted CO₂ into the environment during decarbonisation of calcium carbonate and magnesium carbonate. Fossil fuel combustion, vehicular traffic, incineration and other burning activities, also contributed to more carbon dioxide levels.

4.2.4 Suspended particulate matter

The particulate matter mean results during both dry and wet season were higher than the WHO standard of 150-230 µg/m³. The mean results were 3890 µg/m³ during the dry season and 3210 µg/m³ during the wet season (tables 4.1 and 4.2). SPM ranged from 1600 - 5000 µg/m³ during the dry season and from 1440 – 5760 µg/m³ during the wet season. The high levels of SPM in both seasons may be due to dust emissions from the cement manufacturing companies of Bamburi and Mombasa cement. Dust was emitted during off-loading of raw materials at conveyor belts, at the milling area and during final loading of cement. High density of vehicular traffic and those delivering raw materials into the cement companies as well as those ferrying finished cement products may have contributed to increased SPM levels into the atmosphere. Diesel exhaust is the prime contributor to SPM. Resuspension of dust by the heavy transportation along the busy Bamburi Road and Athi River-Namanga Highway may have increased the levels of SPM into the environment. In addition, fossil fuel combustion in the factories also contributed to high levels of SPM.

4.3 Site B (Vannilaz club)

4.3.1 Sulphur dioxide

Sulphur dioxide mean levels were 875 $\mu\text{g}/\text{m}^3$ during dry season and 793 $\mu\text{g}/\text{m}^3$ during wet season (tables 4.1 and 4.2). The levels exceeded the WHO allowable limits at 500 $\mu\text{g}/\text{m}^3$. The high level of SO_2 may be attributed due to adjacent Athi River Mining Company and East Africa Portland Cement Company which used fuel oil and pyrites (FeS) in its operation. The traffic along Athi River-Namanga Highway also emitted SO_2 from the diesel engines. The lower concentration of the pollutant during the dry season could be due to wind which dispersed and diluted the pollutants. Also during the day, the high ground temperature heated the air which became turbulent and caused air dispersion.

4.3.2 Nitrogen dioxide

The NO_2 levels recorded the highest level during analysis at this site with mean level of 147 $\mu\text{g}/\text{m}^3$ during dry season and 175 $\mu\text{g}/\text{m}^3$ during wet season (tables 4.1 and 4.2). The levels exceeded the WHO ambient allowable level of 120 $\mu\text{g}/\text{m}^3$. This may be associated with heavy vehicular traffic. The other contributor was the fuel combustion in industries (Athi River Mining and East Africa Portland Cement Company).

4.3.3 Carbon dioxide

The CO_2 mean level was 709 mg/m^3 (table 4.2) during the dry season which exceeded the calculated world average value at 697 mg/m^3 . But the value was lower than OSHA permissible level of 9,000 mg/m^3 . The presence of CO_2 may be due to the biomass burning at the site as it is a meat-eating place. There was also a lot of charcoal burning which increased CO_2 levels. During the wet season the mean level was 460 mg/m^3 lower than the dry season at 709 mg/m^3 . The pollutant low level during wet season was caused by wash out by rain.

4.3.4 Suspended particulate matter

The SPM mean levels were high exceeding the WHO exposure limits of 150-230 $\mu\text{g}/\text{m}^3$. During the dry season and wet season, the mean level was 3710 $\mu\text{g}/\text{m}^3$ for both seasons (tables 4.1 and 4.2). This may be as a result of dust emitted by the cement factories in the vicinity like

East Africa Portland Cement and Athi River Mining Cement. Also the high vehicular traffic along the Athi River – Namanga Highway intensified the levels of SPM in the environment.

4.4 Site C (Redeemed Gospel Church- Athi River)

4.4.1 Sulphur dioxide

Sulphur dioxide mean levels during the dry season was 862 $\mu\text{g}/\text{m}^3$ and 861 $\mu\text{g}/\text{m}^3$ during the wet season (tables 4.1 and 4.2). The results exceeded WHO standard of 500 $\mu\text{g}/\text{m}^3$ (10 minutes). SO_2 high levels were attributed to quarrying activities, lead- acid battery recycling plant, Kifaru Maize Millers, and Athi River Mining Company. These industries used fossil fuels which contributed to the high levels of pollution.

4.4.2 Nitrogen dioxide

The mean levels during dry season were 136 $\mu\text{g}/\text{m}^3$ and 157 $\mu\text{g}/\text{m}^3$ during wet season (tables 4.1 and 4.2). The WHO limits of NO_2 (120 $\mu\text{g}/\text{m}^3$) was exceeded. The quarrying activities increased the levels of NO_2 in the environment due to heavy machinery used in excavation, which used fossil fuels. Makadara Road vehicular traffic and Athi River Mining Company also added more NO_2 into the air.

4.4.3 Carbon dioxide

The CO_2 mean level during wet season was 596 mg/m^3 while during dry season the level was higher at 769 mg/m^3 exceeding the limit of mean CO_2 of 697 mg/m^3 at ambient air. The values were still lower than OSHA permissible level of 9,000 mg/m^3 for an 8 hour working day. During the dry season, the high levels may have been due to biomass burning at Redeemed Gospel church School. Nearby industries (Athi River Mining and Associated Battery Manufacturing Company) also could have generated substantial quantities of carbon dioxide.

4.4.4 Suspended particulate matter

The SPM mean level during dry season was the highest recorded during analysis at 4390 $\mu\text{g}/\text{m}^3$ above the WHO standard of 150- 230 $\mu\text{g}/\text{m}^3$. During the wet season the level was lower at 2370 $\mu\text{g}/\text{m}^3$ but still exceeded the WHO standard. The SPM high levels may be as a result of dust from the cement companies within the study site as well as vehicular traffic. The presence

of lead-acid battery recycling plant (Associated Battery Manufacturers) within the vicinity could have added more particulates to the atmosphere. Dust from Kifaru Maize Millers and quarrying activities may have also contributed to more SPM in the atmosphere.

4.5 Site D (Sabaki Residential Estate)

4.5.1 Sulphur dioxide

The SO₂ mean level during the dry season was at 664 µg/m³ slightly above the WHO standard of 500 µg/m³ (table 4.2). The scenario may be due to pollution from nearby industries carried along by the wind. These industries included Bamburi Cement and Mombasa cement. The mean level during wet season was at 370 µg/m³ (table 4.1) which was below the WHO limit of 500 µg/m³ (10 minute exposure). This may have been due to reduced vehicular movement since it is a residential area which is about 2 km from the highway. Since it is a residential site, manufacturing industries were far hence lower levels of this gaseous pollutant.

4.5.2 Nitrogen dioxide

The mean levels of NO₂ were 91 µg/m³ during dry season and at 111 µg/m³ during the wet season (tables 4.1 and 4.2). Both were below the WHO limit of 120 µg/m³. The absence of heavy vehicular movement and lack of industries could have led to minimum pollution with this gas.

4.5.3 Carbon dioxide

The CO₂ mean levels were high at 1548 mg/m³ during dry season and 1614 mg/m³ during wet season (tables 4.1 and 4.2). The site have a high population of residential houses and a lot of domestic cooking could have taken place. Garbage burning was also witnessed. The use of biomass burning for cooking and heating may have escalated the production of CO₂ into the environment. The levels were lower than OSHA level of 9,000 mg/m³ but higher than the calculated world mean carbon dioxide level at 697 mg/m³ in the atmosphere.

4.5.4 Suspended particulate matter

The SPM mean levels at Sabaki residential site was 1690 µg/m³ during dry season and 1680 µg/m³ during the wet season. The levels were above the WHO standards of 150- 230

$\mu\text{g}/\text{m}^3$. Construction activities at the site may have contributed to high levels of SPM as well as the dust blown by wind. In addition, the trucks delivering raw materials for building could also have contributed to increased SPM levels into the environment. The presence of cement plants (Mombasa Cement and Bamburi Cement) may have contributed to dust increase due to wind-assisted dispersal.

4.6 The meteorological parameters results

Table 4.5 shows relative humidity, wind direction, wind speed and temperature values recorded during the wet season.

Table 4.5: Mean Relative humidity, wind direction, wind speed and temperature during wet season

| SAMPLING SITE | PERIOD OF THE DAY | RELATIVE HUMIDITY | WIND SPEED (m/sec) | WIND DIRECTION | TEMPERATURE ($^{\circ}\text{C}$) |
|---------------|-------------------|-------------------|--------------------|----------------|------------------------------------|
| SITE A | AM | 51-60 | 2-3 | NW,SW | 23-26 |
| | PM | 53-55 | 2-3 | NW,SW | 26-28 |
| SITE B | AM | 56-62 | 1-2.5 | NW,SW | 25 |
| | PM | 51-55 | 2.5-3 | SW,W | 27-29 |
| SITE C | AM | 60-70 | 1.5-2 | SW | 24-25 |
| | PM | 54-61 | 1.5-2 | SW | 26-27 |
| SITE D | AM | 56-66 | 1.5-2 | W,SW | 24-25 |
| | PM | 52-59 | 1.5-2 | NW,SW | 26-28 |

AM= Morning hours; PM=Afternoon hours

Table 4.6. shows relative humidity, wind direction, wind speed and temperature values recorded during the dry season.

Table 4.6.: Mean Relative humidity, wind direction, wind speed and temperature during dry season.

| SAMPLING SITE | PERIOD OF THE DAY | RELATIVE HUMIDITY | WIND SPEED(m/sec) | WIND DIRECTION | TEMPERATURE (°C) |
|---------------|-------------------|-------------------|-------------------|----------------|------------------|
| SITE A | AM | 58-60 | 1-1.5 | SW,NW | 25 |
| | PM | 53-54 | 1.5-2 | SW, NW | 26-27 |
| SITE B | AM | 54-62 | 1-2 | NW | 24-26 |
| | PM | 53-64 | 1-2 | NW | 24-28 |
| SITE C | AM | 58-61 | 1.5-2 | SW | 24-26 |
| | PM | 53-58 | 2-2.5 | SW | 24-28 |
| SITE D | AM | 55-58 | 1-2 | SW, NW | 24-26 |
| | PM | 53-55 | 1-1.5 | SW,NW | 26-28 |

AM= Morning hours; PM= Afternoon hours

4.6.3 Wind speed

The wind speed ranged from 1-3 m/sec which was moderate for both dry and wet seasons (tables 4.5 and 4.6). Highest concentrations occur when the wind speed is less than 2 m/s, speed enough to blow a paper along the ground (Fisher *et al.*, 2005). Strong winds transport pollutants to a large area, while in stable or moderate environment there is little mixing and the air pollutants build up. This may result to high pollutant level due to stagnant conditions and longer residence time of particulates in the atmosphere. Wind speed affects the dispersal and dilution of pollutants. The higher the wind speed, the higher the dispersal of air pollutants and the lower their concentrations. The Pearson's correlation of wind speed in relation to concentration showed a weak correlation. The regression values for the pollutants were; SO₂ ($r^2 = 0.14$), NO₂ ($r^2 = 0.044$), SPM ($r^2 = 0.005$) and CO₂ ($r^2 = 0.020$). However, high wind speed can also generate dust in dry areas.

4.6.4 Relative humidity

The relative humidity from tables 4.5 and 4.6 were high as well as the pollutants level. The relative humidity ranged between 51 and 70% during wet season, 53 and 64% during dry season. High humidity reduces the amount of solar radiation reaching the earth's surface. This phenomena minimizes atmospheric temperature nearer to earth's surface, hence reducing up-going currents affecting vertical mixing of air leading to trapping of air pollutants and eventually increase in pollutants. It exhibited a positive Pearson's correlation in relation to pollutant levels. The coefficient values were; SO₂ ($r^2 = 0.59$), NO₂ ($r^2 = 0.84$), SPM ($r^2 = 0.62$) and CO₂ ($r^2 = 0.77$).

4.6.5 Wind direction

The south west wind direction favored high pollutant concentration in this study as shown in tables 4.5 and 4.6. The results in sites A-C were polluted with SO₂, NO₂ and SPM while site D was polluted with SPM and CO₂ (tables 4.1 and 4.2).

4.6.7 Temperature

The temperature recorded in the study area ranged between 23⁰C to 29⁰C during both wet and dry season. During the dry season, the atmospheric temperature will increase and the concentration of pollutants may be on the higher side due to failure of natural washout process.

4.7 Epidemiological effects of pollution

The projected epidemiological effects of air pollutants to the high growing population density in Athi River are;

- a) Sulphur dioxide which destroys the epithelium of the airways, causes bronchoconstriction to the asthmatic individuals, decreases lung function and causes irritation of the nose and throat.
- b) Nitrogen dioxide inflames lung lining causing wheezing, coughing and bronchitis. It also causes increased asthmatic attacks.
- c) Suspended particulate matter which causes lung irritation, changes the blood chemistry that can result in blood clot and can increase susceptibility to bacterial infection leading to pneumonia.
- d) Carbon dioxide as an asphyxiant cuts oxygen supply for breathing in confined space, which may cause unconsciousness or even death. It can also cause lung congestion, abrupt muscle contraction, headache and fatigue.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

During the dry season, the SO₂ content for sites A-D had higher levels than the WHO value of 500 µg/m³. In the wet season, all the sites A-C also had higher levels except for site D (370 µg/m³) which was lower than the WHO value.

The NO₂ levels in the dry season for sites A-C were above the WHO value of 120 µg/m³ except at site D which had lower levels. In the wet season sites A-C had higher levels of NO₂ except site D which had 111 µg/m³ which was below the recommended value.

The CO₂ level during the dry season in all the sites were above the mean world value of 697mg/m³ but still lower than OSHA value of 9,000 mg/m³. During the wet season, the content of CO₂ for sites A-C were lower than the recommended mean value of 697 mg/m³ except for site D (1614 mg/m³) which was more than twice the mean value but still all values were lower than OSHA value of 9,000 mg/m³.

The SPM values during both the wet and dry season at all the sites A-D were higher than the WHO value of 150-230 µg/m³. The major sources of the pollutants in the study sites were from cement industries, other light industries, vehicular traffic and quarrying activities.

During the wet season, the level of pollution was much lower than during the dry season due to washout. During windy season, at speeds greater or equal to 1.5m/s (≥ 1.5 m/s) the level of pollution was less compared with calm periods that recorded higher values. When wind speed is high, pollutants are diluted by dispersion.

Relative humidity showed positive correlation with concentration of air pollutants. The higher it is, the higher the concentration of pollutants. However, temperature in this study had no correlation with pollutants level. In all the sites (A-D), at least three of the four pollutants were higher than the recommended values and this is of much concern due to possible detrimental health effects.

5.2 RECOMENDATIONS

In relation to this study, the following recommendations were made;

1. Installation by industries of more efficient wet adsorption scrubbers to reduce content of NO₂ and SO₂.
2. Installation of bag filters by industries to reduce SPM. In addition, planting of more trees can be encouraged to reduce SPM.
3. Use of low sulfur diesel in motor vehicles and other machinery to reduce SO₂ content.
4. Study the health effects of SPM, SO₂ and NO₂ on humans in Athi River.
5. NEMA to enforce adherence to air quality guidelines by industries and ensure monitoring schedule for companies is up to date.

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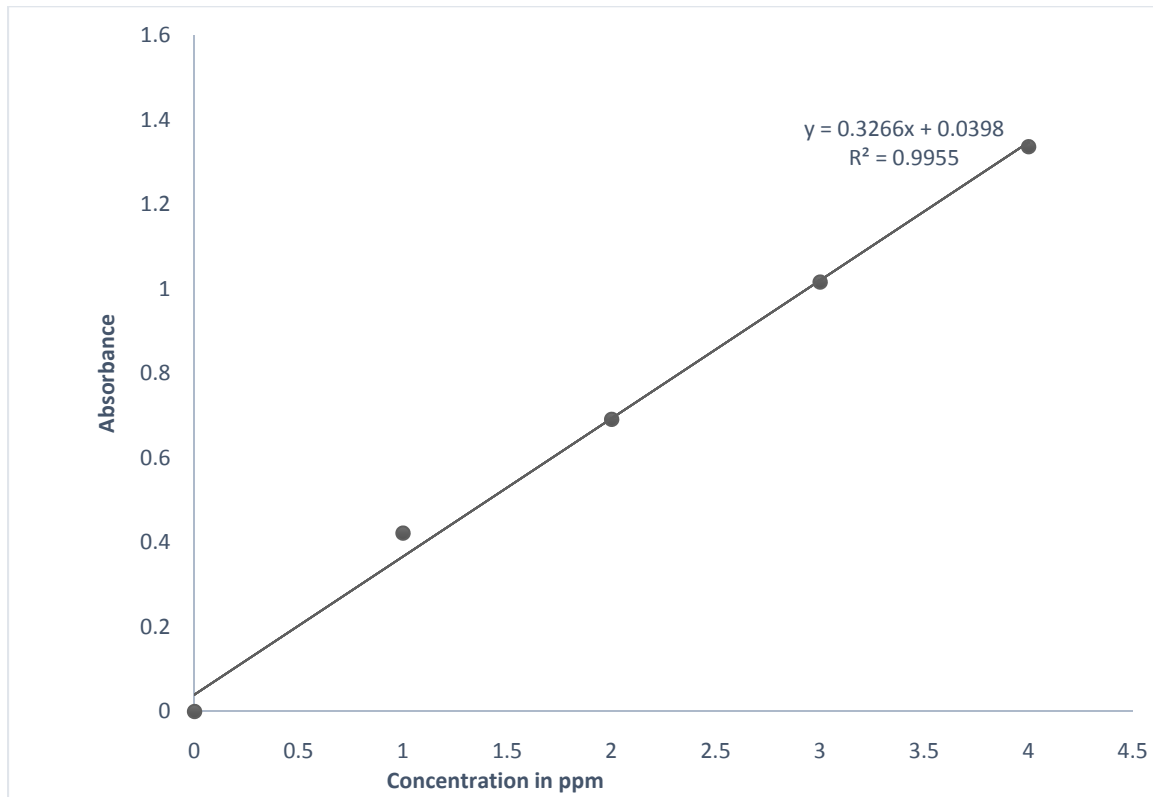
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APPENDICES

Appendix : A Typical Calibration Graph for Sulphur Dioxide

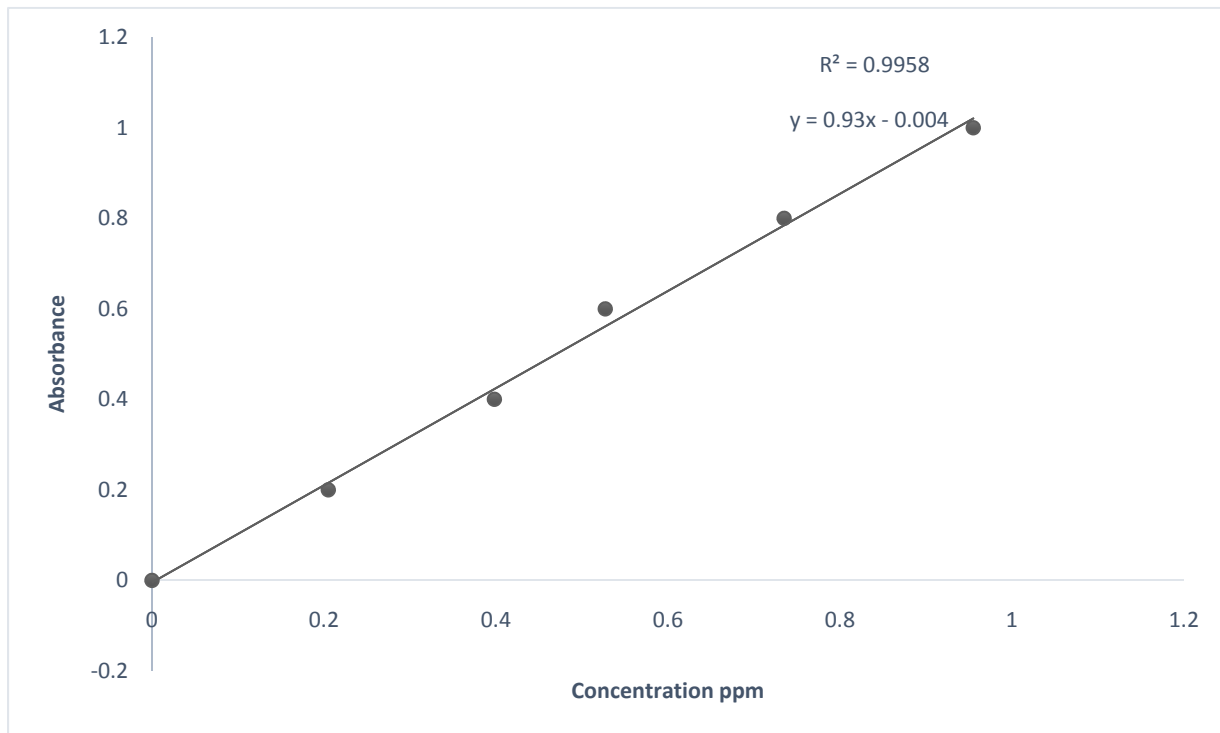


Appendix 1.1 Sulphur dioxide concentration versus absorbance of standards

| Standards (ppm) | Absorbance |
|-----------------|------------|
| 0 | 0 |
| 1 | 0.422 |

| | |
|---|-------|
| 2 | 0.691 |
| 3 | 1.016 |
| 4 | 1.336 |

Appendix : A Typical Calibration Graph for Nitrogen Dioxide



Appendix 2.1: Nitrogen dioxide concentration versus absorbance of standards

| Standards (ppm) | Absorbance |
|-----------------|------------|
|-----------------|------------|

| | |
|-----|-------|
| 0 | 0 |
| 0.2 | 0.205 |
| 0.4 | 0.398 |
| 0.6 | 0.527 |
| 0.8 | 0.735 |
| 1.0 | 0.955 |

Appendix 3: Sulphur Dioxide Levels at Site A During Rainy Season

The level of sulphur dioxide was calculated using the formula;

$$\text{SO}_2 \text{ in } \mu\text{g}/\text{m}^3 = \frac{\text{Absorbance} \times (1/\text{Slope}) \times \text{dilution factor} \times \text{Volume of sample (ml)} \times 1000}{\text{Total volume of air (litres)}}$$

Total volume of air(litres)

The slope was 0.325 hence, 1/Slope = 3.07. The dilution factor was 5 and the sample volume used was 50 ml for all the samples analyzed.

| Site | Total volume of air (litre) | Readings | Absorbance | Concentrations ($\mu\text{g}/\text{m}^3$) | DATE | Period of the Day |
|--------|-----------------------------|----------|------------|---|------------|-------------------|
| site A | 66.6 | 0.213 | 0.043 | 496 | 12/12/2014 | AM |
| site A | 66.6 | 0.214 | 0.044 | 507 | 12/12/2014 | PM |
| site A | 66.6 | 0.217 | 0.047 | 542 | 12/12/2014 | AM |
| site A | 66.6 | 0.219 | 0.049 | 565 | 12/12/2014 | PM |
| site A | 66.3 | 0.222 | 0.052 | 602 | 13/12/2014 | AM |
| site A | 66.3 | 0.217 | 0.047 | 544 | 13/12/2014 | PM |
| site A | 66.3 | 0.227 | 0.057 | 660 | 13/12/2014 | AM |

| | | | | | | |
|--------|-------|-------|-------|---------------------------|------------|----|
| site A | 66.3 | 0.226 | 0.056 | 648 | 13/12/2014 | PM |
| site A | 69.45 | 0.243 | 0.073 | 807 | 14/12/2014 | AM |
| site A | 69.45 | 0.226 | 0.056 | 619 | 14/12/2014 | PM |
| site A | 69.45 | 0.227 | 0.057 | 630 | 14/12/2014 | AM |
| site A | 69.45 | 0.225 | 0.055 | 608 | 14/12/2014 | PM |
| | | | | Mean= 602 Std.dev.= 84 | | |

Appendix 4: Sulphur Dioxide Levels at Site B During Rainy Season

| Site | Total volume of air (litre) | Readings | Absorbance | Concentrations ($\mu\text{g}/\text{m}^3$) | DATE | Period of the Day |
|--------|-----------------------------|----------|------------|---|------------|-------------------|
| site B | 68.85 | 0.252 | 0.082 | 914 | 18/12/2014 | AM |
| site B | 68.85 | 0.239 | 0.069 | 769 | 18/12/2014 | PM |
| site B | 68.85 | 0.238 | 0.068 | 758 | 18/12/2014 | AM |
| site B | 68.85 | 0.234 | 0.064 | 713 | 18/12/2014 | PM |
| site B | 69.45 | 0.239 | 0.069 | 763 | 19/12/2014 | AM |
| site B | 69.45 | 0.234 | 0.064 | 708 | 19/12/2014 | PM |
| site B | 69.45 | 0.247 | 0.077 | 851 | 19/12/2014 | AM |
| site B | 69.45 | 0.241 | 0.071 | 785 | 19/12/2014 | PM |
| site B | 70.95 | 0.244 | 0.074 | 800 | 20/12/2014 | AM |
| site B | 70.95 | 0.241 | 0.071 | 768 | 20/12/2014 | PM |

| | | | | | | |
|--------|-------|-------|-------|---------------------------|------------|----|
| site B | 70.95 | 0.251 | 0.081 | 876 | 20/12/2014 | AM |
| site B | 70.95 | 0.245 | 0.075 | 811 | 20/12/2014 | PM |
| | | | | Mean= 793 Std.dev.= 62 | | |

Appendix 5: Sulphur Dioxide Levels at Site C During the Rainy Season

| Site | Total volume of air (litre) | Readings | Absorbance | Concentrations ($\mu\text{g}/\text{m}^3$) | Date | Period of the Day |
|--------|-----------------------------|----------|------------|---|------------|-------------------|
| site C | 69.15 | 0.248 | 0.078 | 866 | 25/12/2014 | AM |
| site C | 69.15 | 0.25 | 0.08 | 888 | 25/12/2014 | PM |
| site C | 69.15 | 0.248 | 0.078 | 866 | 25/12/2014 | AM |
| site C | 69.15 | 0.244 | 0.074 | 821 | 25/12/2014 | PM |
| site C | 69.30 | 0.25 | 0.08 | 886 | 26/12/2014 | AM |
| site C | 69.30 | 0.248 | 0.078 | 864 | 26/12/2014 | PM |
| site C | 69.30 | 0.245 | 0.075 | 831 | 26/12/2014 | AM |
| site C | 69.30 | 0.25 | 0.08 | 886 | 26/12/2014 | PM |
| site C | 72.45 | 0.247 | 0.077 | 816 | 27/12/2014 | AM |
| site C | 72.45 | 0.254 | 0.084 | 890 | 27/12/2014 | PM |

| | | | | | | |
|--------|-------|-------|-------|-----------------------------|------------|----|
| site C | 72.45 | 0.252 | 0.082 | 869 | 27/12/2014 | AM |
| site C | 72.45 | 0.25 | 0.08 | 847 | 27/12/2014 | PM |
| | | | | Mean= 861 Std.dev.= 26.4 | | |

Appendix 6: Sulphur Dioxide Levels at Site D During the Rainy Season

| Site | Total volume of air (litre) | Readings | Absorbance | Concentrations ($\mu\text{g}/\text{m}^3$) | Date | Period of the Day |
|--------|-----------------------------|----------|------------|---|------------|-------------------|
| site D | 69.30 | 0.201 | 0.031 | 343 | 29/12/2014 | AM |
| site D | 69.30 | 0.197 | 0.027 | 299 | 29/12/2014 | PM |
| site D | 69.30 | 0.197 | 0.027 | 299 | 29/12/2014 | AM |
| site D | 69.30 | 0.194 | 0.024 | 266 | 29/12/2014 | PM |
| site D | 68.70 | 0.208 | 0.038 | 425 | 30/12/2014 | AM |
| site D | 68.70 | 0.208 | 0.038 | 425 | 30/12/2014 | PM |
| site D | 68.70 | 0.206 | 0.036 | 402 | 30/12/2014 | AM |
| site D | 68.70 | 0.207 | 0.037 | 413 | 30/12/2014 | PM |
| site D | 69.75 | 0.208 | 0.038 | 418 | 31/12/2014 | AM |
| site D | 69.75 | 0.202 | 0.032 | 352 | 31/12/2014 | PM |

| | | | | | | |
|--------|-------|-------|-------|---------------------------|------------|----|
| site D | 69.75 | 0.206 | 0.036 | 396 | 31/12/2014 | AM |
| site D | 69.75 | 0.207 | 0.037 | 407 | 31/12/2014 | PM |
| | | | | Mean= 370 Std.dev.= 57 | | |

Appendix 7: Nitrogen Dioxide Levels at Site A During Rainy Season

The level of nitrogen dioxide was calculated using the formula;

$$\text{NO}_2 \text{ in } \mu\text{g}/\text{m}^3 = \frac{\text{Absorbance} \times (1/\text{Slope}) \times \text{dilution factor} \times \text{Volume of sample (ml)} \times 1000}{\text{Total volume of air (litres)}}$$

Total volume of air (litres)

The slope was 0.93 (Appendix 2) hence, 1/Slope = 1.07. The dilution factor was 2.5 and the sample volume used was 50 ml for all the samples analyzed.

| Site | Total volume of air (litre) | Reading | Absorbance | Concentration ($\mu\text{g}/\text{m}^3$) | DATE | Period of The day |
|--------|-----------------------------|---------|------------|--|------------|-------------------|
| site A | 66.6 | 0.116 | 0.092 | 185 | 12/12/2014 | AM |
| site A | 66.6 | 0.09 | 0.066 | 133 | 12/12/2014 | PM |
| site A | 66.6 | 0.104 | 0.08 | 161 | 12/12/2014 | AM |
| site A | 66.6 | 0.1 | 0.076 | 153 | 12/12/2014 | PM |
| site A | 66.3 | 0.115 | 0.091 | 184 | 13/12/2014 | AM |
| site A | 66.3 | 0.099 | 0.075 | 151 | 13/12/2014 | PM |
| site A | 66.3 | 0.106 | 0.082 | 165 | 13/12/2014 | AM |

| | | | | | | |
|--------|-------|-------|-------|---------------------------|------------|----|
| site A | 66.3 | 0.105 | 0.081 | 163 | 13/12/2014 | PM |
| site A | 69.45 | 0.102 | 0.078 | 150 | 14/12/2014 | AM |
| site A | 69.45 | 0.12 | 0.096 | 185 | 14/12/2014 | PM |
| site A | 69.45 | 0.099 | 0.075 | 144 | 14/12/2014 | AM |
| site A | 69.45 | 0.092 | 0.068 | 131 | 14/12/2014 | PM |
| | | | | Mean= 159 Std.dev.= 19 | | |

Appendix 8: Nitrogen Dioxide Levels at Site B During the Rainy Season

| Site | Total volume of air (litre) | Readings | Absorbance | Concentrations ($\mu\text{g}/\text{m}^3$) | Date | Period of the Day |
|--------|-----------------------------|----------|------------|---|------------|-------------------|
| site B | 68.85 | 0.118 | 0.094 | 183 | 18/12/2014 | AM |
| site B | 68.85 | 0.115 | 0.091 | 177 | 18/12/2014 | PM |
| site B | 68.85 | 0.113 | 0.089 | 173 | 18/12/2014 | AM |
| site B | 68.85 | 0.116 | 0.092 | 179 | 18/12/2014 | PM |
| site B | 69.45 | 0.117 | 0.093 | 179 | 19/12/2014 | AM |
| site B | 69.45 | 0.114 | 0.09 | 173 | 19/12/2014 | PM |
| site B | 69.45 | 0.118 | 0.094 | 181 | 19/12/2014 | AM |
| site B | 69.45 | 0.114 | 0.09 | 173 | 19/12/2014 | PM |
| site B | 70.95 | 0.117 | 0.093 | 175 | 20/12/2014 | AM |
| site B | 70.95 | 0.111 | 0.087 | 164 | 20/12/2014 | PM |
| site B | 70.95 | 0.114 | 0.09 | 170 | 20/12/2014 | AM |

| | | | | | | |
|--------|-------|-------|-------|----------------------------|------------|----|
| site B | 70.95 | 0.116 | 0.092 | 173 | 20/12/2014 | PM |
| | | | | Mean= 175 Std.dev.= 5.5 | | |

Appendix 9: Nitrogen Dioxide Levels at Site C during the Rainy Season

| Site | Total volume of air (litre) | Readings | Absorbance | Concentrations ($\mu\text{g}/\text{m}^3$) | Date | Period of the Day |
|--------|-----------------------------|----------|------------|---|------------|-------------------|
| site C | 69.15 | 0.108 | 0.084 | 162 | 25/12/2014 | AM |
| site C | 69.15 | 0.105 | 0.081 | 157 | 25/12/2014 | PM |
| site C | 69.15 | 0.103 | 0.079 | 153 | 25/12/2014 | AM |
| site C | 69.15 | 0.106 | 0.082 | 159 | 25/12/2014 | PM |
| site C | 69.30 | 0.112 | 0.088 | 170 | 26/12/2014 | AM |
| site C | 69.30 | 0.114 | 0.09 | 174 | 26/12/2014 | PM |
| site C | 69.30 | 0.11 | 0.086 | 166 | 26/12/2014 | AM |
| site C | 69.30 | 0.109 | 0.085 | 164 | 26/12/2014 | PM |
| site C | 72.45 | 0.103 | 0.079 | 146 | 27/12/2014 | AM |
| site C | 72.45 | 0.101 | 0.077 | 142 | 27/12/2014 | PM |
| site C | 72.45 | 0.105 | 0.081 | 150 | 27/12/2014 | AM |
| site C | 72.45 | 0.102 | 0.078 | 144 | 27/12/2014 | PM |

| | | | | | | |
|--|--|--|--|--------------|--|--|
| | | | | Mean= 157 | | |
| | | | | Std.dev.= 10 | | |

Appendix 10: Nitrogen dioxide levels at site D During the rainy season

| Site | Total volume of air (litre) | Readings | Absorbance | Concentrations ($\mu\text{g}/\text{m}^3$) | Date | Period of the Day |
|--------|-----------------------------|----------|------------|---|------------|-------------------|
| site D | 69.30 | 0.08 | 0.056 | 108 | 29/12/2014 | AM |
| site D | 69.30 | 0.081 | 0.057 | 110 | 29/12/2014 | PM |
| site D | 69.30 | 0.079 | 0.055 | 106 | 29/12/2014 | AM |
| site D | 69.30 | 0.089 | 0.065 | 125 | 29/12/2014 | PM |
| site D | 68.70 | 0.081 | 0.057 | 111 | 30/12/2014 | AM |
| site D | 68.70 | 0.085 | 0.061 | 119 | 30/12/2014 | PM |
| site D | 68.70 | 0.079 | 0.055 | 107 | 30/12/2014 | AM |
| site D | 68.70 | 0.075 | 0.051 | 99 | 30/12/2014 | PM |
| site D | 69.75 | 0.08 | 0.056 | 107 | 31/12/2014 | AM |
| site D | 69.75 | 0.082 | 0.058 | 111 | 31/12/2014 | PM |
| site D | 69.75 | 0.086 | 0.062 | 118 | 31/12/2014 | AM |
| site D | 69.75 | 0.083 | 0.059 | 113 | 31/12/2014 | PM |
| | | | | Mean= 111 | | |
| | | | | Std.dev.= 7 | | |

Appendix 11: Carbon Dioxide Levels at Site A During the Rainy Season

The level of carbon dioxide was calculated using the formula:

$$CO_2 \text{ in } mg/m^3 = \left[\frac{M_{KOH} \times vol.KOH}{1000} - \frac{M_{HCl} \times vol.HCl}{1000} \right] \times \frac{1}{2} \times \frac{5 \times 44 \times 1000 \times 1000}{\text{volume of air}(l)}$$

| Site | Total volume of air (litre) | Titre volume ml (0.5M HCl) | CO ₂ Conc.(mg m ⁻³) | DATE | Period of the day |
|--------|-----------------------------|----------------------------|--|------------|-------------------|
| site A | 66.6 | 9.3 | 578 | 12/12/2014 | AM |
| site A | 66.6 | 9.4 | 496 | 12/12/2014 | PM |
| site A | 66.6 | 9.7 | 248 | 12/12/2014 | AM |
| site A | 66.6 | 9.8 | 165 | 12/12/2014 | PM |
| site A | 66.3 | 9.7 | 249 | 13/12/2014 | AM |
| site A | 66.3 | 9.8 | 166 | 13/12/2014 | PM |
| site A | 66.3 | 9.9 | 83 | 13/12/2014 | AM |
| site A | 66.3 | 9.8 | 166 | 13/12/2014 | PM |
| site A | 69.45 | 9.6 | 317 | 14/12/2014 | AM |
| site A | 69.45 | 9.9 | 79 | 14/12/2014 | PM |
| site A | 69.45 | 9.9 | 79 | 14/12/2014 | AM |
| site A | 69.45 | 9.6 | 317 | 14/12/2014 | PM |
| | | | Mean= 245 | | |
| | | | Std.dev.= 161 | | |

Appendix 12: Carbon Dioxide Levels at Site B During the Rainy Season

| Site | Total volume of air (litre) | Titre volume ml (0.5M HCl) | CO ₂ Conc.(mg m ⁻³) | DATE | Period of the day |
|--------|-----------------------------|----------------------------|--|------------|-------------------|
| Site B | 68.85 | 9.2 | 639 | 18/12/2014 | AM |
| Site B | 68.85 | 9.4 | 479 | 18/12/2014 | PM |
| Site B | 68.85 | 9.5 | 399 | 18/12/2014 | AM |
| Site B | 68.85 | 9.2 | 639 | 18/12/2014 | PM |
| Site B | 69.45 | 9.5 | 397 | 19/12/2014 | AM |
| Site B | 69.45 | 9.8 | 158 | 19/12/2014 | PM |
| Site B | 69.45 | 9.4 | 475 | 19/12/2014 | AM |
| Site B | 69.45 | 9.6 | 317 | 19/12/2014 | PM |
| Site B | 70.95 | 9.4 | 465 | 20/12/2014 | AM |
| Site B | 70.95 | 9.5 | 388 | 20/12/2014 | PM |
| Site B | 70.95 | 9.3 | 543 | 20/12/2014 | AM |
| Site B | 70.95 | 9.2 | 620 | 20/12/2014 | PM |
| | | | Mean=460 | | |
| | | | Std.dev.= 142 | | |

Appendix 13: Carbon Dioxide Levels at Site C During the Rainy Season

| Site | Total volume of air (litre) | Titre volume ml (0.5M HCl) | CO ₂ Conc.(mg m ⁻³) | DATE | Period of the day |
|--------|-----------------------------|----------------------------|--|------------|-------------------|
| site C | 69.15 | 9 | 796 | 25/12/2014 | AM |
| site C | 69.15 | 9.1 | 716 | 25/12/2014 | PM |
| site C | 69.15 | 9.2 | 636 | 25/12/2014 | AM |
| site C | 69.15 | 9 | 796 | 25/12/2014 | PM |
| site C | 69.30 | 9.3 | 556 | 26/12/2014 | AM |
| site C | 69.30 | 9.6 | 318 | 26/12/2014 | PM |
| site C | 69.30 | 9 | 794 | 26/12/2014 | AM |
| site C | 69.30 | 9.1 | 714 | 26/12/2014 | PM |
| site C | 72.45 | 9.3 | 536 | 27/12/2014 | AM |
| site C | 72.45 | 9.2 | 607 | 27/12/2014 | PM |
| site C | 72.45 | 9.5 | 380 | 27/12/2014 | AM |
| site C | 72.45 | 9.6 | 304 | 27/12/2014 | PM |
| | | | Mean= 596 | | |
| | | | Std.dev.= 182 | | |

Appendix 14: Carbon Dioxide Levels at Site D During the Rainy Season

| Site | Total volume of air (litre) | Titre volume ml (0.5M HCl) | CO ₂ Conc.(mg m ⁻³) | DATE | Period of the day |
|--------|-----------------------------|----------------------------|--|------------|-------------------|
| site D | 69.30 | 7.8 | 1746 | 29/12/2014 | AM |
| site D | 69.30 | 7.9 | 1667 | 29/12/2014 | PM |
| site D | 69.30 | 8.2 | 1429 | 29/12/2014 | AM |
| site D | 69.30 | 8 | 1588 | 29/12/2014 | PM |
| site D | 68.70 | 8.1 | 1521 | 30/12/2014 | AM |
| site D | 68.70 | 8.7 | 1041 | 30/12/2014 | PM |
| site D | 68.70 | 7.9 | 1682 | 30/12/2014 | AM |
| site D | 68.70 | 8 | 1601 | 30/12/2014 | PM |
| site D | 69.75 | 7.8 | 1735 | 31/12/2014 | AM |
| site D | 69.75 | 7.6 | 1893 | 31/12/2014 | PM |
| site D | 69.75 | 7.6 | 1893 | 31/12/2014 | AM |
| site D | 69.75 | 8 | 1577 | 31/12/2014 | PM |
| | | | Mean= 1614 | | |
| | | | Std.dev.= 227 | | |

Appendix 15: Suspended Particulate Matter Levels at Site A During the Rainy Season

The formula for calculation of particulate matter was as follows:

$$\text{Concentration (mg/m}^3\text{)} = \frac{\text{Weight difference (mg)} \times 1000}{\text{Total volume of air (L)}}$$

| Site | Total volume of air (litre) | Weight difference (mg) | Concentration (mg/m ³) | DATE | Period of the day |
|--------|-----------------------------|------------------------|------------------------------------|------------|-------------------|
| site A | 66.6 | 0.1 | 1.502 | 12/12/2014 | AM |
| site A | 66.6 | 0.2 | 3 | 12/12/2014 | PM |
| site A | 66.6 | 0.1 | 1.502 | 12/12/2014 | AM |
| site A | 66.6 | 0.2 | 3 | 12/12/2014 | PM |
| site A | 66.3 | 0.3 | 4.52 | 13/12/2014 | AM |
| site A | 66.3 | 0.2 | 3.01 | 13/12/2014 | PM |
| site A | 66.3 | 0.3 | 4.52 | 13/12/2014 | AM |
| site A | 66.3 | 0.2 | 3.01 | 13/12/2014 | PM |
| site A | 69.45 | 0.1 | 1.44 | 14/12/2014 | AM |
| site A | 69.45 | 0.2 | 2.88 | 14/12/2014 | PM |
| site A | 69.45 | 0.4 | 5.76 | 14/12/2014 | AM |
| site A | 69.45 | 0.3 | 4.32 | 14/12/2014 | PM |
| | | | Mean= 3.21 | | |
| | | | Std.dev.= 1.36 | | |

Appendix 16: Suspended Particulate Matter Levels at Site B During the Rainy Season

| Site | Total volume of air (litre) | Weight difference (mg) | Concentration (mg/m ³) | DATE | Period of the day |
|--------|-----------------------------|------------------------|------------------------------------|------------|-------------------|
| Site B | 68.85 | 0.1 | 1.45 | 18/12/2014 | AM |
| Site B | 68.85 | 0.2 | 2.9 | 18/12/2014 | PM |
| Site B | 68.85 | 0.1 | 1.45 | 18/12/2014 | AM |
| Site B | 68.85 | 0.4 | 5.81 | 18/12/2014 | PM |
| Site B | 69.45 | 0.5 | 7.2 | 19/12/2014 | AM |
| Site B | 69.45 | 0.2 | 2.88 | 19/12/2014 | PM |
| Site B | 69.45 | 0.5 | 7.2 | 19/12/2014 | AM |
| Site B | 69.45 | 0.2 | 2.88 | 19/12/2014 | PM |
| Site B | 70.95 | 0.1 | 1.41 | 20/12/2014 | AM |
| Site B | 70.95 | 0.2 | 2.82 | 20/12/2014 | PM |
| Site B | 70.95 | 0.3 | 4.23 | 20/12/2014 | AM |
| Site B | 70.95 | 0.3 | 4.23 | 20/12/2014 | PM |
| | | | Mean= 3.71 Std.dev.= 2.08 | | |

Appendix 17: Suspended Particulate Matter Levels at Site C During the Rainy Season

| Site | Total volume of air (litre) | Weight difference (mg) | Concentration (mg/m ³) | DATE | Period of the day |
|--------|-----------------------------|------------------------|------------------------------------|------------|-------------------|
| site C | 69.15 | 0.2 | 2.89 | 25/12/2014 | AM |
| site C | 69.15 | 0.2 | 2.89 | 25/12/2014 | PM |
| site C | 69.15 | 0.2 | 2.89 | 25/12/2014 | AM |
| site C | 69.15 | 0.2 | 2.89 | 25/12/2014 | PM |
| site C | 69.30 | 0.2 | 2.89 | 26/12/2014 | AM |
| site C | 69.30 | 0.3 | 4.33 | 26/12/2014 | PM |
| site C | 69.30 | 0.1 | 1.44 | 26/12/2014 | AM |
| site C | 69.30 | 0.1 | 1.38 | 26/12/2014 | PM |
| site C | 72.45 | 0.2 | 2.76 | 27/12/2014 | AM |
| site C | 72.45 | 0.1 | 1.38 | 27/12/2014 | PM |
| site C | 72.45 | 0.1 | 1.38 | 27/12/2014 | AM |
| site C | 72.45 | 0.1 | 1.38 | 27/12/2014 | PM |
| | | | Mean= 2.37 Std.dev.= 0.95 | | |

Appendix 18: Suspended Particulate Matter Levels at Site D During the Rainy Season

| Site | Total volume of air (litre) | Weight difference (mg) | Concentration (mg/m ³) | DATE | Period of the day |
|--------|-----------------------------|------------------------|------------------------------------|------------|-------------------|
| site D | 69.30 | 0.1 | 1.44 | 29/12/2014 | AM |
| site D | 69.30 | 0.1 | 1.44 | 29/12/2014 | PM |
| site D | 69.30 | 0.1 | 1.44 | 29/12/2014 | AM |
| site D | 69.30 | 0.1 | 1.44 | 29/12/2014 | PM |
| site D | 68.70 | 0.1 | 1.46 | 30/12/2014 | AM |
| site D | 68.70 | 0.2 | 1.46 | 30/12/2014 | PM |
| site D | 68.70 | 0.2 | 2.91 | 30/12/2014 | AM |
| site D | 68.70 | 0.1 | 1.46 | 30/12/2014 | PM |
| site D | 69.75 | 0.1 | 1.43 | 31/12/2014 | AM |
| site D | 69.75 | 0.1 | 1.43 | 31/12/2014 | PM |
| site D | 69.75 | 0.1 | 1.43 | 31/12/2014 | AM |
| site D | 69.75 | 0.2 | 2.87 | 31/12/2014 | PM |
| | | | Mean= 1.68 Std.dev.= 0.56 | | |

Appendix 19: Meteorological Parameters Results at Site A During the Rainy Season

| Site | Relative humidity | Temperature | Wind direction | Wind speed (m/sec) | Date | Period of the Day |
|--------|-------------------|-------------|----------------|--------------------|------------|-------------------|
| site A | 58 | 23 | NW | 2 | 12/12/2014 | AM |
| site A | 55 | 26 | NW | 2 | 12/12/2014 | PM |
| site A | 60 | 24 | SW | 2 | 13/12/2014 | AM |
| site A | 53 | 28 | SW | 3 | 13/12/2014 | PM |
| site A | 51 | 26 | NW | 3 | 14/12/2014 | AM |
| site A | 54 | 27 | NW | 2.5 | 14/12/2014 | PM |

Appendix 20: Meteorological Parameters Results at Site B During the Rainy Season

| Site | Relative humidity | Temperature | Wind direction | Wind speed (m/sec) | Date | Period of the Day |
|--------|-------------------|-------------|----------------|--------------------|------------|-------------------|
| site B | 60 | 25 | SW | 2.5 | 18/12/2014 | AM |
| site B | 54 | 27 | SW | 2.5 | 18/12/2014 | PM |
| site B | 62 | 25 | NW | 1 | 19/12/2014 | AM |
| site B | 55 | 28 | NW | 3 | 19/12/2014 | PM |
| site B | 56 | 25 | W | 2 | 20/12/2014 | AM |
| site B | 51 | 29 | W | 3 | 20/12/2014 | PM |

Appendix 21: Meteorological Parameters Results at Site C During the Rainy Season

| Site | Relative humidity | Temperature | Wind direction | Wind speed (m/sec) | Date | Period of the Day |
|--------|-------------------|-------------|----------------|--------------------|------------|-------------------|
| site C | 70 | 25 | SW | 1.5 | 25/12/2014 | AM |
| site C | 61 | 27 | SW | 2 | 25/12/2014 | PM |
| site C | 70 | 25 | SW | 2 | 26/12/2014 | AM |
| site C | 60 | 27 | SW | 1.5 | 26/12/2014 | PM |
| site C | 60 | 24 | SW | 1.5 | 27/12/2014 | AM |
| site C | 54 | 26 | SW | 1.5 | 27/12/2014 | PM |

Appendix 22: Meteorological Parameters Results at Site During the Rainy Season

| Site | Relative humidity | Temperature | Wind direction | Wind speed (m/sec) | Date | Period of the Day |
|--------|-------------------|-------------|----------------|--------------------|------------|-------------------|
| site D | 66 | 24 | W | 1.5 | 29/12/2014 | AM |
| site D | 59 | 26 | NW | 2 | 29/12/2014 | PM |
| site D | 60 | 24 | SW | 1.5 | 30/12/2014 | AM |
| site D | 53 | 28 | SW | 2 | 30/12/2014 | PM |
| site D | 56 | 25 | SW | 2 | 31/12/2014 | AM |
| site D | 52 | 27 | NW | 1.5 | 31/12/2014 | PM |

Appendix 23: Sulphur Dioxide Levels at Site A During the Dry Season

| Site | Total volume of air (litre) | Readings | Absorbance | Concentrations ($\mu\text{g}/\text{m}^3$) | Date | Period of the Day |
|--------|-----------------------------|----------|------------|---|------------|-------------------|
| site A | 66.6 | 0.117 | 0.072 | 830 | 27/03/2015 | AM |
| site A | 66.6 | 0.12 | 0.075 | 864 | 27/03/2015 | PM |
| site A | 66.6 | 0.119 | 0.074 | 853 | 27/03/2015 | AM |
| site A | 66.6 | 0.119 | 0.074 | 853 | 27/03/2015 | PM |
| site A | 66.3 | 0.124 | 0.079 | 915 | 28/03/2015 | AM |
| site A | 66.3 | 0.121 | 0.076 | 880 | 28/03/2015 | PM |
| site A | 66.3 | 0.126 | 0.081 | 938 | 28/03/2015 | AM |
| site A | 66.3 | 0.12 | 0.075 | 868 | 28/03/2015 | PM |
| site A | 69.45 | 0.12 | 0.075 | 828 | 29/03/2015 | AM |
| site A | 69.45 | 0.121 | 0.076 | 840 | 29/03/2015 | PM |
| site A | 69.45 | 0.122 | 0.077 | 851 | 29/03/2015 | AM |
| site A | 69.45 | 0.121 | 0.076 | 840 | 29/03/2015 | PM |
| | | | | Mean= 863 Std.dev.= 33 | | |

Appendix 24: Sulphur Dioxide Levels at Site B During Dry Season

| Site | Total volume of air (litre) | Readings | Absorbance | Concentrations ($\mu\text{g}/\text{m}^3$) | Date | Period of the Day |
|--------|-----------------------------|----------|------------|---|-----------|-------------------|
| site B | 68.85 | 0.123 | 0.078 | 869 | 3/04/2015 | AM |
| site B | 68.85 | 0.124 | 0.079 | 881 | 3/04/2015 | PM |
| site B | 68.85 | 0.123 | 0.078 | 869 | 3/04/2015 | AM |
| site B | 68.85 | 0.128 | 0.083 | 925 | 3/04/2015 | PM |
| site B | 69.45 | 0.125 | 0.08 | 884 | 4/04/2015 | AM |
| site B | 69.45 | 0.126 | 0.081 | 895 | 4/04/2015 | PM |
| site B | 69.45 | 0.125 | 0.08 | 884 | 4/04/2015 | AM |
| site B | 69.45 | 0.122 | 0.077 | 851 | 4/04/2015 | PM |
| site B | 70.95 | 0.122 | 0.077 | 833 | 5/04/2015 | AM |
| site B | 70.95 | 0.127 | 0.082 | 887 | 5/04/2015 | PM |
| site B | 70.95 | 0.128 | 0.083 | 898 | 5/04/2015 | AM |
| site B | 70.95 | 0.122 | 0.077 | 833 | 5/04/2015 | PM |
| | | | | Mean= 875 | | |
| | | | | Std.dev.= 27 | | |

Appendix 25: Sulphur Dioxide Levels at Site C During Dry Season

| Site | Total volume of air (litre) | Readings | Absorbance | Concentrations ($\mu\text{g}/\text{m}^3$) | Date | Period of the Day |
|--------|-----------------------------|----------|------------|---|------------|-------------------|
| site C | 69.15 | 0.121 | 0.076 | 844 | 15/04/2015 | AM |
| site C | 69.15 | 0.12 | 0.075 | 832 | 15/04/2015 | PM |
| site C | 69.15 | 0.128 | 0.083 | 921 | 15/04/2015 | AM |
| site C | 69.15 | 0.125 | 0.08 | 888 | 15/04/2015 | PM |
| site C | 69.30 | 0.126 | 0.081 | 897 | 16/04/2015 | AM |
| site C | 69.30 | 0.127 | 0.082 | 908 | 16/04/2015 | PM |
| site C | 69.30 | 0.129 | 0.084 | 930 | 16/04/2015 | AM |
| site C | 69.30 | 0.12 | 0.075 | 831 | 16/04/2015 | PM |
| site C | 72.45 | 0.122 | 0.077 | 816 | 17/04/2015 | AM |
| site C | 72.45 | 0.124 | 0.079 | 837 | 17/04/2015 | PM |
| site C | 72.45 | 0.124 | 0.079 | 837 | 17/04/2015 | AM |
| site C | 72.45 | 0.121 | 0.076 | 805 | 17/04/2015 | PM |
| | | | | Mean= 862 Std.dev.= 44 | | |

Appendix 26: Sulphur Dioxide Levels at Site D During Dry Season

| Site | Total volume of air (litre) | Readings | Absorbance | Concentrations ($\mu\text{g}/\text{m}^3$) | Date | Period of the Day |
|--------|-----------------------------|----------|------------|---|------------|-------------------|
| site D | 69.30 | 0.106 | 0.061 | 676 | 18/04/2015 | AM |
| site D | 69.30 | 0.105 | 0.06 | 665 | 18/04/2015 | PM |
| site D | 69.30 | 0.11 | 0.065 | 720 | 18/04/2015 | AM |
| site D | 69.30 | 0.102 | 0.057 | 631 | 18/04/2015 | PM |
| site D | 68.70 | 0.106 | 0.061 | 681 | 19/04/2015 | AM |
| site D | 68.70 | 0.104 | 0.059 | 659 | 19/04/2015 | PM |
| site D | 68.70 | 0.105 | 0.06 | 670 | 19/04/2015 | AM |
| site D | 68.70 | 0.104 | 0.059 | 659 | 19/04/2015 | PM |
| site D | 69.75 | 0.105 | 0.06 | 660 | 20/04/2015 | AM |
| site D | 69.75 | 0.103 | 0.058 | 638 | 20/04/2015 | PM |
| site D | 69.75 | 0.104 | 0.059 | 649 | 20/04/2015 | AM |
| site D | 69.75 | 0.105 | 0.06 | 660 | 20/04/2015 | PM |
| | | | | Mean= 664 | | |
| | | | | Std.dev.= 23 | | |

Appendix 27: Carbon Dioxide Levels at Site A During Dry Season

| Site | Total volume of air (L) | Titre volume ml (0.5M HCl) | Concentration (mg/m ³) | Date | Period of the day |
|--------|-------------------------|----------------------------|------------------------------------|------------|-------------------|
| site A | 66.6 | 8.8 | 991 | 27/03/2015 | AM |
| site A | 66.6 | 8.9 | 908 | 27/03/2015 | PM |
| site A | 66.6 | 9.1 | 743 | 27/03/2015 | AM |
| site A | 66.6 | 9.1 | 743 | 27/03/2015 | PM |
| site A | 66.3 | 9.1 | 747 | 28/03/2015 | AM |
| site A | 66.3 | 9.1 | 747 | 28/03/2015 | PM |
| site A | 66.3 | 8.7 | 1078 | 28/03/2015 | AM |
| site A | 66.3 | 8.9 | 913 | 28/03/2015 | PM |
| site A | 69.45 | 8.8 | 950 | 29/03/2015 | AM |
| site A | 69.45 | 8.9 | 871 | 29/03/2015 | PM |
| site A | 69.45 | 8.9 | 871 | 29/03/2015 | AM |
| site A | 69.45 | 9 | 792 | 29/03/2015 | PM |
| | | | Mean= 863 | | |
| | | | Std.dev.= 111 | | |

Appendix 28: Carbon Dioxide Levels at Site B During Dry Season

| Site | Total volume of air (litre) | Titre volume ml (0.5M HCl) | Concentration (mg/m ³) | Date | Period of the day |
|--------|-----------------------------|----------------------------|------------------------------------|-----------|-------------------|
| site B | 68.85 | 9.2 | 639 | 3/04/2015 | AM |
| site B | 68.85 | 9.1 | 718 | 3/04/2015 | PM |
| site B | 68.85 | 9 | 798 | 3/04/2015 | AM |
| site B | 68.85 | 9.3 | 559 | 3/04/2015 | PM |
| site B | 69.45 | 9.3 | 554 | 4/04/2015 | AM |
| site B | 69.45 | 9.2 | 633 | 4/04/2015 | PM |
| site B | 69.45 | 9.3 | 554 | 4/04/2015 | AM |
| site B | 69.45 | 9 | 792 | 4/04/2015 | PM |
| site B | 70.95 | 8.8 | 930 | 5/04/2015 | AM |
| site B | 70.95 | 8.9 | 853 | 5/04/2015 | PM |
| site B | 70.95 | 9.1 | 698 | 5/04/2015 | AM |
| site B | 70.95 | 9 | 775 | 5/04/2015 | PM |
| | | | Mean= 709 | | |
| | | | Std.dev.= 124 | | |

Appendix 29: Carbon Dioxide Levels at Site C During Dry Season

| Site | Total volume of air (litre) | Titre volume ml (0.5M HCl) | Concentration (mg/m ³) | Date | Period of the day |
|--------|-----------------------------|----------------------------|------------------------------------|------------|-------------------|
| site C | 69.15 | 9 | 795 | 15/04/2015 | AM |
| site C | 69.15 | 9.1 | 715 | 15/04/2015 | PM |
| site C | 69.15 | 9.2 | 636 | 15/04/2015 | AM |
| site C | 69.15 | 9 | 795 | 15/04/2015 | PM |
| site C | 69.30 | 9.1 | 714 | 16/04/2015 | AM |
| site C | 69.30 | 8.9 | 873 | 16/04/2015 | PM |
| site C | 69.30 | 9.1 | 714 | 16/04/2015 | AM |
| site C | 69.30 | 9 | 794 | 16/04/2015 | PM |
| site C | 72.45 | 9.1 | 683 | 17/04/2015 | AM |
| site C | 72.45 | 9 | 759 | 17/04/2015 | PM |
| site C | 72.45 | 8.8 | 911 | 17/04/2015 | AM |
| site C | 72.45 | 8.9 | 835 | 17/04/2015 | PM |
| | | | Mean= 769 Std.dev.= 80 | | |

Appendix 30: Carbon Dioxide Levels at Site D During Dry Season

| Site | Total volume of air (litre) | Titre volume ml (0.5M HCl) | Concentration (mg/m ³) | Date | Period of the day |
|--------|-----------------------------|----------------------------|------------------------------------|------------|-------------------|
| site D | 69.30 | 8 | 1587 | 18/04/2015 | AM |
| site D | 69.30 | 7.9 | 1666 | 18/04/2015 | PM |
| site D | 69.30 | 8.4 | 1270 | 18/04/2015 | AM |
| site D | 69.30 | 8.3 | 1349 | 18/04/2015 | PM |
| site D | 68.70 | 7.9 | 1681 | 19/04/2015 | AM |
| site D | 68.70 | 7.8 | 1761 | 19/04/2015 | PM |
| site D | 68.70 | 8.3 | 1361 | 19/04/2015 | AM |
| site D | 68.70 | 8.2 | 1441 | 19/04/2015 | PM |
| site D | 69.75 | 7.9 | 1656 | 20/04/2015 | AM |
| site D | 69.75 | 7.8 | 1734 | 20/04/2015 | PM |
| site D | 69.75 | 8 | 1577 | 20/04/2015 | AM |
| site D | 69.75 | 8.1 | 1498 | 20/04/2015 | PM |
| | | | Mean= 1548 | | |
| | | | Std.dev=163 | | |

Appendix 31: Nitrogen Dioxide Levels at Site A During Dry Season

| Site | Total volume of air (litre) | Readings | Absorbance | conc.($\mu\text{g}/\text{m}^3$) | Date | Period of the day |
|--------|-----------------------------|----------|------------|-----------------------------------|------------|-------------------|
| site A | 66.6 | 0.07 | 0.066 | 132 | 27/03/2015 | AM |
| site A | 66.6 | 0.073 | 0.069 | 138 | 27/03/2015 | PM |
| site A | 66.6 | 0.078 | 0.074 | 148 | 27/03/2015 | AM |
| site A | 66.6 | 0.078 | 0.074 | 148 | 27/03/2015 | PM |
| site A | 66.3 | 0.079 | 0.075 | 151 | 28/03/2015 | AM |
| site A | 66.3 | 0.078 | 0.074 | 149 | 28/03/2015 | PM |
| site A | 66.3 | 0.071 | 0.067 | 135 | 28/03/2015 | AM |
| site A | 66.3 | 0.075 | 0.071 | 143 | 28/03/2015 | PM |
| site A | 69.45 | 0.072 | 0.068 | 131 | 29/03/2015 | AM |
| site A | 69.45 | 0.076 | 0.072 | 139 | 29/03/2015 | PM |
| site A | 69.45 | 0.071 | 0.067 | 129 | 29/03/2015 | AM |
| site A | 69.45 | 0.068 | 0.064 | 123 | 29/03/2015 | PM |
| | | | | Mean= 139 | | |
| | | | | Std.dev.= 9 | | |

Appendix 32: Nitrogen Dioxide Levels at Site B During Dry Season

| Site | Total volume of air (L) | Readings | Absorbance | conc.($\mu\text{g}/\text{m}^3$) | Date | Period of the day |
|--------|-------------------------|----------|------------|-----------------------------------|-----------|-------------------|
| site B | 68.85 | 0.084 | 0.08 | 155 | 3/04/2015 | AM |
| site B | 68.85 | 0.077 | 0.073 | 142 | 3/04/2015 | PM |
| site B | 68.85 | 0.076 | 0.072 | 140 | 3/04/2015 | AM |
| site B | 68.85 | 0.082 | 0.078 | 152 | 3/04/2015 | PM |
| site B | 69.45 | 0.082 | 0.078 | 150 | 4/04/2015 | AM |
| site B | 69.45 | 0.088 | 0.084 | 162 | 4/04/2015 | PM |
| site B | 69.45 | 0.083 | 0.079 | 152 | 4/04/2015 | AM |
| site B | 69.45 | 0.077 | 0.073 | 141 | 4/04/2015 | PM |
| site B | 70.95 | 0.074 | 0.07 | 132 | 5/04/2015 | AM |
| site B | 70.95 | 0.076 | 0.072 | 136 | 5/04/2015 | PM |
| site B | 70.95 | 0.083 | 0.079 | 149 | 5/04/2015 | AM |
| site B | 70.95 | 0.083 | 0.079 | 149 | 5/04/2015 | PM |
| | | | | Mean= 147 Std.dev.= 9 | | |

Appendix 33: Nitrogen Dioxide Levels at Site C During Dry Season

| Site | Total volume of air (litre) | Readings | Absorbance | conc.($\mu\text{g}/\text{m}^3$) | Date | Period of the day |
|--------|-----------------------------|----------|------------|-----------------------------------|------------|-------------------|
| site C | 69.15 | 0.075 | 0.071 | 137 | 15/04/2015 | AM |
| site C | 69.15 | 0.074 | 0.07 | 135 | 15/04/2015 | PM |
| site C | 69.15 | 0.075 | 0.071 | 137 | 15/04/2015 | AM |
| site C | 69.15 | 0.071 | 0.067 | 130 | 15/04/2015 | PM |
| site C | 69.30 | 0.077 | 0.073 | 141 | 16/04/2015 | AM |
| site C | 69.30 | 0.088 | 0.084 | 162 | 16/04/2015 | PM |
| site C | 69.30 | 0.084 | 0.08 | 154 | 16/04/2015 | AM |
| site C | 69.30 | 0.071 | 0.067 | 129 | 16/04/2015 | PM |
| site C | 72.45 | 0.079 | 0.075 | 138 | 17/04/2015 | AM |
| site C | 72.45 | 0.072 | 0.068 | 125 | 17/04/2015 | PM |
| site C | 72.45 | 0.074 | 0.07 | 129 | 17/04/2015 | AM |
| site C | 72.45 | 0.071 | 0.067 | 124 | 17/04/2015 | PM |
| | | | | Mean= 136 Std.dev.= 11 | | |

Appendix 34: Nitrogen Dioxide Levels at Site D During Dry Season

| Site | Total volume of air | Readings | Absorbance | conc.($\mu\text{g}/\text{m}^3$) | Date | Period of the day |
|--------|---------------------|----------|------------|-----------------------------------|------------|-------------------|
| site D | 69.30 | 0.058 | 0.054 | 104 | 18/04/2015 | AM |
| site D | 69.30 | 0.053 | 0.049 | 95 | 18/04/2015 | PM |
| site D | 69.30 | 0.053 | 0.049 | 95 | 18/04/2015 | AM |
| site D | 69.30 | 0.049 | 0.045 | 87 | 18/04/2015 | PM |
| site D | 68.70 | 0.051 | 0.047 | 92 | 19/04/2015 | AM |
| site D | 68.70 | 0.047 | 0.043 | 84 | 19/04/2015 | PM |
| site D | 68.70 | 0.045 | 0.041 | 80 | 19/04/2015 | AM |
| site D | 68.70 | 0.056 | 0.052 | 101 | 19/04/2015 | PM |
| site D | 69.75 | 0.054 | 0.05 | 96 | 20/04/2015 | AM |
| site D | 69.75 | 0.058 | 0.054 | 104 | 20/04/2015 | PM |
| site D | 69.75 | 0.059 | 0.055 | 105 | 20/04/2015 | AM |
| site D | 69.75 | 0.049 | 0.045 | 86 | 20/04/2015 | PM |
| | | | | Mean= 94 | | |
| | | | | Std.dev.= 9 | | |

Appendix 35: Suspended Particulate Matter Levels at Site A During Dry Season

| Site | Total volume of air (litre) | Weight difference (mg) | Concentration (mg/m ³) | Date | Period of the day |
|--------|-----------------------------|------------------------|------------------------------------|------------|-------------------|
| site A | 66.6 | 0.22 | 3.33 | 27/03/2015 | AM |
| site A | 66.6 | 0.33 | 5.00 | 27/03/2015 | PM |
| site A | 66.6 | 0.33 | 5.00 | 27/03/2015 | AM |
| site A | 66.6 | 0.22 | 3.33 | 27/03/2015 | PM |
| site A | 66.3 | 0.34 | 5.00 | 28/03/2015 | AM |
| site A | 66.3 | 0.22 | 3.33 | 28/03/2015 | PM |
| site A | 66.3 | 0.22 | 3.33 | 28/03/2015 | AM |
| site A | 66.3 | 0.34 | 5.13 | 28/03/2015 | PM |
| site A | 69.45 | 0.18 | 1.67 | 29/03/2015 | AM |
| site A | 69.45 | 0.23 | 3.33 | 29/03/2015 | PM |
| site A | 69.45 | 0.23 | 3.33 | 29/03/2015 | AM |
| site A | 69.45 | 0.34 | 5.13 | 29/03/2015 | PM |
| | | | Mean= 3.90 Std.dev.= 1.11 | | |

Appendix 36: Suspended Particulate Matter Levels at Site B During Dry Season

| Site | Total volume of air (litre) | Weight difference (mg) | Concentration (mg/m ³) | Date | Period of the day |
|--------|-----------------------------|------------------------|------------------------------------|-----------|-------------------|
| site B | 68.85 | 0.12 | 1.74 | 3/04/2015 | AM |
| site B | 68.85 | 0.23 | 3.33 | 3/04/2015 | PM |
| site B | 68.85 | 0.46 | 6.68 | 3/04/2015 | AM |
| site B | 68.85 | 0.23 | 3.33 | 3/04/2015 | PM |
| site B | 69.45 | 0.11 | 1.58 | 4/04/2015 | AM |
| site B | 69.45 | 0.34 | 4.90 | 4/04/2015 | PM |
| site B | 69.45 | 0.46 | 6.63 | 4/04/2015 | AM |
| site B | 69.45 | 0.11 | 1.58 | 4/04/2015 | PM |
| site B | 70.95 | 0.22 | 3.10 | 5/04/2015 | AM |
| site B | 70.95 | 0.22 | 3.10 | 5/04/2015 | PM |
| site B | 70.95 | 0.11 | 1.55 | 5/04/2015 | AM |
| site B | 70.95 | 0.46 | 6.49 | 5/04/2015 | PM |
| | | | Mean= 3.66 Std.dev.= 2.02 | | |

Appendix 37: Suspended Particulate Matter Levels at Site C During Dry Season

| Site | Total volume of air (litre) | Weight difference (mg) | Concentration (mg/m ³) | Date | Period of the day |
|--------|-----------------------------|------------------------|------------------------------------|------------|-------------------|
| site C | 69.15 | 0.56 | 8.09 | 15/04/2015 | AM |
| site C | 69.15 | 0.56 | 8.09 | 15/04/2015 | PM |
| site C | 69.15 | 0.46 | 6.65 | 15/04/2015 | AM |
| site C | 69.15 | 0.34 | 4.92 | 15/04/2015 | PM |
| site C | 69.30 | 0.34 | 4.90 | 16/04/2015 | AM |
| site C | 69.30 | 0.22 | 3.17 | 16/04/2015 | PM |
| site C | 69.30 | 0.34 | 4.90 | 16/04/2015 | AM |
| site C | 69.30 | 0.11 | 1.59 | 16/04/2015 | PM |
| site C | 72.45 | 0.12 | 1.64 | 17/04/2015 | AM |
| site C | 72.45 | 0.24 | 3.31 | 17/04/2015 | PM |
| site C | 72.45 | 0.24 | 3.31 | 17/04/2015 | AM |
| site C | 72.45 | 0.12 | 1.64 | 17/04/2015 | PM |
| | | | Mean= 4.35 Std.dev.= 2.33 | | |

Appendix 38: Suspended Particulate Matter Levels at Site D During Dry Season.

| Site | Total volume of air (litre) | Weight difference (mg) | Concentration (mg/m ³) | Date | Period of the day |
|--------|-----------------------------|------------------------|------------------------------------|------------|-------------------|
| site D | 69.30 | 0.11 | 1.59 | 18/04/2015 | AM |
| site D | 69.30 | 0.11 | 1.59 | 18/04/2015 | PM |
| site D | 69.30 | 0.11 | 1.59 | 18/04/2015 | AM |
| site D | 69.30 | 0.11 | 1.59 | 18/04/2015 | PM |
| site D | 68.70 | 0.11 | 1.60 | 19/04/2015 | AM |
| site D | 68.70 | 0.11 | 1.60 | 19/04/2015 | PM |
| site D | 68.70 | 0.11 | 1.60 | 19/04/2015 | AM |
| site D | 68.70 | 0.11 | 1.60 | 19/04/2015 | PM |
| site D | 69.75 | 0.11 | 1.58 | 20/04/2015 | AM |
| site D | 69.75 | 0.11 | 1.58 | 20/04/2015 | PM |
| site D | 69.75 | 0.23 | 3.29 | 20/04/2015 | AM |
| site D | 69.75 | 0.11 | 1.58 | 20/04/2015 | PM |
| | | | Mean= 1.73 | | |
| | | | Std.dev.= 0.49 | | |

Appendix 39: Meteorological Parameters Results at Site A During Dry Season Sampling

| Site location | Relative Humidity | Temperature (°C) | wind speed (m/sec) | wind direction | Period of the day | Date |
|---------------|-------------------|------------------|--------------------|----------------|-------------------|------------|
| Site A | 58 | 25 | 1 | SW | AM | 27/03/2015 |
| Site A | 54 | 26 | 1.5 | SW | PM | 27/03/2015 |
| Site A | 61 | 25 | 1.5 | NW | AM | 28/03/2015 |
| Site A | 54 | 27 | 2 | NW | PM | 28/03/2015 |
| Site A | 60 | 25 | 1.5 | SW | AM | 29/03/2015 |
| Site A | 53 | 27 | 2 | SW | PM | 29/03/2015 |

Appendix 40: Meteorological Parameters Results at Site B During Dry Season Sampling

| Site location | Relative Humidity | Temperature (°C) | wind speed (m/sec) | wind direction | Period of the day | Date |
|---------------|-------------------|------------------|--------------------|----------------|-------------------|-----------|
| site B | 60 | 25 | 1.5 | NW | AM | 3/04/2015 |
| site B | 55 | 27 | 1 | NW | PM | 3/04/2015 |
| site B | 54 | 26 | 2 | NW | AM | 4/04/2015 |
| site B | 53 | 27 | 2 | NW | PM | 4/04/2015 |
| site B | 62 | 24 | 1 | NW | AM | 5/04/2015 |
| site B | 64 | 24 | 1.5 | NW | PM | 5/04/2015 |

Appendix 41: Meteorological Parameters Results at Site C During Dry Season Sampling

| Site location | Relative Humidity | Temperature (°C) | wind speed (m/sec) | wind direction | Period of the day | Date |
|---------------|-------------------|------------------|--------------------|----------------|-------------------|------------|
| site C | 58 | 25 | 2 | SW | AM | 15/04/2015 |
| site C | 53 | 27 | 2.5 | SW | PM | 15/04/2015 |
| site C | 61 | 26 | 2 | SW | AM | 16/04/2015 |
| site C | 53 | 28 | 2 | SW | PM | 16/04/2015 |
| site C | 59 | 24 | 1.5 | SW | AM | 17/04/2015 |
| site C | 58 | 24 | 2 | SW | PM | 17/04/2015 |

Appendix42: Meteorological Parameters Results at Site D During Dry Season Sampling

| Site location | Relative Humidity | Temperature (°C) | wind speed (m/sec) | wind direction | Period of the day | Date |
|---------------|-------------------|------------------|--------------------|----------------|-------------------|------------|
| site D | 57 | 26 | 1.5 | NW | AM | 18/04/2015 |
| site D | 55 | 27 | 1.5 | NW | PM | 18/04/2015 |
| site D | 58 | 24 | 1 | SW | AM | 19/04/2015 |
| site D | 53 | 26 | 1.5 | SW | PM | 19/04/2015 |
| site D | 55 | 24 | 2 | SW | AM | 20/04/2015 |
| site D | 53 | 26 | 1 | SW | PM | 20/04/2015 |

