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Urban Air Quality in the City of Nairobi, Kenya: Application of Energy Dispersive X-Ray Fluorescence and Principal Component Analysis.

by

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A thesis submitted in partial fulfillment for the degree of Master of Science in Nuclear Science in the Institute of Nuclear Science in the University of Nairobi.

Declaration

This thesis is my original work and has not been presented for any degree in any other university.

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DEDICATION

This thesis is dedicated to my mum, whose encouragement and support always put a smile on my face.

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LIST OF ABBREVIATIONS AND ACRONYMS

Agl	Above ground level

AXIL	Analysis of X-ray spectrometry by Iterative Least square
BC	Black Carbon
CBD	Central Business District
CFC'S	Chlorofluorocarbons
CMB	Chemical Mass Balance model
EDXRF	Energy Dispersive X-ray Fluorescence
KIPPRA	Kenya Institute for Public Policy Research and Analysis
KMT	Kenya Ministry of Transport
KNBS	Kenya National Bureau of Statistics
MDGs	Millennium Development Goals
MoNMD	Ministry of Nairobi Metropolitan Development
PAH	Polycyclic Aromatic Hydrocarbons
PCA	Principal Component Analysis
$PM_{2.5}$	Particles with aerodynamic diameters less than 2.5µm
PM_{10}	Particles with aerodynamic diameters between 10µm and 2.5µm
QXAS	Quantitative X-ray Analysis System
SPM	Suspended Particulate Matter
SRM	Standard Reference Material
TSP	Total Suspended Matter
UNEP	United Nation Environmental Program
U.S.EPA	United states Environmental Protection Agency
WHO	World Health Organization

ABSTRACT

Air pollution is a widespread problem affecting millions of people exposed to high levels of air pollution that exceed one or more ambient limit values. One of these air pollutants is the airborne particulate matter (PM), which is composed of a broad class of chemically and physically diverse substances. PM varies in size, chemical composition, formation mechanism and origin. In order to formulate mitigation policies and control measures, there is need to identify the sources. In the recent past Nairobi city has gone through rapid and haphazard urbanization under the pressure of rural to urban migration. On the other hand there has been a huge unprecedented increase in the number of on-road vehicles, rapid establishment and growth of the informal sector, industries and uncontrolled burning of biomass and waste among other anthropogenic activities. These activities contribute heavily to urban air pollution and understanding of the current situation is very important in view of implementing Kenya Vision 2030 and the Millennium Development Goals. In this study airborne PM samples were collected for 8 hours on filter media using BGI 400 personal samplers at two selected locations; at Mines and Geology premises (Industrial site) and University of Nairobi main campus in Nairobi city (CBD site) for a period of 2 weeks in the month of January/February in 2012. $PM_{2.5}$ was sampled simultaneously at two sites in each location; at 1.5 m above ground (abg) at both locations and at 14m abg at industrial site and 17 m at CBD. Sampling was done at alternate times; morning (0700h-1500h) and afternoon (1200h-2000h) on alternate days. Analysis of trace elements in the samples was done using EDXRF spectrometer and Quantitative X-ray Analysis Software (QXAS) was used for spectra analysis and elemental quantification. Principal Component Analysis (PCA) was used to identify the sources of the sampled

particles using the evaluated elemental concentrations in all the samples. Mean daytime concentration of $PM_{2.5}$ at both sites ranged from 1 to 260 μgm^{-3}. The PCA components apportioned mineral dust, industrial emissions, traffic related emissions and biomass burning as the main sources of particulate matter in Nairobi area. Mn, Fe, Cu and Zn registered high concentration and implied mineral dust was a major source of $PM_{2.5}$ in Nairobi. In vertical dispersion, PM concentration near ground was higher than those collected at the rooftop by a factor of 1 to 8 in most of the days and less than 1 in a few days. These heavily influences urban air quality thus formal legislation need to be set.

CHAPTER ONE

INTRODUCTION

1.1 Background

Due to rapid industrialization, urbanization and increasing population there is an alarming pollution of the basic essentials for life and resources required to sustain life. Air, water and shelter are the basic essentials while resources include ample fertile land and different forms of energy. Globally, air and water pollution, and degradation and over use of land have rapidly contaminated and depleted these basic life essentials and resources. There is therefore, a critical need to educate the public worldwide on the serious problems associated with overpopulation, urbanization and natural resources shortages. This task requires scientific evidence, which calls for investigation of pollution levels since air is considered the most critical resource.

Outdoor air pollution is the most studied field compared to indoor pollution and its effects which include smog, temperature inversion, acid rain, greenhouse effect and ozone depletion have been associated with health, environmental, physiological and economic problems which are heavily felt in urban centers and cities (John, 2003).

Air quality inside buildings, whether naturally or mechanically ventilated, is strongly dependent on outdoor air pollution. The final quality of air inside buildings is determined by among others the pollution of the outdoor air in the neighborhood of the building with respect to both continuous and intermittent sources such as biomass burning, mineral dust and vehicular traffic (Ando et al.,1996). The evaluation of outdoor air in the proximity of a building is a key step in the assessment of global

indoor air quality since the outdoor concentration of airborne pollutants at the air supply point to the ventilation system is the main parameter determining the quality of air supplied to the occupants inside the building (Sparks, 1992).

According to WHO (1987), pollution at the levels found in the outdoor air of large cities has been implicated in both acute and chronic illnesses (for example asthma and chronic bronchitis), damage to property, kills trees, harms animals, causes floods, drought and massive forest fires. WHO (2002) reported that PM particles are in highest concentration in countries with low economic power, and high poverty and rate of population growth. Two countries in Africa, namely Egypt and Sudan were featured in the report and Kenya falls under that category of countries and thus similar results are expected. Another study by University of Washington showed that patients living near and around regions polluted by PM had an increased risk of pulmonary exacerbations and decrease in lung function (Christopher et al., 2004).

The country's new development blueprint, Kenya vision 2030 (GoK, 2007), aims to transform Kenya into an industrialized and middle-income status country providing a high quality life to all its citizens by the year 2030. In health sector, Kenya aims to provide an efficient and high quality health care system with the best standards. This is to be done through shifting the bias of the national health bill from curative to preventive care and devolution of funds and management of healthcare. In environment, it aims to be a Nation that has a clean, secure and sustainable environment. Environmental goals for 2012 include reducing all environmental related diseases by half.

With all these industrialization projects, growth in population and urbanization, air quality and health will definitely be a big issue in future as Kenya tries to achieve the vision. There is therefore need for long-term improvements in air quality and health. Specific strategies will involve; promoting environmental conservation in order to provide better support to the economic pillar flagship projects and for purposes of Millennium Development Goals (MDGs). This includes improving pollution and waste management through design and application of economic incentives. In addition, the country needs to harmonize environment-related laws for better environmental planning and governance. Consequently, assessment of outdoor and indoor air quality is essential in achieving the planned goals.

Source apportionment is the estimation of the contributions to the airborne concentrations that arise from the emissions of natural and anthropogenic sources. To obtain a source apportionment, data analysis tools like receptor models are applied to elicit information on the sources of air pollutants from the measured constituent concentrations (Hopke, 2009). In general, it involves identification of the sources of materials emitted into air, quantitative estimation of the emission rates of the pollutants, understanding of the transport of the substances from the sources to downwind locations, and knowledge of the physical and chemical transformation processes that can occur during that transport. All these variables can be put together in a mathematical model (e.g. receptor model) that is used to estimate the changes in observable airborne concentrations that might be expected to occur (Hopke, 2003). Application of receptor models for source identification and apportionment have been intensified in countries like United States of America, Canada, and some countries in

Europe and Asia. In most of the studies, principal component analysis (PCA) has been used for source identification and chemical mass balance (CMB) for source apportionment.

Particulate matter pollution is nowadays one of the main problems of most concern in modern cities not only because of the adverse health effects but also for the reduced visibility and on a global scale effects on the radiation balance (Watson, 2002). Other adverse effects include damage to materials and ecological damages. With this in mind, the sources of this particulate matter need to be identified and controlled.

1.2 Nairobi Metropolitan Area

Nairobi is one of the fast growing cities in sub-Saharan Africa. Central Nairobi had a resident population of 3.2 million in 2009 with a daytime population of 4.2 million (KNBS, 2007; KMT, 2010). Similarly, the overall proportion of urban dwellers in Kenya increased from 8 % in the 1980s to over 34 % in 2003 and is expected to reach by 50 % by 2020 (KNBS, 2007). The larger Nairobi metropolitan area had a population of 6.1 million in 2007 and it is projected to rise to over 12 million by 2030 (MoNMD, 2008). Due to the fast growth in population, air pollution levels in Nairobi are expected to increase to concentrations of potential in serious consequences. It is therefore important to monitor the quality of air around the area to guide implementation of preventive and control measures. However, lack of ambient monitoring data for particulate matter in sub-Saharan Africa cities (Nairobi being one of them) severely hinders the ability to describe temporal and spatial patterns of concentrations, to characterize exposure–response relationships for key health

outcomes, to estimate disease burdens and to promote policy initiatives to address air quality.

1.3 Problem statement

Air quality is currently a major problem in many cities in the developing countries. Its impact is realized through adverse health effects, reduced visibility, and damage to materials and ecosystems. Nairobi city is a home to millions of Kenyans, thousands of businesses, and many international companies, organizations and industries. Its fast growing population due to rural-urban immigration contributes to a wide range of human activities especially high increase of on-road vehicles and burning of fossil fuels, with consequences of high levels of air pollution. The threat posed to human life and property by air pollution makes it mandatory to develop and invoke control measures. Within the Central Business District (CBD) people working in offices and college students in various storey buildings and along busy highways' passengers, drivers, hawkers, traffic officers and pedestrians are exposed to high levels of pollution. There is need therefore to carry out a study to mine enough evidence on the levels of exposure both near ground and at selected heights from the ground besides identifying the possible sources of the pollutants.

1.4 Research justification and significance

Among several short studies carried out on Nairobi city air pollution, only a few have addressed vertical dispersion of aerosols and their possible sources. The phenomenon of road traffic air pollution shows considerable variation within a street canyon as a function of distance to the source of pollution both in horizontal and vertical dimensions. There is little attention given to the vertical variation and thus offers no or little information to inhabitants living on upper floors of high-rise buildings. To fill this gap this study will endeavor to provide information on vertical dispersion of particulate matter in Nairobi. Nairobi city being a commercial, industrial and travel hub is visited by millions of people daily besides its high population. It means an air polluted Nairobi may impact on the health of millions of human beings, both citizens and visitors. National and international air quality programs and standards are continually requiring government bodies to address air quality at their megacities to help ensure both the short term and the long-term welfare of the city inhabitants. This study will be focused on providing information on particulate matter levels in Nairobi, sources and vertical dispersion in the ambient air of Nairobi city. The information will help in the development of health related pollution abatement programs and provide evidence-based advice to policy making. It will also motivate future research studies in monitoring the trends of air quality within Nairobi city and other cities in Kenya and in the region.

1.5 Scope

This research will mainly focus on air quality within Nairobi area which will involve identifying the elements present in airborne $PM_{2.5}$, assessment of the elemental concentrations and mean concentration, identifying their possible sources and assessing vertical dispersion of $PM_{2.5}$ particles. The number of samples was limited by the limited funds which paid for the fieldwork.

1.6 Objectives

Main objective

The overall objective of this study was to identify the sources of $PM_{2.5}$ that contribute to air pollution in Nairobi with regard to human health implications.

Specific objectives

The specific objectives were:

(i) To determine outdoor daytime $PM_{2.5}$ concentration levels at selected sites in Nairobi.

(ii) To analyze trace element levels in $PM_{2.5}$ particles from the measurement sites using EDXRF technique.

(iii) To identify the possible sources of the aerosol composites using principal component analysis.

(iv) To assess vertical dispersion of $PM_{2.5}$ particles.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Airborne particulate matter (PM) is a complex mixture of extremely small solid particles and liquid droplets suspended in air. Sources of PM include both natural and anthropogenic processes. They are made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. These components are characterized by concentrations (mass, number and volume), size, phase (solid or liquid) and chemical composition (USEPA, 2006).

Air pollution constitutes a widespread problem affecting millions exposed to high levels of air pollution that exceed one or more ambient limit values. In defining both ambient and indoor air quality there are seven criteria pollutants (CO, NO_2, O_3, Pb, PM_{10}, $PM_{2.5}$ and SO_2). These pollutants are known to negatively impact on human beings, plants and materials (Bascom et al., 1996a). One of these air pollutants, particulate matter (PM = PM_{10} or $PM_{2.5}$) is composed of a broad class of chemically and physically diverse substances and the particles are variable in size, chemical composition, formation mechanism and origin. In addition, concentration is variable across space and time and is a function of sources, atmospheric reactions and meteorological conditions. Health effects associated with PM are linked to respiratory, cardiovascular health problems and premature mortality.

Urban air pollution and indoor air quality are listed as two of the world's worst pollution problem by Blacksmith (2012). The two caused approximately 7 million deaths worldwide in 2012. WHO estimates 4.3 million deaths every year as a result of

exposure to household pollution and 3.7 million deaths every year attributed to exposure to fine particulate matter. Recent evaluations have also shown that many health effects have stronger links to fine particles and have therefore recommended the regulation of $PM_{2.5}$ instead of PM_{10} (WHO, 2003). Approximately 88% of these deaths occur in low and middle income countries. Children aged less than five years that live in developing countries are the most vulnerable population in terms of total deaths attributable to indoor and outdoor air pollution (WHO, 2012).

Fine particulate matter ($PM_{2.5}$) generated in fuel combustion (e.g., in motor vehicles) have been linked to a wide range of health effects, including more than 800,000 deaths in cities around the world (Cohen et al., 2004; Pope and Dockery, 2006). $PM_{2.5}$ is a complex mixture of solid or liquid organic and inorganic particles that share the property of being $\leq 2.5\mu m$ in aerodynamic diameter. Because of their small sizes, $PM_{2.5}$ particles are able to penetrate deep into the lungs where they can cause adverse health effects. However, little information exists on sources and levels of particulate air pollutants currently experienced by urban residents in Africa (Gatari et al., 2005; Maina et al., 2006; Vliet and Kinney, 2007). This data gap hinders health impact assessments, the development of cost-effective strategies to reduce the health burden due to outdoor air pollution and the ability to influence urban transportation and planning policies in relation to air quality and health.

2.2 Sources of air pollution in urban areas

2.2.1 Air pollution from motor vehicles

Mobile source emissions are extremely complex and comprise hundreds of compounds that are present in the atmosphere as gases, particulates and liquids. Many of these compounds are transformed in the atmosphere producing secondary pollutants such as tropospheric ozone, acid aerosols and carcinogenic hydrocarbons which are sometimes more harmful than their directly emitted precursors (WHO, 1992).

In areas of high population densities, particularly in cities, motor vehicle emissions pose direct risks to human health. Health effects linked to mobile source emissions include aggregated respiratory symptoms, morbidity, and increased cancer mortality associated with exposures to PAH (WHO, 1992). They are also responsible for several forms of environmental degradation on the regional and global levels. Environmental damage linked to motor vehicle range from negative aesthetic effects, crop or material damage to more profound disruptions of regional ecosystems and aggravation of global environmental problems such as greenhouse gas accumulation (Spengler et al., 1990).

The increase of vehicles in big cities is responsible for the greater part of motor vehicles related emissions and urban air pollution. Consequently, lakes, streams and even remote forests have also experienced significant degradation. As evidence of anthropogenic impacts on the upper atmosphere accumulates, concern that motor vehicles are contributing to global changes that could alter the climate of the planet are increasing (Broecker, 1987). Thus, motor vehicle emissions are now associated with

virtually all the major air pollution problems at the local, regional and global scale (UNEP, 1987).

Direct health risks from motor vehicle related air pollution is common in urban areas where large percentages of the population are regularly exposed to high concentrations of pollutants (WHO, 1992). According to a study on urban air quality conducted by the United Nations in 1988, only 20 % of the world's 2.26 billion urban dwellers lived in cities with acceptable air quality (UNEP, 1991).

2.2.2 Air pollution from industries

Industrial emissions contribute to urban air pollution, especially in locations close to industrial areas. With the rapid rate of industrialization and urbanization in developing countries, there is bound to be higher contribution to air pollution in the cities. Studies carried out in Nairobi (Karue et al., 1992) confirmed high pollution within the neighborhood of industrial areas and the estates located downwind from the industries.

2.3 Effects of air pollution

Recent concern about the health effects of air pollution has focused on particulate matter with several epidemiological studies from the United States indicating a strong link between increased PM concentrations, mortality and morbidity (Dockey et al., 1993; Pope et al., 1995 and Schwartz, 1993). According to Schwartz (1993) fine particulate ($PM_{2.5}$) have the greatest impact on health. This is because of their ability to penetrate deeper into the lungs and also because they contain more of the trace elements and other toxic chemicals. While breathing, particles are retained according to their size within the respiratory system. Smaller (finer) particles penetrate deeper

into the lungs, where they are retained for long while larger particles are deposited in the upper respiratory tract. Fine particles ($PM_{2.5}$) penetrate into the alveolar area and the deposition probability might amount up to 60 %. The elimination process of these deposited particles takes between days and even years.

The hazards caused by deposited particles in the respiratory system range from respiratory infections, bronchitis, asthma, pneumonia, impaired lung function, hospitalization for respiratory and cardiac disease to increase in mortality. Whereas acute health effects of particulate matter is probably best related to the deposited dose, chronic and long-term effects may be related to cumulative or retained dose but may also arise from recurring cycles of pulmonary injury and repair (Clarke et al., 1988).

Outdoor and indoor air quality is important to human health. The average 70 kg adult inhales about 20 m^3 of air per day (Berne et al., 1998). Certain groups of patients such as asthmatics, atopic patients, patients with emphysema and bronchitis, heart and stroke patients, diabetes, pregnant women, the elderly and children are sensitive to the health effects of outdoor air toxicants (Akimoto H, 2003). In addition, outdoor air also serves as a major source of particulate and gaseous pollutants for indoor air.

Epidemiological studies in America suggest that more than 500,000 Americans die each year from cardiopulmonary disease linked to breathing airborne fine particles (EKA 2011). A study by the University of Birmingham observed a strong correlation between pneumonia related deaths and air pollution from motor vehicles (The Guardian, 2011). Air pollution also has possible links to cancer. A large Danish epidemiological study found out an increased risk of lung cancer for patients who

lived in areas with high nitrogen oxide concentrations. In that study, the association was higher for non-smokers than smokers (Raaschou et al., 2011a). It has also been reported that there might be possible associations between air pollution and other forms of cancer including cervical cancer and brain cancer (Raaschou et al., 2011b).

There is a correlation between health and economy. In relatively clean areas or in areas with relatively low levels of air pollution, public health effects can be significant and costly since a large number of people breathe in such pollutants. A scientific study for the British Columbia Lung Association in 2005 showed that a small improvement in air quality (1 % reduction of ambient $PM_{2.5}$ and ozone concentrations) would produce a $29 million in annual savings in the Metro Vancouver region in 2010 (Blacksmith , 2012). This finding was based on health valuation of lethal (death) and sub lethal (illness) effects. This implies that an effort put forth in improving our air quality will go a long way in improving the country's economy.

2.4 Air pollution studies in Kenya

Existing literature on urban air pollution in Kenya is mainly on Nairobi city. Studies done by Karue et al. (1992) and UNEP (1996) were carried out with the aim of determining the concentration of total suspended particulate matter (TSP) in Nairobi city center, industrial area and one residential area. The TSP samples were analyzed for trace elements using Energy Dispersive X-Ray Fluorescence (EDXRF) technique. Their study findings showed various activities in the city such as construction work, industrial processes, use of road unworthy vehicles and dust blown from unpaved roads contributed enormously to suspended particulate matter (SPM) in the air. However, the TSP data obtained could not provide adequate information on the health

implications because mass concentration of TSP is poorly related to the actual pollutant burden on exposed individuals (Dockey et al., 1993).

In their study of characterization of airborne particles at an industrial background site in Nairobi, Kenya, Gatari et al. (2009) contributed tangible data in terms of source identification and justification of air pollution problems in Nairobi. They observed that soil dust, industrial activities and vehicles emissions were the main contributors of aerosol pollution at that site. They also found the difference between fine and coarse particles, which could be used for source apportionment. However, they suggested that more measurements of aerosol particles in Nairobi are necessary to give a realistic long-term average of elemental levels that will facilitate estimation of source strengths.

Another study by Gatari et al. (2005) on elemental composition of tropospheric aerosols in Hanoi, Vietnam and Nairobi, Kenya observed that silicon, chlorine, potassium and iron exceeded atmospheric concentrations of 100 ng m^{-3} at both cities. The elemental concentrations in both cities were orders of magnitude higher than their respective rural towns. The main sources of air pollution in Nairobi city were implicated as emissions of traffic, and biomass and waste burning while coal combustion and road transport were the major sources in Hanoi. The study also warned that there could be high levels of air pollution due to high rate of population growth. Another study by Gatari et al. (2005) in Nairobi air, found that sulfur was mainly emitted from vehicular emissions as a dominant element in fine particles collected at a rooftop, approximately 20 m above the ground.

A study by Vilet and Kinney (2007) on impacts of roadway emissions on urban particulate matter concentration in sub-Saharan Africa, Nairobi, Kenya indicated that roadway concentrations of $PM_{2.5}$ were approximately 20-fold higher than those from urban background site whereas black carbon differed by 10-fold. Another study by Kinney et al. (2011) on traffic impacts on $PM_{2.5}$ air quality in Nairobi reported a mean daytime concentration to range from 10.7 µg m^{-3} at a rural background site to 98.1 µg m^{-3} on a sidewalk in the CBD.

2.5 Vertical dispersion

Vertical variability of PM is of great importance in studying ambient air, because PM emitted from the traffic, factories and residents as well as regional emission can be transported, transformed, diluted and get depleted in the boundary layer. Therefore, understanding vertical dispersion of particulate matter is important for our central and county governments to be able take effective counter measures mitigate air pollution and to develop informed guiding policies for infrastructure development in cities.

Several studies on the sources, concentration, distribution and dynamics of atmospheric pollutants done in Kenya have been mainly near ground level measurements (Karue et al.1992; Gatari et al., 2005 and 2009; Vliet and Kinney., 2007). None of these studies have been done on vertical characterization of particulate matter. However, Kinney et al. (2011) did a two week study on traffic impacts on $PM_{2.5}$ in Nairobi ranging from high-traffic roadways to rural background. They also did a horizontal dispersion measurement and a decrease in $PM_{2.5}$ concentration over 100 m downwind was observed. Vertical dispersion experiment revealed a decrease in

concentration measured at street level compared to those measured at a third floor of a building in the CBD.

There are several studies related to concentration gradients of pollutants in urban air. Qin and Kot (1993) studied air dispersion in urban street canyons. Horizontal and vertical gradients of CO and NO_x were measured within a street canyon. The results showed that during low wind speed conditions, the difference in concentrations between the leeward and windward side of the road was small. However, the concentrations at the centerline of a street differed from concentrations at the pavement. The measurements showed an average vertical difference of approximately a factor of two for both CO and NO_x level between street level and the 25 m rooftop level.

The vertical gradient for PM and CO has also been investigated by Zoumakis (1995). The difference in concentrations between ground level and a 29 m rooftop was found to be approximately from 3 to 4. Semi-empirical curves to experimental data measured were plotted and it was found that the average vertical profile of vehicular pollutant concentrations follows the general exponential form.

Bauman et al. (1982) measured the vertical gradient of CO and aerosol particles. CO concentrations were found to be higher by a factor of 4 at ground level than at rooftop of height 60 m. For fine particles it was higher by a factor of 2 to 4 between road level and 60 m high rooftop. It was concluded that for CO and particulate Pb and Br there was good mixing and rapid vertical dilution. A large decrease in concentration with height was found to be characteristic for pollutants emitted at street level. They further

concluded that the absence of a dilution factor between rooftop height and ground levels can be used to determine the presence of transported aerosol. In a study on vertical comparison of fine particles, Vakeva et al. (1999) found that the number concentration of ultrafine particles (6 to 300 nm) was 5 times higher at street level (at 1.5 m high) than at the rooftop 25 m high.

Another study comparing street level and rooftop measurements of PM was done by Kumar et al. (2009). In their study they did simultaneous measurements at three different heights (0.20 m, 1.0 m and 2.60 m) above the road level and found that the values were close to each other, showing a small, but consistent decrease with height. Measurements were also done at rooftop level (20 m high) and there was a significant difference between the rooftop and road level measurements by a factor of 6 to 7. These observations depended on the traffic volume and ambient meteorology, especially wind speed and wind direction. There was a linear correlation between particle concentration and the traffic volume.

In all of the above mentioned studies, it was found that the concentrations of air pollutants, such as carbon monoxide and particulate matter, are typically high at street levels more so on urban street roads with heavy traffic. The concentrations have strong gradients within tens of meters away.

2.6 Air pollution modeling

Air pollution modeling is a numerical tool used to describe the causal relationship between emissions, meteorology, atmospheric concentrations, deposition, and other

factors. Air pollution measurements give important, quantitative information about ambient concentrations and deposition, but they can only describe air quality at specific locations and times, without giving clear guidance on the identification of the causes of the air quality problem. Air pollution modeling, instead, can give a more complete deterministic description of the air quality problem, including an analysis of factors and causes (emission sources, meteorological processes, and physical and chemical changes) and some guidance on the implementation of mitigation measures. The models play an important role in science, because of their capability to assess the relative importance of the relevant processes. Air pollution models are the only method that quantifies the deterministic relationship between emissions and concentrations/depositions, including the consequences of past and future scenarios and the determination of the effectiveness of abatement strategies. This makes air pollution models indispensable in regulatory, research, and forensic applications. The concentrations of substances in the atmosphere are determined by: transport, diffusion, chemical transformation and ground deposition. (Builtjes, 2003).

2.6.1 Receptor modeling

Receptor modeling is the application of multivariate statistical methods addressed to the identification and quantitative apportionment of air pollutants to their sources (Hopke et al., 2006). Unlike photochemical and dispersion models, receptor models do not use pollutant emissions, meteorological data and chemical transformation mechanisms to estimate the contribution of sources to receptor concentrations. Instead, receptor models use the chemical and physical characteristics of gases and particles measured at source and receptor to both identify the presence of and to quantify source

contributions to receptor concentrations. (Builtjes, 2003). During the last years, these models have been accepted for developing effective and efficient air quality management plans. Different models including principal component analysis-absolute principal component scores (PCA–APCS) (Garcia et al., 2006; Song et al., 2006a), edge analysis (Unmix) (Song et al., 2006a; Olson and Norris, 2008), chemical mass balance (CMB) (Cooper et al., 1984; Chow and Watson, 2002) and positive matrix factorization (PMF) (Paatero, 1997, 1999; Gildemeister et al., 2007) have been applied to identify and to establish the sources contribution to observed ambient concentrations.

2.6.2 Principal component analysis

Principal component analysis is probably the oldest and best-known technique of multivariate analysis. It was first introduced by Pearson (1901), and developed independently by Hotelling (1933). Like many multivariate methods, it was widely used until the advent of electronic computers, but it is now well entrenched in virtually every statistical computer package. The central idea of principal component analysis (PCA) is to reduce the dimensionality of a data set consisting of a large number of interrelated variables, while retaining as much as possible of the variation present in the data set. This is achieved by transforming to a new set of variables, the principal components (PCs), which are uncorrelated and are ordered so that the first few retain most of the variation present in all of the original variables. Computation of the principal components reduces to the solution of an Eigen value-Eigen vector problem for a positive–semi definite symmetric matrix. This simple technique has a wide variety of different applications, as well as a number of different derivations.

2.7 Studies on source apportionment

Research carried out in India by Srivastava et al. (2008) on source apportionment of TSP in coarse and fine size ranges over Delhi using PCA revealed two major sources i.e. vehicular and crustal re-suspension in both coarse and fine size ranges. The correlation of sources with the metals showed that in coarse size range the dominant source was crustal re-suspension followed by vehicular pollution. However, this was reversed for fine size range where vehicular pollution dominated over crustal re-suspension.

In Africa, PCA was used in Tanzania in a study to measure the elemental and ionic components of atmospheric aerosols (TSP) and associated gaseous pollutants in Dar es Salaam. The study was done at three sites, coastal line, urban and industrial sites, during wet and dry season (Mmari et al., 2013). PCA identified sea spray, local combustion, vehicular traffic, biomass burning and re-suspended road dust as the dominant sources of aerosols at the coastal and urban sites but at the rural site sea spray, crustal sources, soil dust re-suspension and long range transport were found to be possible sources of suspended particulates.

Application of PCA by Nyanganyura et al. (2007) on chemical composition of fine ($PM_{2.0}$) and coarse ($PM_{2.0–10}$) tropospheric aerosols at a continental background site in northern Zimbabwe found crustal matter, sea salt, biogenic emission/biomass burning and a copper component. All these components were identified as the main sources of fine particles in both wet and dry seasons.

In Kenya, PCA has been used in the characterization of aerosol particles at an industrial background site in Nairobi (Gatari et al., 2009). The study targeted black carbon, $PM_{2.5}$ (fine) and $PM_{2.5-10}$ (coarse). The dominant elements were BC, K and S in fine fraction and Si, Ca and Fe in coarse fraction. PCA and correlation evaluation of fine particles implicated industrial, vehicular and biomass burning as the main sources of the measured elements.

2.8 Heavy metals in the particulate.

Particles size and shape can be quite complex and can affect the deposition of a particle in the respiratory tract and how it behaves after it has been deposited (Colbeck, 1998). From a toxicological standpoint, the particle chemical composition is of particular concern for health, since potentially toxic elements such as copper, zinc and lead can cause both short and long term medical problems. Metals such as zinc, copper and iron are essential for man yet chronic metabolic disturbances may occur from a deficiency or an excess of these metals. Similarly, non- essential metals like lead, cadmium and mercury can cause profound biochemical and neurological changes in the human body even at trace levels. Therefore these parameters are of fundamental importance in the understanding of the behavior and potential health impact of an aerosol, and they are of current concern in terms of air and public health. The sources of heavy metal pollutants are metal mining, metal smelting, metallurgical industries, and other metal-using industries, waste disposal, corrosions of metals in use, fossil fuel combustion, and sports and leisure activities, agriculture and forestry. Heavy metal contamination affects large areas worldwide. Hot spots of heavy metal pollution are located close to industrial sites, around large cities and in the vicinity of mining and

smelting plants. Agriculture in these areas faces major problems due to heavy metal transfer into crops and subsequently into the food chain.

2.9 Theory of X-Ray Fluorescence (XRF)

2.9.1 The Physics of XRF

When materials are exposed to X-rays or gamma rays (**hv** in figure 1), ionization of their component atoms may take place. Ionization consists of the ejection of one or more electrons from the atom, and may take place if the atom is exposed to the radiation with the energy greater than its ionization potential. X-rays and gamma rays can be energetic enough to expel tightly held electrons from the inner orbital of the atom, indicated as (a) in Figure 1. The removal of an electron in this way renders the electronic structure of the atom unstable, the electrons in higher orbital "fall" into the lower orbital to fill the vacancy left behind, indicated as (b) in Figure 1. In this process energy (**hv'** in Figure 1) is released in the form of a photon, the energy of which is equal to the difference in binding energy of the two orbitals involved. Thus, the material emits radiation, which energy is characteristic of the related atom. The term fluorescence is applied to phenomena in which the absorption of higher energy radiation results in the emission of lower energy radiation.

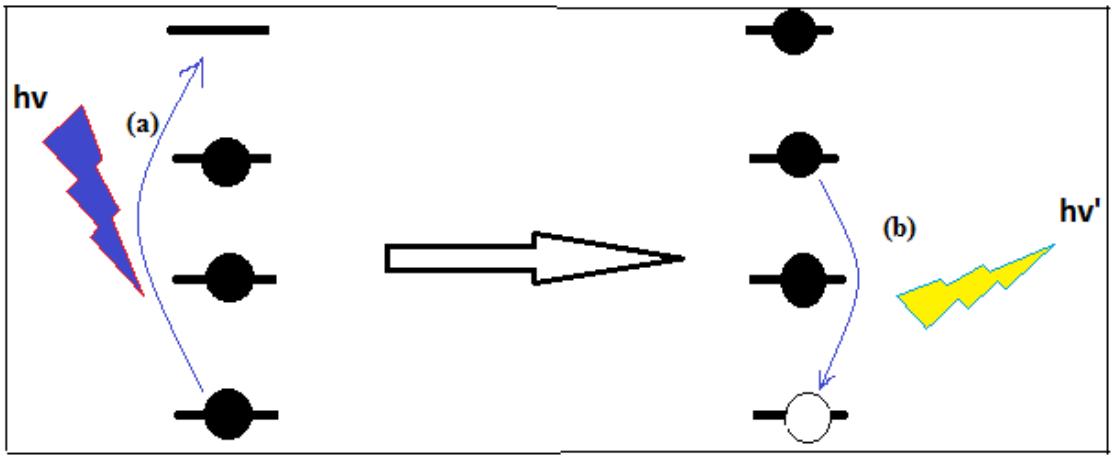


Figure 1: Physics of X-ray fluorescence, in a schematic representation.

2.9.2 Characteristic Radiation

Each element has electronic orbital of characteristic binding energies. Following removal of an inner electron by an energetic photon provided by a primary radiation source, an electron from an outer shell drops into its place. There are a limited number of ways in which this can happen, as shown in Figure 2. The main transitions are given names: an L→K transition is traditionally called Kα, an M→K transition is called Kβ, and an M→L transition is called Lα, and so on. Each of these transitions yields a fluorescent photon with a characteristic energy equal to the difference in energy of the initial and final orbital. The wavelength of this fluorescent radiation can be calculated from Planck's Law: Elements in a sample can be analyzed either by sorting the energies of the photons (energy-dispersive analysis) or by separating the wavelengths of the radiation (wavelength-dispersive analysis). Once sorted, the intensity of each characteristic radiation is directly related to the amount of each element in the material. This is the basis of a powerful technique in elemental analysis in samples.

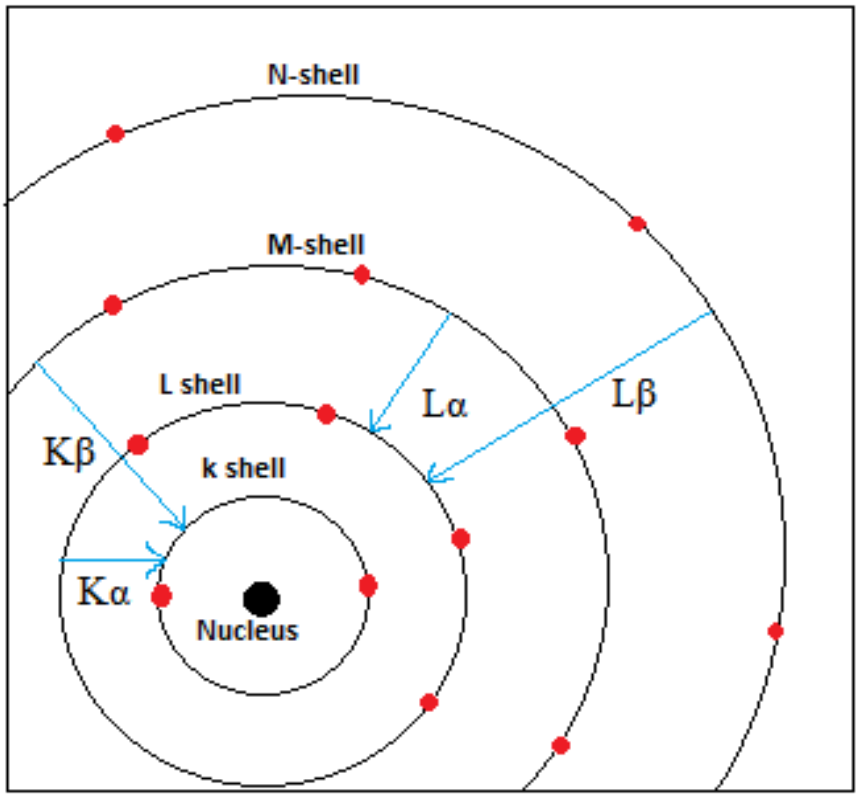


Figure 2: Main transitions in an atom.

2.9.3 Theory of Energy Dispersive X-ray Fluorescence (EDXRF)

In energy dispersive spectrometers, the detector allows the determination of the energy of the photon when it is detected. The EDXRF analyzer also uses an x-ray source to excite the sample but it may be configured in one of two ways. The first is direct excitation where the x-ray beam is pointed directly at the sample. Filter made of various elements may be placed between the source and the sample to increase the sensitivity of the element of interest or reduce the background in the region of interest. The second uses a secondary target; where the source irradiates a target, the target element characteristic X-rays excites the sample. A detector is positioned to measure

the fluorescence and scattered x-rays from the sample and multi-channel analyzer software assigns each detector pulse an energy value thus producing a spectrum.

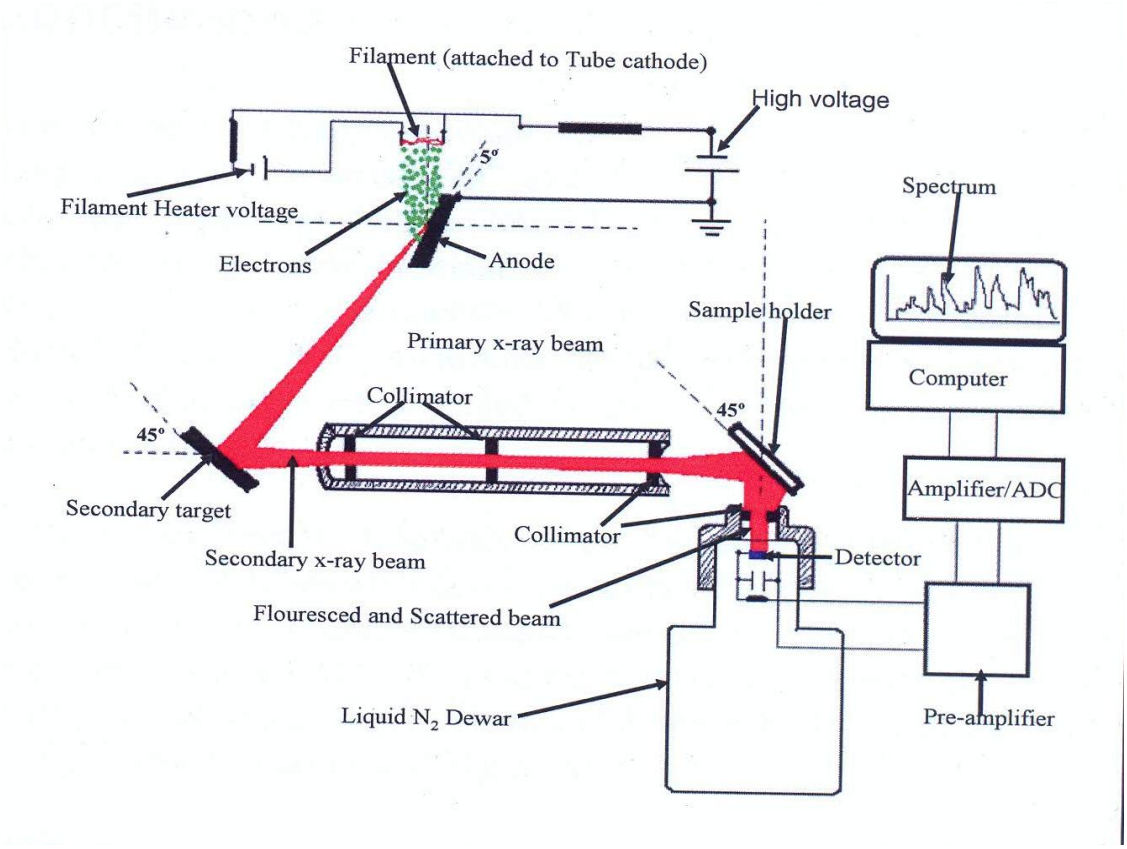


Figure 3: Schematic diagram of EDXRF spectrometer found at the Institute of Nuclear Science and Technology, University of Nairobi. (Adapted from Gatari, 2006).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The study was carried out in Nairobi city in the sites shown in Figure 4. The global location of Nairobi city is at 1.3^0 S, 36.8^0 E and 1700 m above sea level and it is the main urban center of Nairobi Metropolitan area. Nairobi is a national, regional and international strategic centre for education, industries, commerce, transport, regional cooperation and economic development. It also connects the Eastern, Central and Southern African countries and it is one of the largest and fast growing cities in sub Saharan Africa. The city had a population of 3.2 million in 2009 and a daytime population of 4.2 million (KMT, 2010). The Nairobi Metropolitan area has a population of 6.1 million and it has a tropical climate supported by reasonably stable meteorological conditions throughout the year and two main seasons, long heavy rains and short lighter rains (Gatari and Boman, 2003).

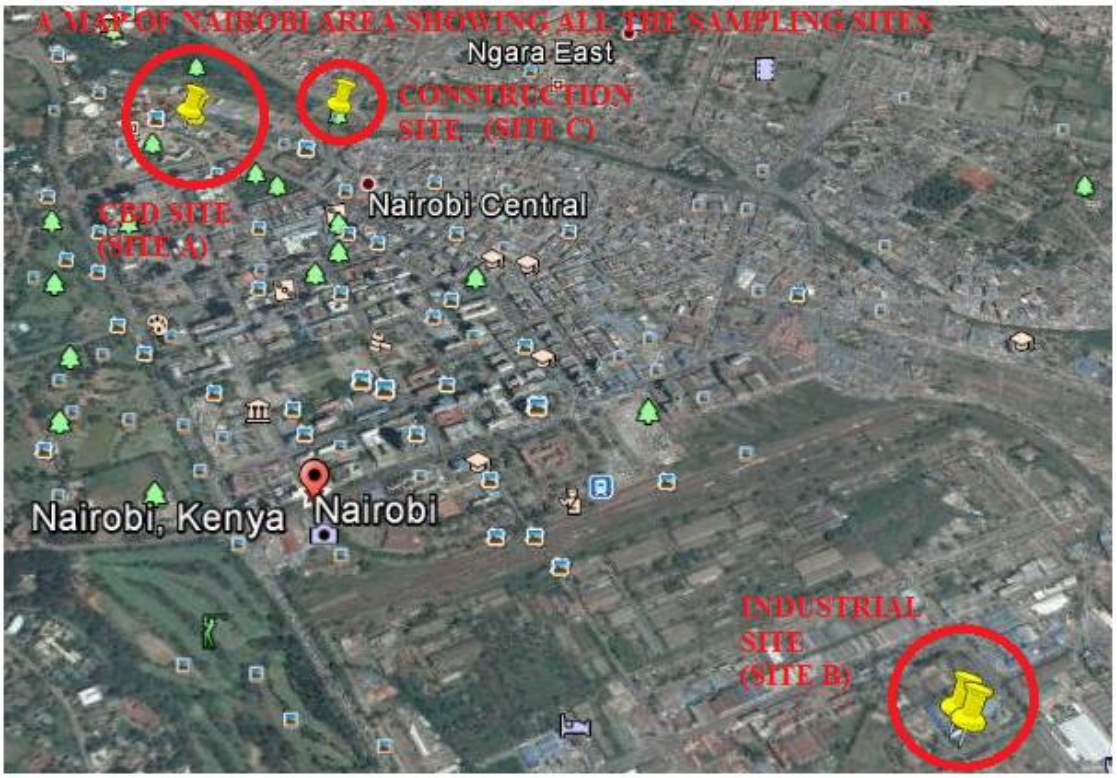


Figure 4: Sampling sites (Site A and B) and the construction site (Site C).

3.2 Selected sampling sites.

Engineering department, University of Nairobi is at the outskirts of Nairobi CBD and was selected as the urban background site (Site A) located at the junction of Harry Thuku road and University way as shown in Figure 4 and 5. University way runs from Northeast-Southwest and is lined by tall buildings to a height more than 20 m above the ground level. All nearby roads and walking paths around this region are concrete and tar paved and usually with varying human and vehicle traffic volume. Estimated traffic densities on these streets were about 2390 vehicles per hour on University way and 375 vehicles per hour on Harry Thuku road. The vehicles were manually counted during the measurement period and the estimated uncertainty was ± 10 %. Human traffic along these two roads was equally high at all times. Traffic consisted mainly of

light-duty petrol and diesel-engine motor vehicles most of them being personal and PSVs (‘matatus’, mini buses and buses). Monitoring was undertaken at two heights: at street level and at rooftop. The street level samples were taken at the boundary of the pedestrian path 3 m from the road and about 20 m from the crossroads at a height of 1.5 m at 1°16'44.83"S and 36°49'2.74"E at 1681 m above sea level (Fig 5). The rooftop measurements were taken on top of the department of Electrical Engineering building, University of Nairobi, whose approximate height is 18 m and approximately 10 m from the road at 1°16'44.19"S and 36°49'2.26"E at 1681 m above sea level (Fig 5). The sampling site was close to (approximately 0.43km from and 20 m above) a road construction site at Globe Cinema round-about indicated as Site C in Figure 5 at 1°16'42.65"S and 36°49'16.33"E at 1660 m above the sea level.

Figure 5: Actual sampling sites at the CBD site and the construction site.
Adopted from Google Earth © 2014.

At industrial area, Madini House [Mines and Geology] was selected as an industrial site (Site B) as shown in Figure 6. It is located in the northern part of the industrial area and to the southeast of Nairobi CBD along Machakos road and approximately 50 m from the junction of Machakos road and Enterprise road. It houses the department of mines and geology. It is surrounded by industries like Unilever Kenya, Unga Mills, Iberia Africa etc. Traffic densities along these roads were 1295 vehicles per hour along Enterprise road and 250 vehicles per hour, at estimated 10 % uncertainty, along Machakos road where most of them were heavy trucks and trailers. Human traffic was high in the morning as workers reported to work places, over lunch hour when they were out for lunch and from 1700 h when leaving for their residence. The roadside sampler was placed 5 m from the kerbside at a height of 1.5m at 1°17'53.36"S, 36°50'3.46"E at 1661 m above sea level and the rooftop sampler was placed at an approximate height of 14 m at the balcony of the 3rd floor of Madini house (Mines and geological department) at 1°17'52.37"S and 36°50'3.22"E at 1661 m above sea level approximately 15 m from the kerbside (Fig 6).

Figure 6: Actual sampling sites at the industrial area: Adopted from Google Earth © 2014 Google.

3.3 Study design

BGI 400 personal air samplers were used to collect $PM_{2.5}$ samples on Teflon filters with a diameter of 37 mm for a period of 8 hr. Measurements at the two sites (4 sampling points) were done simultaneously i.e. at the same day and time. Sampling was done both at the rooftop approximately 14 m above ground at the industrial site and 17 m at the urban site, and at the roadside at an approximate height of 1.5 m (average human breathing level) above the ground at each sampling site. Samples were collected interchangeably in the morning (0700h to 1500h) and in the afternoon (1200h to 2000h) on selected days so as to capture both early and late traffic and industrial emissions. Measurements were done for 9 selected days within the month of

January and February 2012. A total of 36 filters were used. Counting of vehicles was also done on the adjacent roads. After sampling, the loaded filters were sealed in Petri dishes to avoid contamination. The weighing of filters before and after use was done using an analytical balance. Energy Dispersive X-Ray Fluorescence (EDXRF) spectrometer was used to analyze the samples for trace elements. The sample spectrum was then evaluated by Quantitative X-ray Analysis System (QXAS) software. This software was used for elemental identification and quantification. Principal component analysis was used to apportion the major sources contributing to the results obtained. Meteorological conditions for the duration of the sampling period were obtained from Jomo Kenyatta International Airport and were considered as the average conditions for the entire city.

3.4 Sampling of particulate matter, $PM_{2.5}$

Four personal samplers (BGI 400s) were used to collect fine particles ($PM_{2.5}$) on Teflon membrane filters of diameter 37 mm and a pore size of 2.0 μm. These filters have been used in previous studies and have a high particle collection efficiency and high purity. Two filters were used for each site, one at the rooftop and one roadside. Filters were loaded to their respective cassettes and labeled according to the filter number. The most critical parameter in aerosol sampling is the airflow rate through the filter. The flow rate was therefore set at 4 LPM (Litres per minute), which is recommended as the optimum flow rate for personal pumps. Flow rate was checked using a calibrated flow meter. The nozzles were carefully cleaned using dry cotton pads to remove dust particles in them.

In the field, the pump was connected to an external battery and the cassette connected to the nozzle and they were all placed at a sampling position. Two samplers were used in every site, one at the rooftop and the other at the roadside. All samplers were placed at a location where flow of air was not obstructed. Samples were collected for 8 h a day after which the filters cassettes were then offloaded and sealed carefully in air tight petri dishes and kept in clean environment to avoid contamination.

After field work the flow rate of the samplers was again measured. The filters were then removed using a metallic tweezer and kept in clean air tight petri dishes. They were then weighed using a 10 µg sensitive Ainsworth weighing balance (Type 24N). The filters were weighed 3 times and the average mass was calculated. All filters were handled with care to avoid contamination. The differences in mass of the used and the unused filters gave the collected particle mass. Concentrations of the particulates were then obtained by dividing the mass of the particulates by the volume of sampled air through the filter during the sampling period as follows;

$$\text{Concentration } (\mu g m^{-3}) = \frac{w_f - w_i}{v} \quad \text{.....Equation 1}$$

Where;

W_f….is the average weight of the loaded filter in µg

W_i….is the weight of the unloaded filter µg

V….is the volume of sampled air in m^3.

3.5 Elemental Analysis

The loaded filters were analyzed using energy-dispersive x-ray fluorescence spectroscopy. An x-ray generator with a molybdenum tube and a tungsten target set at 40 kV and 15 mA was used to irradiate each filter for 2000 s. Spectral data was acquired using S100 multi-channel analyzer interfaced with a micro-computer. The data was processed for peak area determination using Analysis of X-ray spectrum by iterative least square (AXIL) software. Calculation of elemental concentrations was done using Quantitative X-ray Analysis System (QXAS) software from IAEA (Van Grieken and Markowicz 1993). The program is based on Equation 2 below which relates the element intensity (Ii) and its concentration according to Sparks (1979).

$$I_i(E_i) = G_o.K_i.\varepsilon(E_i).\rho_i d_i \quad \text{.....Equation 2}$$

Where,

$I_i(E_i)$ is the measure of fluorescent intensity of element *i*.

G_o is the geometry constant which is also dependent on the source activity as is the case with radioisotope sources.

K_i is the relative excitation efficiency

$(\rho d)_i$ is the mass per unit area of element *i* in the sample (concentration).

d is the thickness of the sample.

ρ is the density of element *i*

$\varepsilon(E_i)$ is the relative efficiency of the detector for photons of energy E.

The EDXRF spectrometer was calibrated for quantitative measurements using a standard reference material (SRM-2783) with known concentrations of calcium, potassium, vanadium, titanium, chromium, manganese, iron, copper, zinc and lead.

3.6 Detection limits

Detection limit (DL) is the lowest quantity of a substance that can be distinguished from the absence of that substance (a *blank value*) within a stated confidence limit. The detection limit of the EDXRF system was determined using the equation

$$DL = 3C\sqrt{\frac{N_B}{N_P}} \quad \text{.....Equation 3}$$

where C is the certified concentration of the element of interest, N_B is the background area and N_P is the element net peak area. Peak intensities of L and K- lines of various elements analyzed in the SRM -2783 were plotted against the atomic number of elements to give the sensitivity curve.

3.7 Data analysis

Microsoft Excel spreadsheet was used for data computation and drawing of pie charts and bar graphs. A statistical tool (Unscrambler) was used for apportionment of sources of the various pollutants. Correlation matrices and scree plots were obtained from PCA which is a component of this statistical tool. Other statistical parameters such as mean, range, standard deviation and standard error of measurements were also calculated.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Detection limit, Accuracy and Recovery.

Table 1 gives the detection limits of 10 elements in μg filter^{-1} calculated from the spectra of thin standards that were analysed for 1000 s at a tube voltage of 40 kV and a current of 15 mA. The standard spectra was evaluated for background area (N_B) and the element net peak area (N_P) , which were then applied to the IUPAC minimum detection limit in equation 3.

Table 1: Detection limits of elements concentration.

ELEMENT	***D.L (μg/filter)***
K	2.0
Ca	1.5
Ti	0.8
V	0.6
Cr	0.4
Mn	0.3
Fe	0.2
Cu	0.1
Zn	0.1
Pb	0.08

Table 2 shows the results obtained by analyzing a certified reference sample, SRM 2783. The results obtained were compared with the certified values and Ca, Fe, Pb, Ti,

and Zn had a of 100% ± 10% recoverability percentage while K and V were below detection limits.

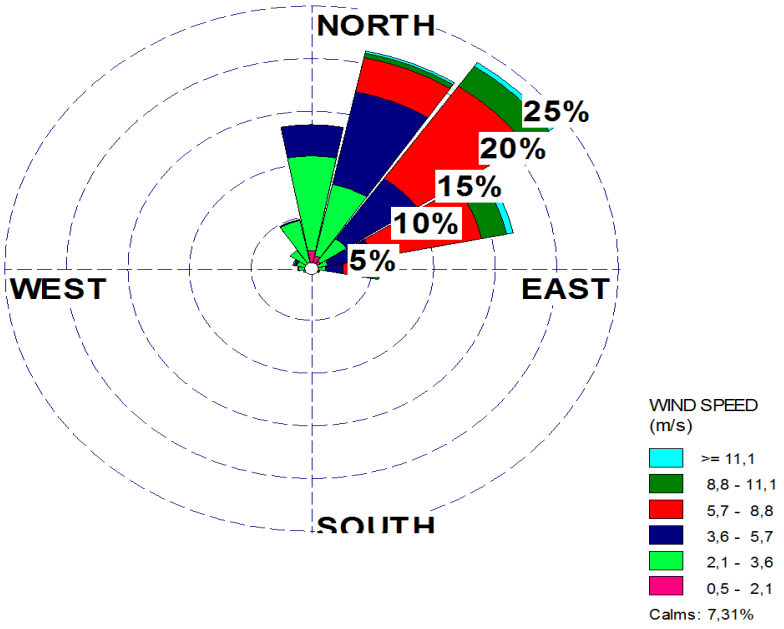
Table 2: Comparison of certified elemental concentrations in SRM - 2783 and results obtained from EDXRF analysis.

ELEMENT	***CERTIFIED VALUES***	***OBTAINED VALUES***	
	CONCENTRATION (µg/filter)	CONCENTRATION (µg/filter)	Percentage Recoverability
Ca	13.2 ± 2.3	11.98 ± 2.1	90.7%
Fe	26.5 ± 1.6	26.11 ± 1.6	98.5%
Cu	0.404 ± 0.1	0.448 ± 0.1	110.9%
Pb	0.317 ± 0.05	0.317 ± 0.05	100%
Ti	1.49 ± 0.48	1.38 ± 0.45	92.6%
Zn	1.79 ± 0.14	1.88 ± 0.15	105%

4.2 Meteorology.

Table 3 shows some weather parameters during the measurement period. This information was obtained from Jomo Kenyatta International Airport, Nairobi. The dominant winds in Nairobi area were North easterlies at an average speed of 5.1 ms^{-1} and agree well with the wind roses as shown by the figures in (Appendices A1, A2 and A3). These wind roses show the average wind direction and speed in Nairobi from 3 stations (Wilson Airport, JKIA and Dagoretti) for a period of 20 years. The wind rose in Figure 7 shows the average wind direction and speed during the measurement period (from 23rd January to 4th February 2012). The measurement period coincided

with a dry season and no precipitation was recorded during the measurement period. The temperatures remained high during the day with a mean of 24 ^{0}c while the sky cover was mainly scattered in some days and clear in some days for the better part of sampling time. There was no observable cloud development during sampling time however clouds were generally dissolving or becoming less developed. Also there were no observable low, middle or high cloud types. As for the visibility, there was dust or sand raised by wind but not well developed dust whirls. Air pollution during this time was influenced by parameters such as wind speed and wind direction among others.



Calm winds were about 7.31% and the average wind speed was 5.1 ms^{-1}

Figure 7: Wind rose showing the variation of wind speed and direction at Jomo Kenyatta Airport, Nairobi for sampling period from 23rd January 2012 to 4th February 2012.

Table 3: Ambient weather parameters for the sampling period.

Factors	January '12	February '12	March '12
Max daytime temp	26 ^{0}C	27 ^{0}C	27 ^{0}C
Min midnight temp	13 ^{0}C	13 ^{0}C	14 ^{0}C
Average temp	18 ^{0}C	19 ^{0}C	19 ^{0}C
Hours of sunshine	9h day^{-1}	9h day^{-1}	8h day^{-1}
Hours of daylight	12h day^{-1}	12h day^{-1}	12h day^{-1}
Relative Humidity	72%	68%	69%
Monthly rainfall (mm)	48	45	95
Wet days(>0.1mm)	4	4	9
Wind direction	North Easterlies	North Easterlies	North Easterlies
Wind speed (ms^{-1})	4.9	4.9	4.9

4.3 Particle mass and Elemental content

CBD site

Table 4: Average mass concentration of filters at the CBD site.

CBD site	$PM_{2.5}$($\mu g\ m^{-3}$)			
DATE	ROOFTOP	ROADSIDE	WINDSPEED (ms^{-1})	NUMBER OF VEHICLES
23-Jan	242.2 ± 12.1	113.1 ± 5.7	6.6	2228
24-Jan	53.4 ± 2.7	19.7 ± 0.9	7.0	3496
25-Jan	2.7 ± 0.1	25.5 ± 1.3	5.6	3517
26-Jan	128.2 ± 6.4	16.0 ± 0.8	6.3	3801
27-Jan	52.5 ± 2.6	131.8 ± 6.6	4.5	3660
31-Jan	53.4 ± 2.6	26.0 ± 1.3	6.9	3798
2-Feb	10.8 ± 0.5	18.8 ± 0.9	5.8	3808
3-Feb	12.5 ± 0.6	10.7 ± 0.5	6.2	3815
4-Feb	102.4 ± 5.1	65.9 ± 3.2	8.0	3446

Concentrations as low as 3, 10, 12 $\mu g\ m^{-3}$ and as high as 260 $\mu g\ m^{-3}$ were recorded and this could be attributed to possible occurrence of temperature inversion since measured meteorological conditions, such as rainfall, wind direction and speed, daytime temperature and humidity, were stable during the sampling time (Table 3 and 4). These values could be as a result of recording and measuring error, incorrect distribution assumption, unknown data structure or just an incidental phenomenon. However recording and measuring errors are often the first source of suspected outliers (Hawkins 1994; High 2004). Potential outliers are normally accommodated and not deleted since they are significant to the study and they point out important

aspects to be considered when carrying out a similar or related study (Tara and Ivan 2006). The mean daily concentrations varied from day to day due to varying meteorological conditions and varying number of sources such as the number of on-road vehicles, industries on operation, biomass burning and thus the mean, mode and median may not be the same. Concentration of $PM_{2.5}$ at 17 m above ground level ranged from 3 to 242 µg m^{-3} with an average of 73 µg m^{-3} and a median of 53 µg m^{-3}. This is higher than the average of 42.8 ±7.8 µg m^{-3} obtained by Kinney et al. (2011) at the same site in July 2009. The two vary from each other since they were done at two different seasons: sunny season (February) and cool season (July).This therefore shows that there is higher mass concentration during sunny season as compared to a cool season due to wet deposition that occurs during the drizzles. Highest PM level of 242 µg m^{-3} was recorded when the number of vehicles along the adjacent road (Harry Thuku road) was highest (3801 cars) suggesting that there was dominance of traffic-related emissions. Mkoma et al. (2009) found out that total carbon accounted for 44% of $PM_{2.5}$ in a similar study done in Morogoro, Tanzania in 2005 during the wet season and they suggested that carbon was likely a larger percentage of the total mass concentration. Saturday recorded the highest concentrations of 242 µg m^{-3} than most of the weekdays. All weekdays had a mean of 70 µg m^{-3}. This is a pointer that Saturdays are equally busy as compared to the weekday. The number of vehicles recorded over the weekend was equally high as compared to other days of the week.

At the roadside of the urban site the PM levels ranged from 11 to 132 µg m^{-3} with an average of 47.5 µg m^{-3}. On average this is lower than the findings by Kinney et al (2011) where roadside levels ranged from 51 to 129 µg m^{-3} with an average of 98 µg

m^{-3}. Sampling was done along Harry Thuku road which is not as busy as compared to Ronald Ngala street, Tom Mboya street, River road and Thika road where the study was carried out by Vliet and Kinney (2007). This is also low as compared to the measurements by Vliet and Kinney (2007) which found that the concentrations collected along the roadway between Nairobi and Ruiru ranged from 397 to 431 µg m^{-3} with a mean of 414 µg m^{-3} for a 12 h sampling period. The highest PM levels of 132 µg m^{-3} and 113 µg m^{-3} were recorded during the afternoon. Saturday recorded 66 µg m^{-3} which is above the total average of 47.5µg m^{-3} of all the measured concentration. Friday afternoon (1200-2000 h) recorded the highest mass concentration of 132 µg m^{-3}. This was attributed to heavy traffic jam on that Friday. A study done by Eliasson et al (2005) checking on the particle concentration in three African cities, Ouagadougou (Burkina Faso), Dar es salaam (Tanzania) and Gaborone (Botswana) during dry season found that the minimum and maximum mean hourly TSP concentration at Dar es salaam was 40 and 110 µg m^{-3}, Ouagadougou (170 and 7900 µg m^{-3}) and Gaborone (15 and 90 µg m^{-3}) respectively. This study found that minimum and maximum mean hourly concentration is 1 and 16 µg m^{-3}. This therefore points out that Nairobi is equally polluted as compared to this other towns although their study was on TSP and this study was only targeting $PM_{2.5}$.

Highest PM levels were recorded when the number of vehicles was highest. This could be attributed to suspended dust from moving vehicles due to the poor state of the roads, since more than 60% of the collected elements were from mineral dust. Current 24 h WHO guidelines and US standard concentrations for $PM_{2.5}$ stands at 25 µg m^{-3} for 24 h and 10 µg m^{-3} for annual mean. We cannot therefore directly compare our

data against air quality standards and guidelines that are defined on the basis of 24 h or annual hourly concentrations since our sampling was done for 8 h. However, if we assume that our data is a representative of typical urban background and roadways exposure then those who spend more hours a day along the busy roadsides are exposed to high and risky levels. On average higher PM concentrations were collected at the urban rooftop (73.1 µg m^{-3}) compared to the urban roadside (47.5 µg m^{-3}) as shown in Table 4. Traffic census from KIPPRA (2006) reveal that private cars transport 22% of Nairobi passengers, second hand private vehicle constitute 64% of total vehicular volume, while public vehicles mainly small, high emitting minivans, "Matatus" and buses transport 78% of Nairobi's passengers and constitute 36% of traffic volume. There is need therefore to have continuous sampling so as to determine the pollution levels related to traffic along our roads so as to come up with informed air pollution mitigation plans. A study in Accra town, Ghana by Nerquaye- Tetteh (2006) found that roadside $PM_{2.5}$ concentrations ranged between 100 – 200 µg m^{-3} but reached as high as 600 – 1200 µg m^{-3} on several days. This shows that Nairobi is less polluted as compared to Accra. The PM concentrations collected near ground correlated highly with those collected at the rooftop with a co-efficient of 0.9517 at a height difference of 17 m as shown in Figure A5 at the appendix. This also suggests increased atmospheric stability within this area. In dry season, the low soil moisture facilitates entrainment of dust and can be part of the explanation.

Industrial site

At the industrial site, concentrations of $PM_{2.5}$ at 14 m above ground level, ranged from 1 to 252 µg m^{-3} with an average of 47 µg m^{-3} as shown in Table 5. The highest PM

level of 252 µgm^{-3} was recorded in the afternoon and Saturday recorded 15 µg m^{-3} which was one of the least recorded PM levels thus indicates that industries are not normally busy over the weekend. Friday afternoon recorded the second highest PM level of 41 µg m^{-3} and the second highest number of cars (3097) for a period of 8 h. This shows that there is a great influence of elements collected at the rooftop from the motor vehicle emissions.

Along the industrial roadside the PM levels ranged from 23 to 260 µg m^{-3} with an average of 71 µg m^{-3}. The highest PM level of 260 µg m^{-3} was recorded in the afternoon. This is in agreement with a similar study done in Dar es Salaam (Jonsson, 2005) where the highest PM concentrations occurred at noon. Friday afternoon recorded the lowest PM level of 23 µg m^{-3}. This was attributed to the change of wind direction during the sampling period on that particular Friday.

Table 5: Average mass concentration of filters at industrial site.

Industrial site	$PM_{2.5}$($\mu g\ m^{-3}$)			
DATE	ROOFTOP	ROADSIDE	WINDSPEED (ms^{-1})	NUMBER OF VEHICLES
23-Jan	252.0 ± 12.6	260.0 ± 13	6.6	2086
24-Jan	28.5 ± 1.4	49.0 ± 2.5	7.0	1326
25-Jan	29.4 ± 1.5	84.6 ± 4.2	5.6	2466
26-Jan	0.9 ± 0.05	41.0 ± 2.1	6.3	3175
27-Jan	41.0 ± 2.0	23.1 ± 1.2	4.5	3097
31-Jan	15.2 ± 0.8	54.3 ± 2.7	6.9	2978
2-Feb	33.8 ± 1.7	37.4 ± 1.9	5.8	2830
3-Feb	7.1 ± 0.4	32.9 ± 1.6	6.2	2517
4-Feb	15.0 ± 0.8	54.3 ± 2.7	8.0	1412

In both sites (CBD and industrial) at the rooftop, 17 m agl and 14 m agl respectively the PM levels are comparable as shown in figure 8. Site A recorded a range of 3 to 242 $\mu g\ m^{-3}$ while site B recorded a range of 1 to 252 $\mu g\ m^{-3}$. However higher PM levels were recorded at the urban rooftop with a mean of 73 $\mu g\ m^{-3}$ than industrial rooftop with a mean of 47 $\mu g\ m^{-3}$. This can be attributed to its proximity (approximately 0.43km from and 20 m above) to the road construction which was taking place at site C as shown in Figure 4 and 5, the high number of vehicles at the urban site and the direction of wind (north-easterlies) as shown in Figure 7. Highest PM levels were recorded in the afternoon.

Along the roadside of the urban site a range of 11 to 132 µg m^{-3} with an average of 47.5 µg m^{-3} was recorded while at industrial area a range of 23 to 260 µg m^{-3} and an average 71 µg m^{-3} was recorded. This indicates that the industrial roadside recorded higher PM levels than the urban roadside. Elements from mineral dust were dominant in this area i.e. Ca (17%), Fe (25%), Ti (5%) and Mn (1%) as shown in Figure 10 and 12. Entrainment of soil particles is facilitated during the dry season (Xuan, 1999). This therefore enhances a lot of suspended dust particles. Measurements in this study were done during the dry season; in line with the above reasoning, this time of the year is thus likely to be associated with peak concentrations of particulate matter. This can be attributed to the poor status of roads within this area since they are mainly used by heavy trucks and lorries.

At industrial site, PM concentration collected at the rooftop correlated positively (r = 0.5314) with those collected at the roadside with a height difference of 14 m as shown in Figure A4 at the appendix. The source of elements collected at the rooftop owes its origin from other sources near to or far from the collection point. At the CBD site, roadside concentrations strongly correlated (r = 0.9567) with rooftop concentrations with a height difference of 17 m as shown in Figure A5 at the appendix.

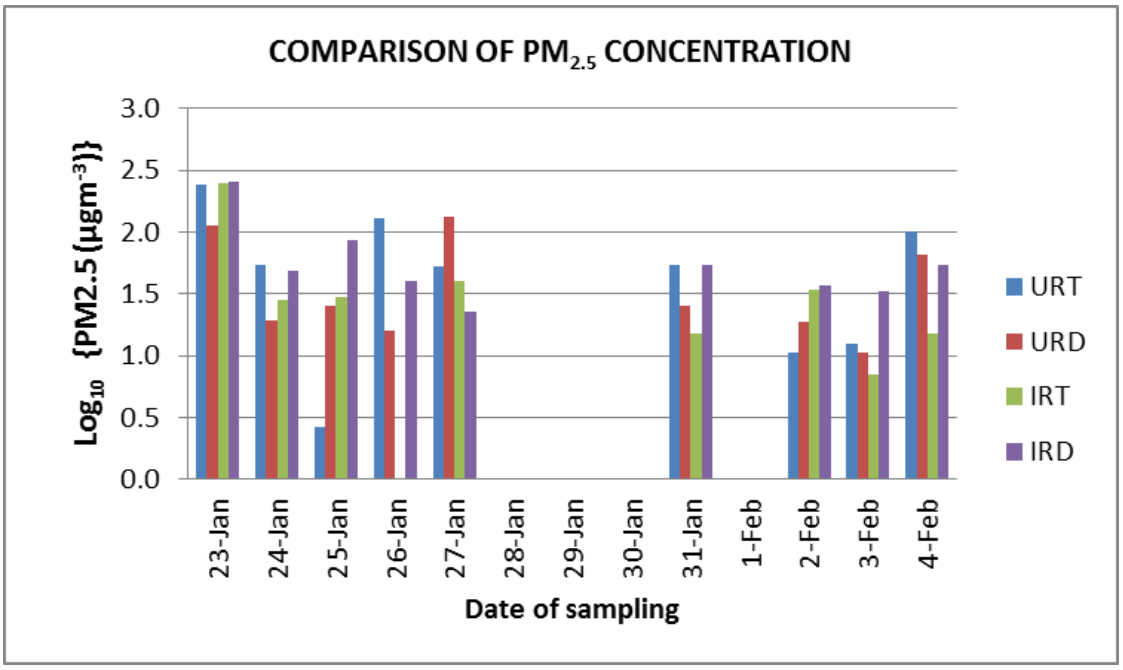


Figure 8: PM concentrations for both rooftop and roadside at industrial and CBD site.

URT– CBD Rooftop, URD- CBD Roadside, IRT – Industrial Rooftop and IRD – Industrial Roadside

Vertical dispersion

Our findings on vertical dispersion revealed that there is a decrease in $PM_{2.5}$ concentrations as well as elemental concentration with vertical distance away from the ground level both at the CBD (for 33% of the total samples) and the industrial site (for 89% of the total samples) as in Table 4 and 5. These findings are in agreement with other studies both locally and internationally (Bauman et al., 1982; Qin and Kot, 1993; Zoumakis, 1995; Vakeva et al., 1999; Kumar et al., 2009; Kinney et al., 2011). Vakeva et al. (1999) found the number concentration of ultrafine particles (6 to 300 nm) to be 5 times higher at street level (1.5 m) than that at rooftop (25 m); Bauman et al. (1982) reported a factor of 2 to 4 difference for fine particles between road level and 60 m rooftop; and Kumar et al.,(2009) found fine particles (5 – 1000 nm) concentrations at

the street level (2.6 m high and 3.05 m away from the kerb) and at the roof top (20 m high) to be approximately 6.5 times higher than at rooftop. This study found out that both mass and elemental concentrations were a factor >1 to 5 higher on the ground level (1.5 m) than at rooftop (14 m and 17 m) at industrial and CBD site respectively. However for a few cases the factor was less than one thus suggesting external sources of $PM_{2.5}$ and elemental concentrations. At CBD site, the $PM_{2.5}$ concentration was of factor 0.38 to 0.83 for 6 days and between 2 and 8 for the rest of the days where the ground level was 1.5 m agl and rooftop height was 17 m agl. The elemental concentration was a factor of 0.54 to 0.97 for 5 days and between 1 and 2 higher for the rest of the days. The days when the concentration factor of both the PM and elemental was less than 1, could be attributed to presence of transported aerosols i.e. suspended dust particles (Bauman et al., 1982). During our sampling period, there was construction of Thika super highway at the Globe cinema round about which is nearly 480 m from and < 20 m below the sampling site. This therefore can be used to explain for the concentration factor (< 1) since there were a lot of suspended dust particles during sampling period. It should also be noted that elements related to soil dust, biomass burning and vehicular emissions had a gradient < 1 and they could also be attributed to external sources. Wind direction therefore plays a key role in distribution of aerosol pollutants. At the industrial site, the PM concentration factor was less than 1 for only one day and between 1 to 5 higher for the rest of the days where the ground level measurements was at 1.5 m agl and rooftop measurements was at 14 m agl. The elemental concentration factor was <1 for 2 days and greater than 1 but less than 2 times higher for the remaining days (Table 6 and 7).

Table 6: Range and mean elemental concentration evaluated in 8 h sampled $PM_{2.5}$ particles at the CBD site.

ELEMENT	ROOFTOP ($ng\ m^{-3}$)			ROADSIDE ($ng\ m^{-3}$)		
	Min	Max	Average	Min	Max	Average
K	<DL	<DL	<DL	<DL	<DL	<DL
V	<DL	<DL	<DL	<DL	<DL	<DL
Ca	3081	11484	7282 ± 5942	1853	6746	4376 ± 2680
Ti	429	2535	1323 ± 1089	397	2753	1163 ± 1023
Cr	<DL	371	371 ± 5	200	206	203 ± 5
Mn	144	2289	575 ± 552	250	1792	634 ± 497
Fe	1659	29068	6130 ± 1657	1411	20531	6144 ± 5109
Cu	108	211	143 ± 29	108	180	140 ± 25
Zn	70	601	177 ± 101	73	602	205 ± 170
Pb	88	143	109 ± 23	55	199	102 ± 43

Table 6 shows elemental concentrations evaluated from particles sampled at 1.5 m and 17 m above ground level. A total of 10 elements were analysed: K, Ca, Ti, Cr, V, Mn, Fe, Cu, Zn and Pb from sampled $PM_{2.5}$ and their mean daily concentrations are as shown in Table 6. K and V were below detection limits in both cases. At 17 m, Ca, Ti and Cr were recorded in samples of a few days while Mn, Fe, Cu, Zn and Pb were in all the days. Ca was recorded in samples of two days; Ti for three days and Cr once. The presence of the crustal elements (Fe, Ca, Mn, Zn and Ti) in large quantities points to the contribution of mineral dust to the urban PM. At the roadside, 1.5 m above the

ground level, Ca, was recorded in samples of 4 days; Ti for 5 days; Cr for 2 days; Zn and Pb for 8 days; Mn, Fe and Cu for all days. Mineral dust elements were dominant and collected in high concentrations while elements like Pb and Cu were collected in all days suggesting that there is consistent source.

Table 7: Comparison of elemental concentrations of aerosol particles from the CBD site collected in different years.

$PM_{2.5}$ concentrations (**ngm^{-3}**)				
	*	**	***	***This study***
Elements	Feb/Mar	Feb/Mar	July/Aug	**Jan/Feb**
	1997	2000	2009	**2012**
K	110 ± 15	550 ± 82	380 ± 140	**BDL**
Ca	100 ± 20	200 ± 77	360 ± 140	**7282 ± 5942**
Ti	16 ± 3	15 ± 4	71 ± 30	**1323 ± 1089**
Mn	NR	NR	61 ± 20	**575 ± 552**
Fe	250 ± 45	170 ± 53	700 ± 260	**6129 ± 1657**
Cu	NR	NR	3.2 ± 3	**143 ± 29**
Zn	NR	NR	170 ± 160	**178 ± 101**
Pb	40 ± 8	27 ± 4	32 ± 20	**109 ± 23**

NR-Not reported

*Stikans et al (1998) ** Gatari et al (2005) *** Gaita (2010)

From Table 7 the particulate measured in 2012 varied between 3 to 20 times higher when compared to the measurements done in 1997, 2000 and 2009. This implied a rise in air pollution within Nairobi area and attributed to rise in the number of on-road vehicles, constructions of roads and buildings, increase in the number of industries and other anthropogenic activities. All the measurements in Table 7 were done at the same site targeting $PM_{2.5}$. The studies by Stikans et al (1998) and Gatari et al (2005) were done using a dichotomous sampler for a period of 24 hours per sample while the study by Gaita (2010) was done using a BGI 400 sampler for a period of 24 hours per sample. This study was done for a period of 8 hours per sample at the same site. The specific month(s) and the year of sampling are indicated in Table 7.

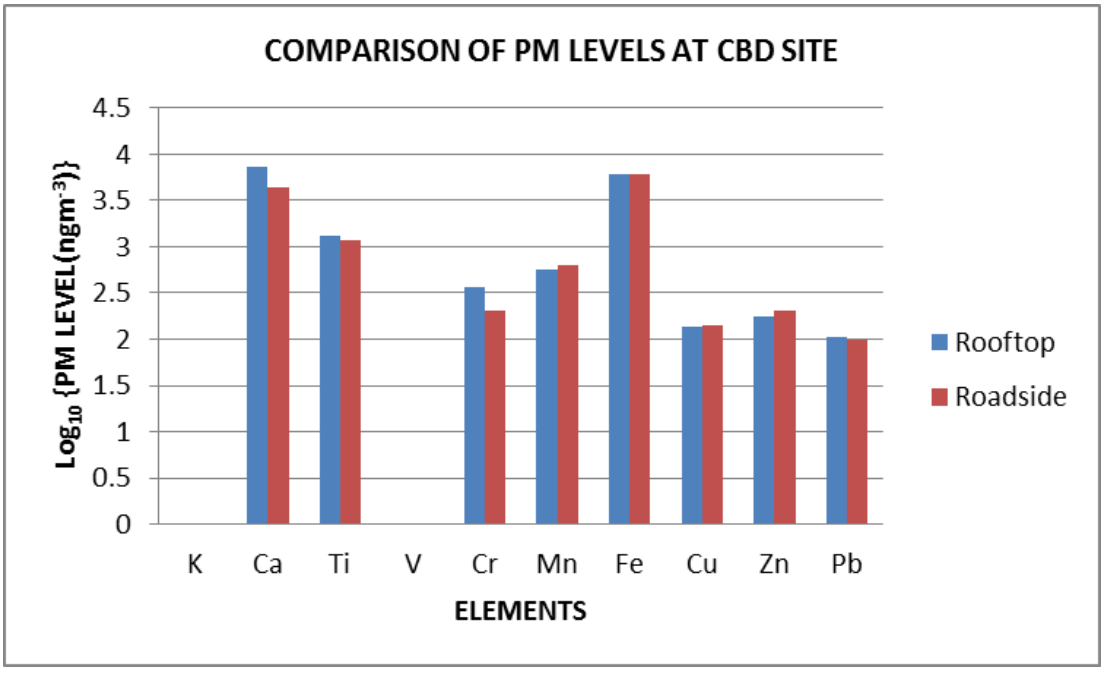


Figure 9: Variations of PM elemental concentrations for both rooftop and roadside at the CBD site.

In all cases, elements in particles collected near ground level were also collected at the roof top. However two thirds of the elements had higher concentrations at the rooftop as compared to the roadside (Ca, Ti, Cr, Cu and Pb) as shown in Figure 9. This implied that the sources of these elements were not only within the collection zone but also from external sources. It also highlighted the role of wind direction and speed in air pollution assessment. The elements associated with mineral dust were attributed to the construction of Thika super highway which was taking place during sampling period. Lead has been phased out from the vehicle fuel since 2006 but it was evaluated in the collected samples suggesting other possible sources such as industrial emissions and mineral dust.

These findings suggests that people who spend most of their time on or near roads especially the pedestrians, motorists , hawkers and traffic police are exposed to these elements and thus can heavily impact on their health. Those working in storey buildings near roads within the urban zone are not safe either since they are exposed to higher $PM_{2.5}$ concentration.

These findings also indicate that mineral dust is a dominant source of elements in Nairobi $PM_{2.5}$ since over 80% of the total evaluated elements are linked to mineral dust as shown in the Figure 10 and 12.

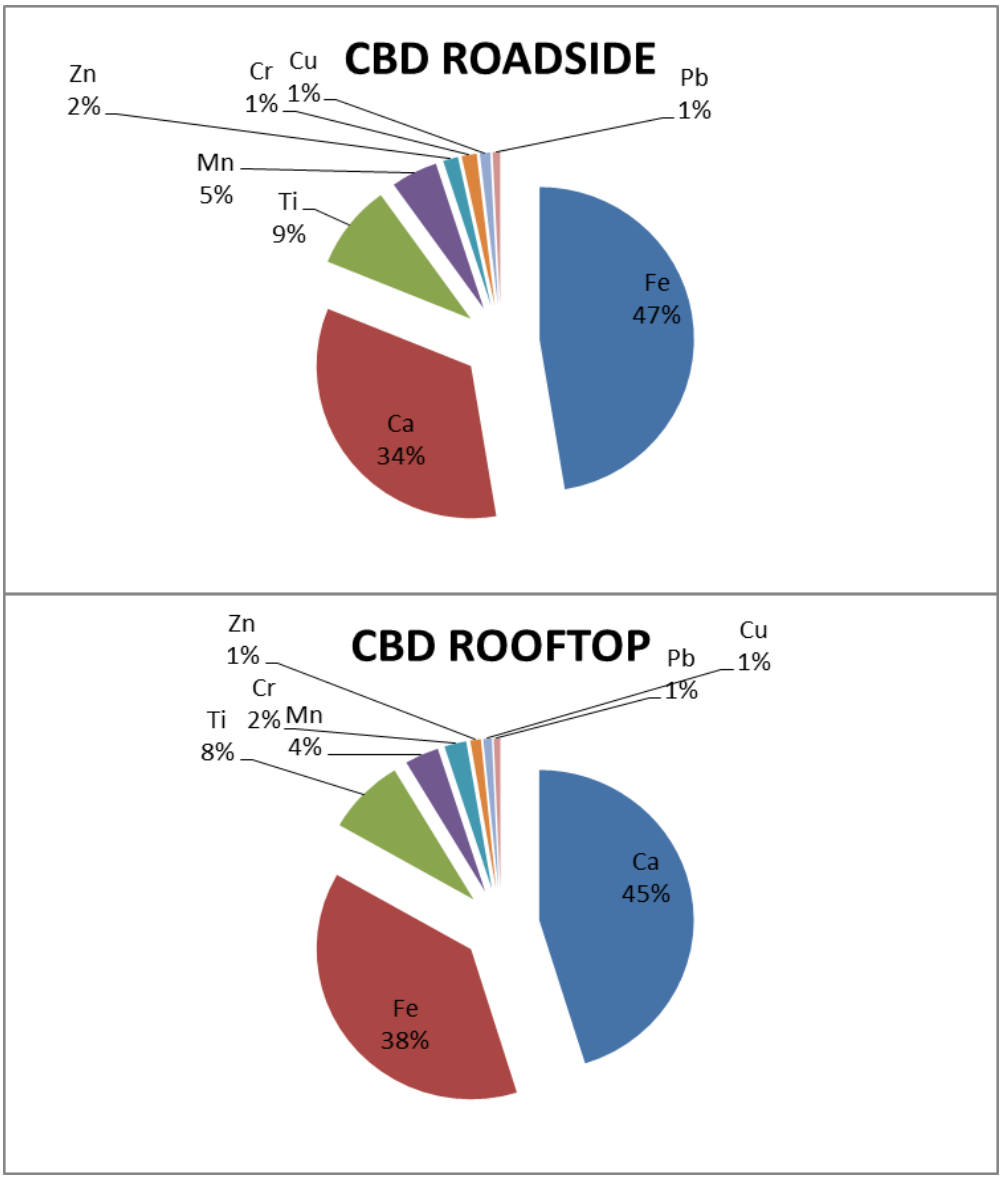


Figure 10: Total evaluated elements in $PM_{2.5}$ at the CBD roadside and rooftop respectively in percentage.

Table 8: Range and mean elemental concentration evaluated in 8 h samples at the industrial site.

ELEMENT	ROOFTOP (ngm^{-3})			ROADSIDE (ngm^{-3})		
	Min	Max	Average	Min	Max	Average
K	<DL	<DL	<DL	<DL	12973	12973
V	<DL	<DL	<DL	<DL	<DL	<DL
Ca	2685	8188	5036 ± 2837	1521	6401	4520 ± 2012
Ti	822	2313	1567 ± 554	763	1851	1474 ± 617
Cr	<DL	187	187 ± 23	286	321	304 ± 24
Mn	220	1726	603 ± 490	178	1334	697 ± 45
Fe	1564	19769	5785 ± 2553	1605	16064	6734 ± 2112
Cu	88	191	134 ± 31	65	222	139 ± 57
Zn	87	601	201 ± 58	105	534	247 ± 121
Pb	56	223	109 ± 56	68	174	120 ± 32

At industrial rooftop (14 m above the ground level) similar trend as that of CBD site was observed. K and V were below detection limits. Cr was recorded in samples once; Ca and Ti for 2 days; Pb for 7 days; Mn for 8 days and Fe, Cu and Zn for all days. At the roadside (1.5m above the ground level), V was below detection limit. K was recorded in a sample of one day; Cr for 2 days; Ti for 3 days; Ca for 5 days ; Cu and Pb for 7 days; Mn, Fe, and Zn for all days. This is an implication that elements related to mineral dust are dominant and are recorded in high quantities, as compared to the rest as shown in Table 8, thus mineral dust is a leading pollutant in Nairobi area.

Table 9: Comparison of measurements done at industrial area in Kenya.

Comparison of studies done at industrial area, Madini house, Nairobi at different times. $PM_{2.5}$ concentrations in ngm^{-3}		
	*	**This study**
Elements	July/Aug 2001	**Jan/Feb 2012**
K	670 ± 31	**BDL**
Ca	63 ± 4	**5036 ± 2837**
Ti	8 ± 1	**1567 ± 554**
Mn	12 ± 2	**603 ± 490**
Cu	3.2 ± 1	**134 ± 31**
Fe	120 ± 39	**5785 ± 2553**
Zn	94 ± 12	**201 ± 58**
Pb	69 ± 27	**109 ± 56**

* Gatari et al (2009)

The results in Table 9 have an observable difference and can be explained by differences in meteorology during the two sampling periods, increase in the number of industries within the 10 year difference, increase in population, increase in the number of vehicles and the poor status of roads within this region. Increase in the number of industries and number of vehicles has led to rise in industrial and vehicular emissions respectively while increase in population has led to increase in construction of roads, houses and other anthropogenic activities. It should also be noted that the sampling by Gatari et al (2009) was done using a dichotomous sampler for a period of 24 hours per

sample while for this study a BGI 400 sampler was used for a sampling period of 8 hours per sample. Both studies targeted $PM_{2.5}$.

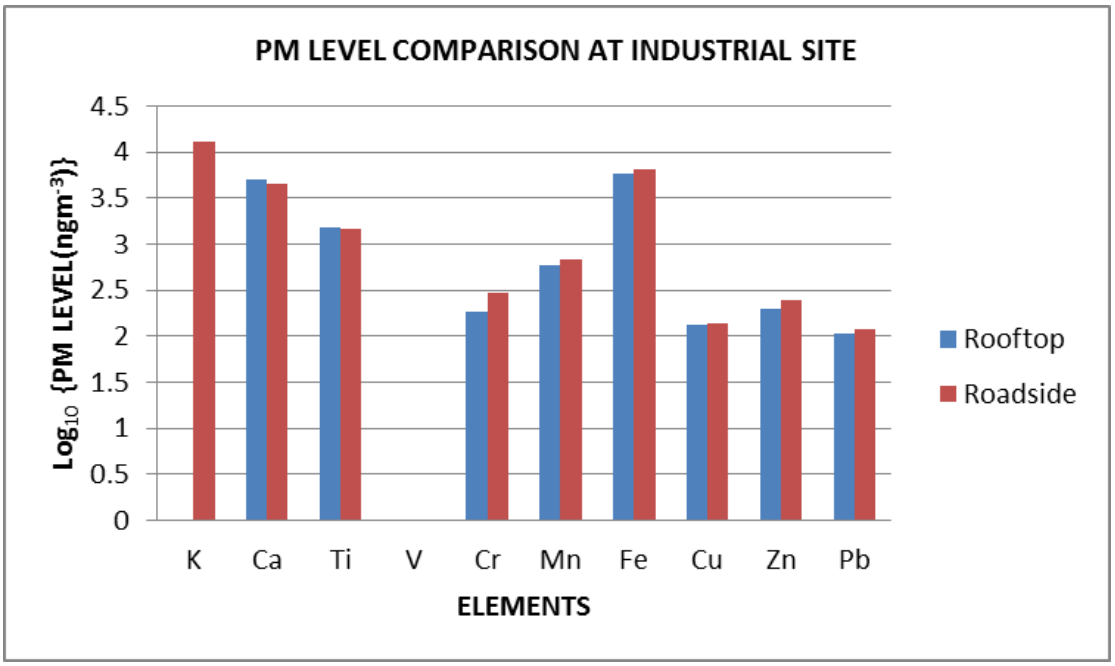


Figure 11: Variations of PM elemental concentrations for both rooftop and roadside at the industrial site.

All elements evaluated in the roadside particle samples were also recorded at the rooftop except K which was below detection limit. K was present in comparatively high concentrations in samples collected at 1.5 m above ground level which implies that there was a source of biomass burning within the area.

On average higher concentrations were recorded near ground as compared to rooftop (14 m) but only Ca and Ti were higher at the rooftop. Elements with higher concentrations were mineral dust related. This suggests that pedestrians, motorists and hawkers along this zone are exposed to more dust particles and biomass burning emissions.

The general scenario is that mineral dust emissions were dominant of airborne particles at the industrial and was enriched by contribution from biomass burning. Contribution from motor vehicle and industrial emissions were lower as shown in Figure 12 below.

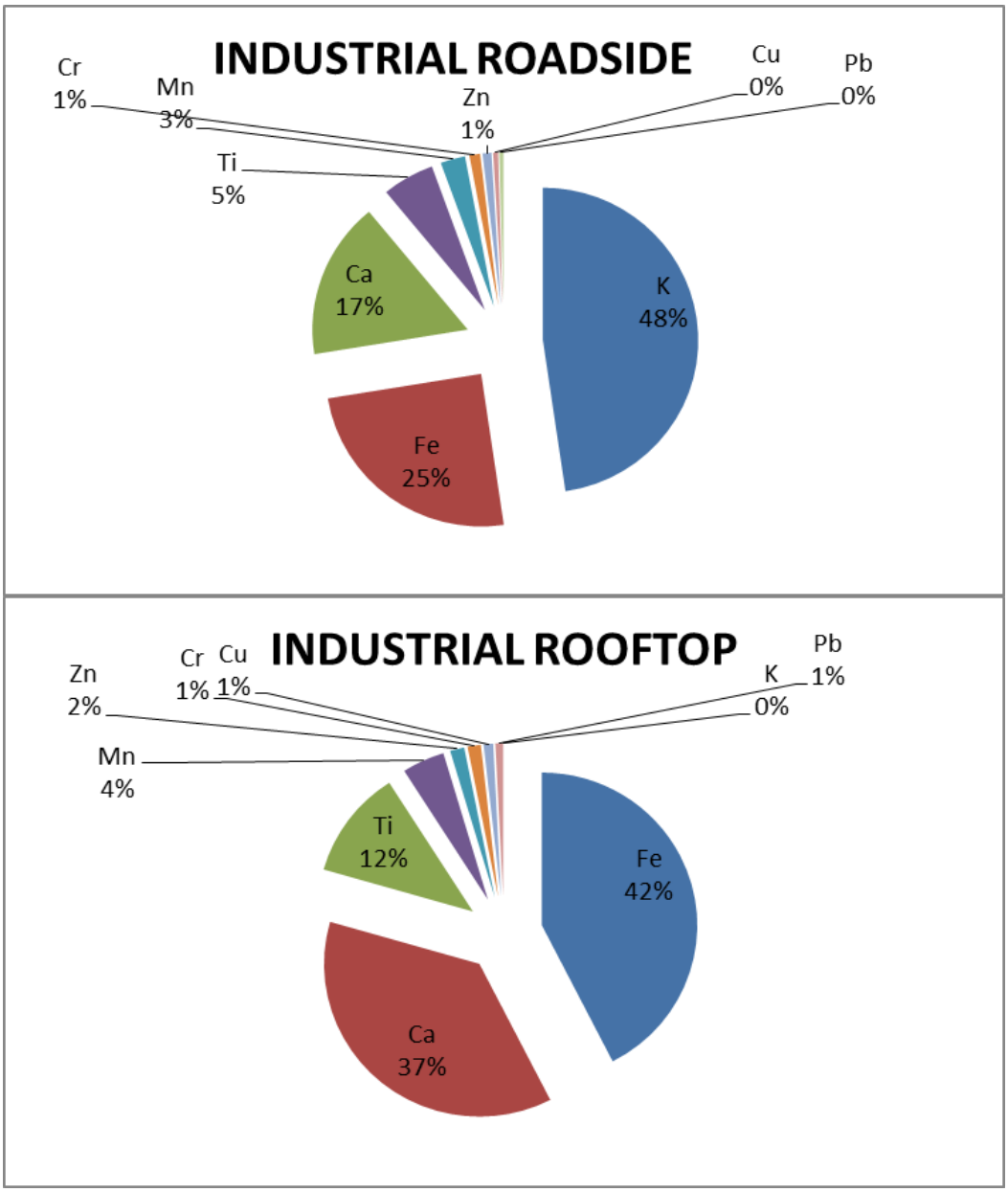


Figure 12: Total evaluated elemental concentrations in percentage in $PM_{2.5}$ at the industrial rooftop (14 m above ground) and roadside (1.5 m).

Correlations

The scree plots in Figure 13 and Figure 16 displays the proportion of the variation in a dataset that is explained by each of the components in a PCA. A scree plot displays the eigenvalues associated with a component or factor in descending order versus the number of the component or factor. Scree plot is used in PCA to visually assess which components or factors explain most of the variability in the data. The point where the slope of the curve is clearly leveling off is called the elbow. The number of components depends on the "elbow" point at which the remaining eigenvalues are relatively small and all about the same size. The scree plot for CBD in Figure 13 and for industrial site in Figure 16 have identified 4 main components that are significant in our data because the line starts to straighten after factor 5. Figures 14 and 15 are in agreement with this as shown in the grouping of elements based on a common or shared source.

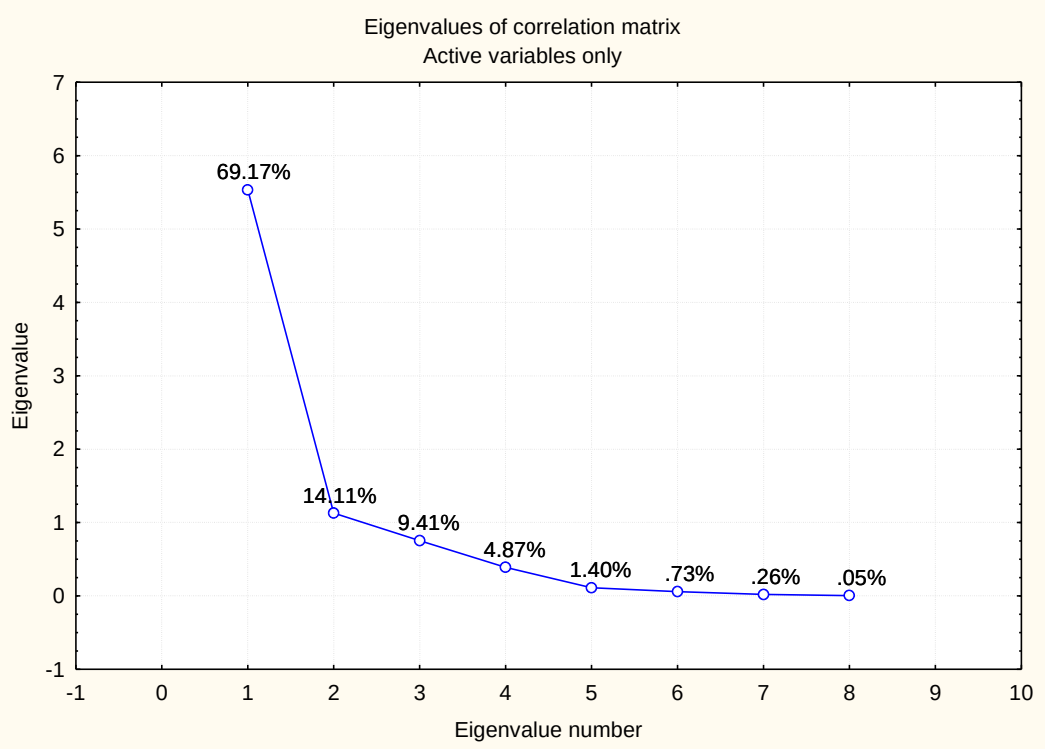


Figure 13: Scree plot Results from PCA for CBD site data (both rooftop and roadside concentrations).

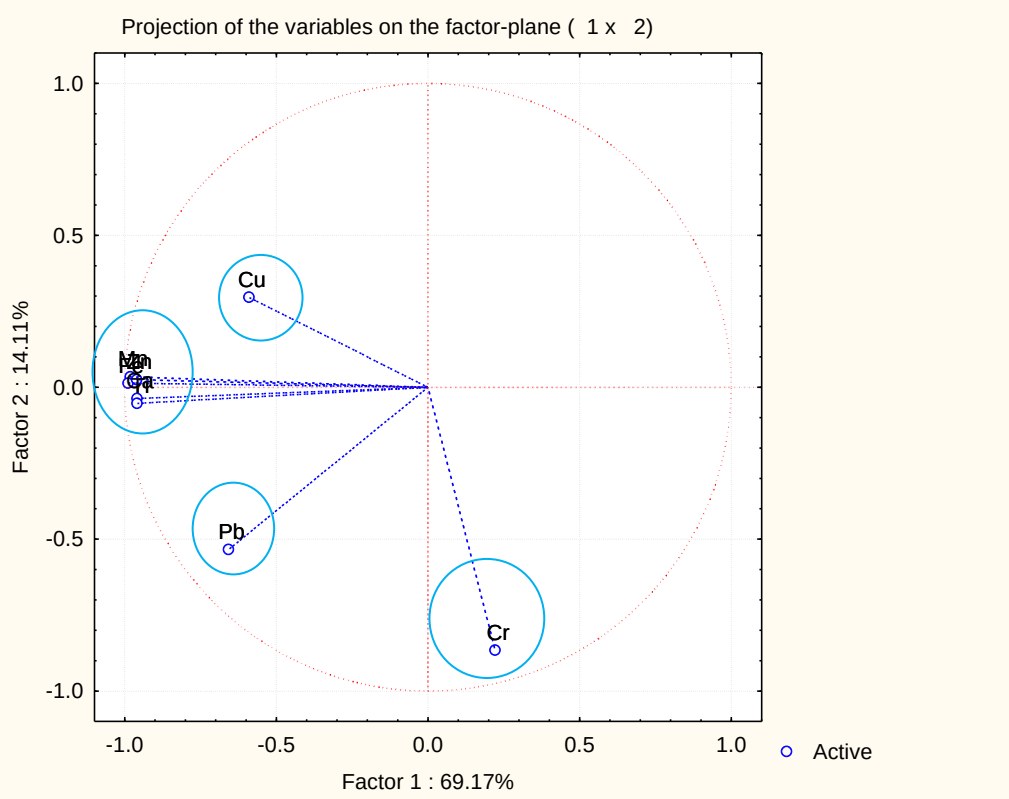


Figure 14: Grouping of elements by PCA analysis.

Table 10: Correlation matrix for elements evaluated at the CBD site.

	Ca	Ti	Cr	Mn	Fe	Cu	Zn	Pb	Cars
Ca	1.000								
Ti	0.939	1.000							
Cr	-0.174	-0.218	1.000						
Mn	0.932	0.917	-0.210	1.000					
Fe	0.967	0.943	-0.206	0.988	1.000				
Cu	0.496	0.401	-0.156	0.609	0.566	1.000			
Zn	0.889	0.939	-0.219	0.949	0.948	0.522	1.000		
Pb	0.598	0.650	0.127	0.585	0.591	0.186	0.569	1.000	
Cars	-0.100	-0.207	0.135	-0.118	-0.233	0.074	-0.145	-0.309	1.00

Table 10 shows the CBD site elemental correlations which were generated using Unscrambler statistics software. The elements Ca, Mn, Fe, Zn and Ti are mainly from mineral dust particles and their high correlations suggested the dominance of dust at the site. This was attributed to a lot of suspended dust during the measurement period which was as a result of road construction activities along Thika super-highway. Cr correlated negatively with all other elements and portrayed a weak positive correlation ($r = 0.1270$) with Pb. This implied a possibility of being emitted from a shared source which was seen as industrial emissions. Cu and Pb correlated positively ($r = 0.1857$) with each other and also with other elements from mineral dust. This pointed out that Pb could be from mineral dust and from motor vehicle resuspended dust and the latter was enriched with Cu. However, the number of vehicles correlated weakly with a few elements i.e. Cr (0.1349), Cu (0.07357), and negatively with all other elements. It can therefore be concluded that Pb is not possibly from motor vehicle but from other sources.

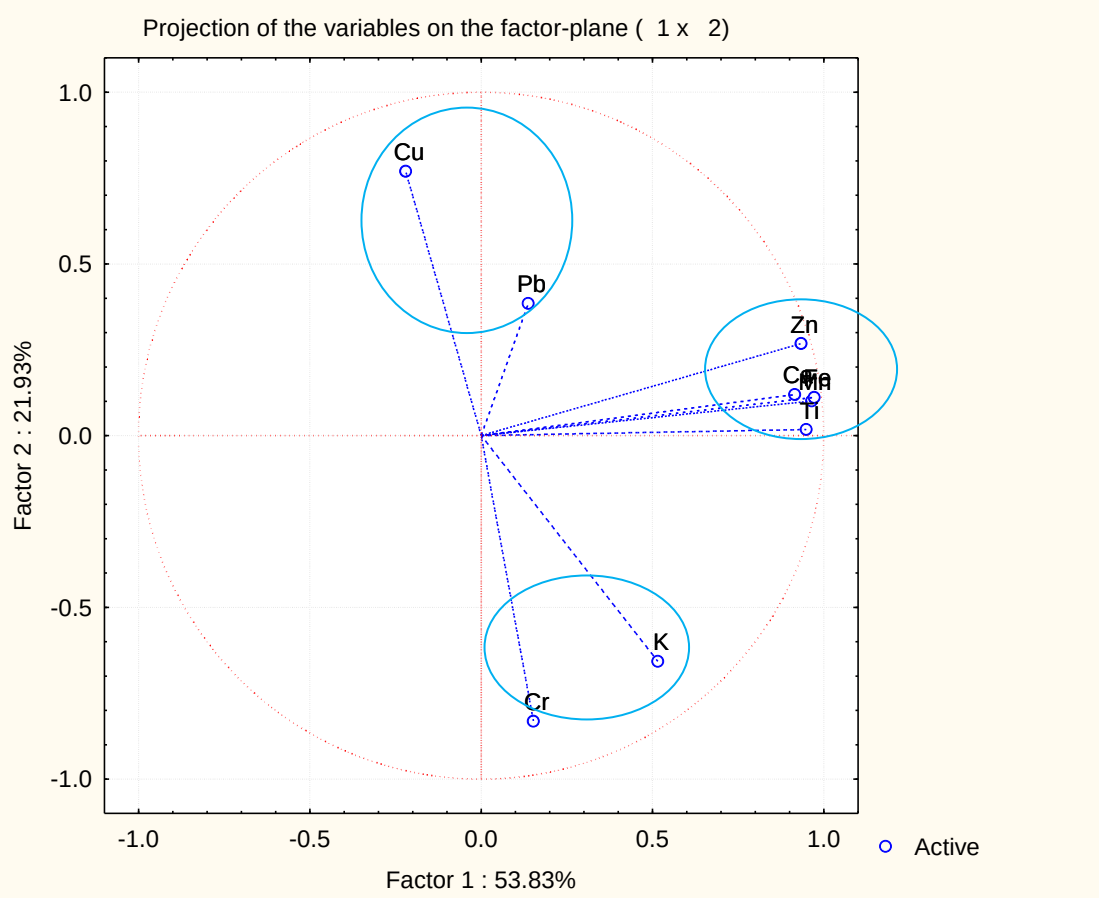


Figure 15: PCA generated factors from the total evaluated elemental concentrations obtained at the Industrial site (Rooftop and Roadside samples).

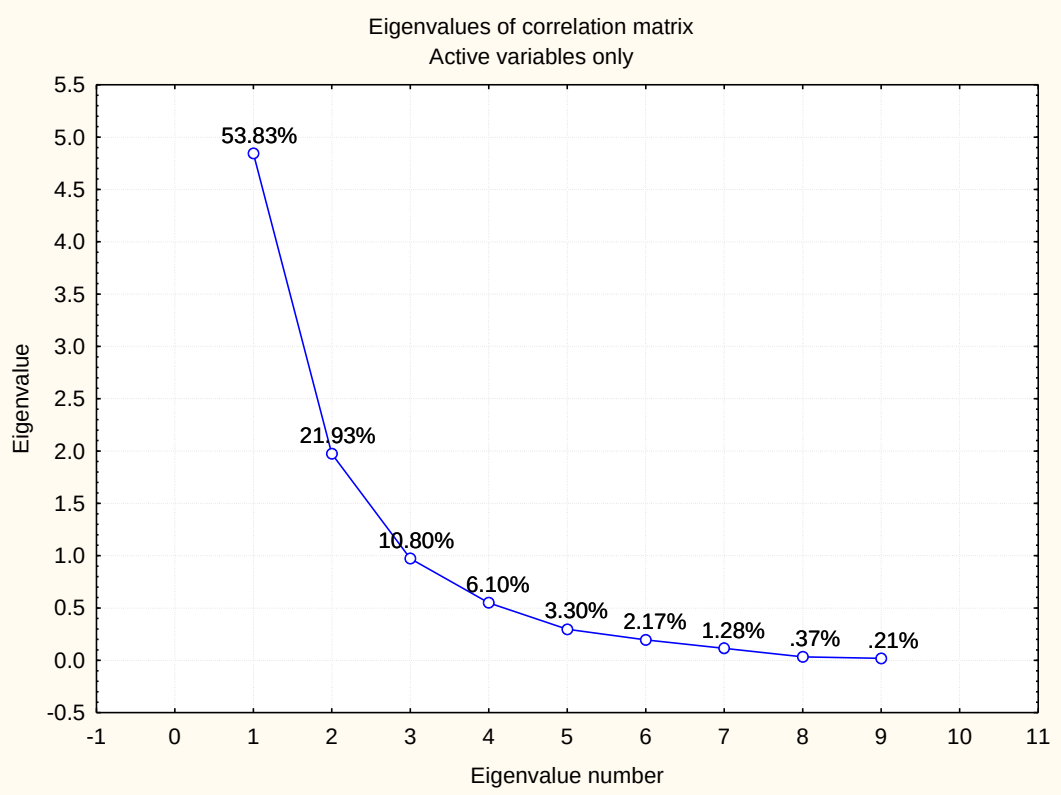


Figure 16: A scree plot for PCA results from Industrial site.

Table 11: Correlation matrix between elements at the industrial site.

	K	Ca	Ti	Cr	Mn	Fe	Cu	Zn	Pb	Cars
K	1.000									
Ca	0.386	1.000								
Ti	0.463	0.818	1.000							
Cr	0.580	0.034	0.144	1.000						
Mn	0.394	0.882	0.873	0.072	1.000					
Fe	0.386	0.874	0.915	0.039	0.971	1.000				
Cu	-0.505	-0.108	-0.169	-0.455	-0.142	-0.155	1.000			
Zn	0.241	0.850	0.917	-0.062	0.928	0.942	0.001	1.000		
Pb	0.075	0.139	0.096	-0.207	0.126	0.114	0.225	0.130	1.000	
Cars	0.203	0.197	0.086	-0.058	0.063	0.014	0.365	0.104	0.541	1.00

At the industrial site similar trend as CBD site was also noted. Table 11 shows high positive correlation between Ca, Ti, Fe, Zn, and Mn which are mineral dust related suggesting that suspended dust is the main source of pollutants at industrial site. Poor status of roads within this area, which is as a result of heavy trucks that use them, is seen as the major source. This therefore puts to risk pedestrians as well as workers in this region. K and Cr correlates positively ($r = 0.5795$) suggesting a common source, possibly, biomass burning or burning of industrial wastes. Cu correlated negatively with all other elements and positively ($r = 0.2253$) with Pb. This implied a shared source which was seen as motor vehicle emissions. This was also supported by the

positive correlation between the number of vehicles with Pb(r = 0.5413) and Cu (r = 0.3649). Pb however had a weak positive correlation with elements from mineral dust suggesting another possible source of Pb as soils.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

High concentrations of $PM_{2.5}$ were near the ground level at industrial site and at the rooftop of the urban site. Concentrations of elements were high in the afternoon samples as compared to morning samples. There was a correlation between elements collected near ground and those collected at the rooftop, ($r = 0.5314$) at the CBD site and ($r = 0.9567$) at the industrial site, implying common sources.

Elements associated to mineral dust were dominant in both sites at rooftop and roadside. There is therefore high exposure to workers in offices, stalls, kiosks and restaurants adjacent to the main roads. Traffic police along these roads, pedestrians and hawkers are also at high risks of exposure. Cumulatively this may pose a serious threat to public health since many are exposed to extremely high levels of these toxic elements.

Mineral dust, industrial emissions, motor vehicle emissions and biomass burning were observed to be the common sources of air pollution in Nairobi. Elements from mineral dust contribute up to about 80 % of all the elements collected in both the urban and industrial sites. The soils influencing urban and industrial air pollution contains high concentrations of iron (red soils) and low concentration of calcium.

On vertical dispersion both mass and elemental concentrations were higher on the ground level by a factor between 2 and 8 than at the rooftop at height of 14 m and 17 m at CBD and industrial site respectively. A case where the factor was less than 1 was

used to implicate external sources of aerosols and strong winds during the sampling period.

There was a correlation between lead and the number of vehicles as well correlation between lead and mineral dust elements suggesting that mineral dust is a possible source of lead since leaded fuel is no longer in use. This poses a risk since lead can find its way to our food chain and eventually to our bodies.

The level of pollution is increasing with increase in anthropogenic activities and at the same time urban population increase poses serious health issues and costs.

5.2 Recommendations

1. More research work on aerosol pollution need to be done within the entire Nairobi area so as to determine the level of pollution. There is need for daily aerosol monitoring stations within the city and its environs as well adhering to our own national guidelines so as to help in reducing the amount of air pollution.

2. There should be formal legislation or policy with which to manage air quality in Kenya and Nairobi specifically. Air quality standards in the country and formal emission limits for stationery or mobile sources need to be effective. Clear lines of authority and strong coordination among them need to be enhanced so as to reduce on urban pollution.

3. There is need to decongest Nairobi city from motor vehicles. There are so many on-road vehicles and most of them are unroadworthy. Effective inspection and maintenance programs can help reduce emissions from older vehicles and ensure that new vehicles remain in good condition.

4. Measurements of other air pollutants i.e. gases (NO_x, O_3, SO_x and CO) should be carried out so as to give complete results of pollution sources for particulate matter and gases within Nairobi area. Similar study should also be extended to other cities, counties and towns as well in the country. More sites within the city need also to be considered i.e. the residential and industrial area.

5. Epidemiological case studies to assess health problems associated with air pollutants among the exposed population in the city should also be carried out. Health data on illnesses such as acute respiratory infections, asthma, cancer,

tuberculosis etc. should be obtained and be correlated with air pollution data to confirm if there are any casual relationships between the diseases and levels of the air pollutants measured.

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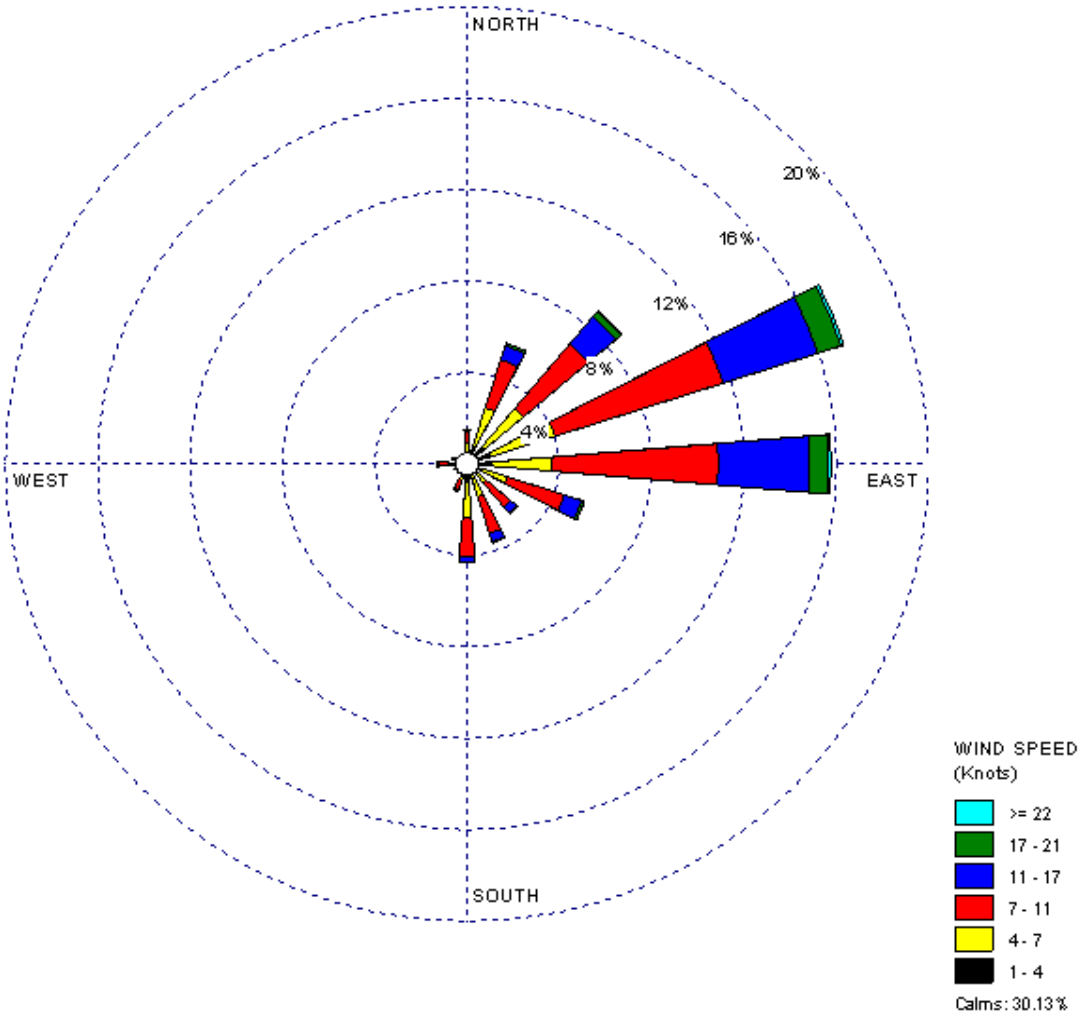
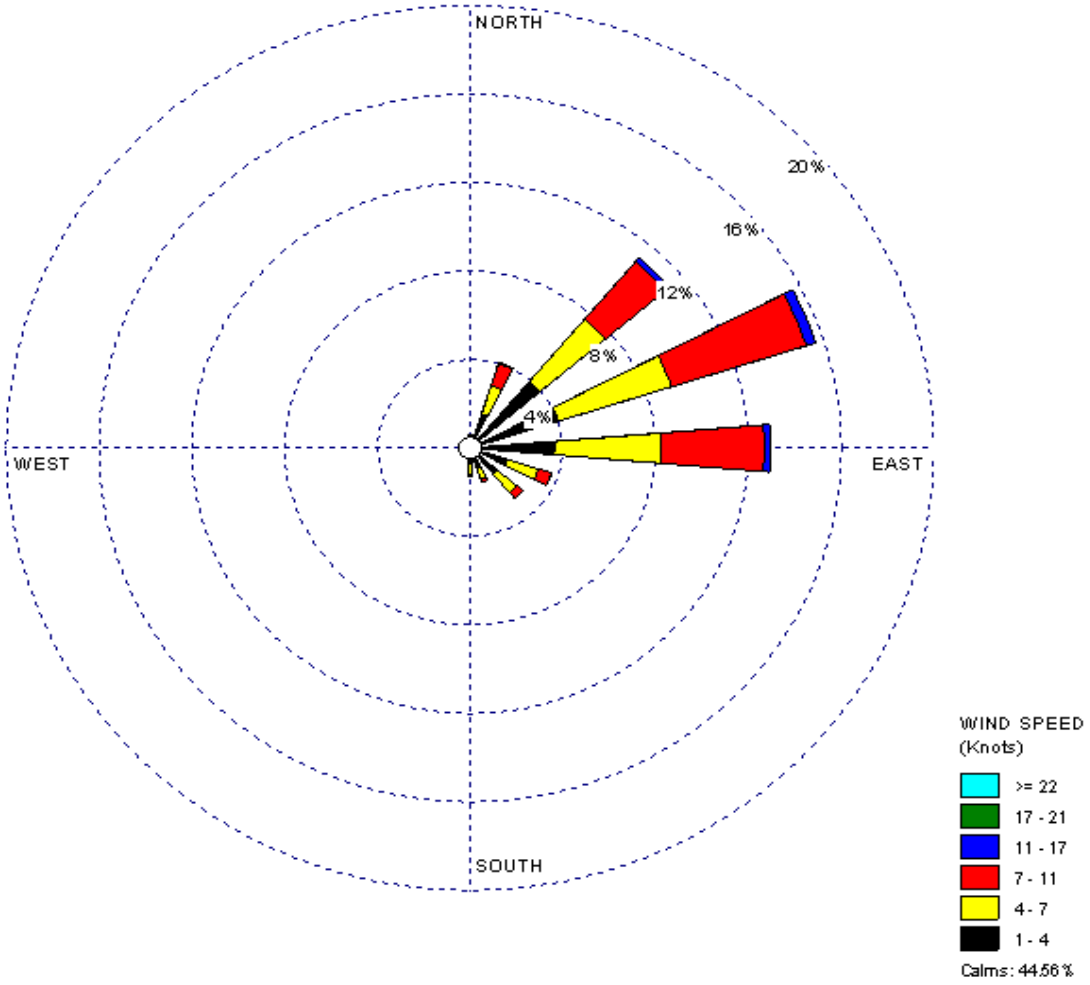
APPENDIX

Figure A1: Wind rose showing the variation of wind speed and direction at Wilson Airport, Nairobi for 15 years from 1st January 1995 to 31st December 2010.



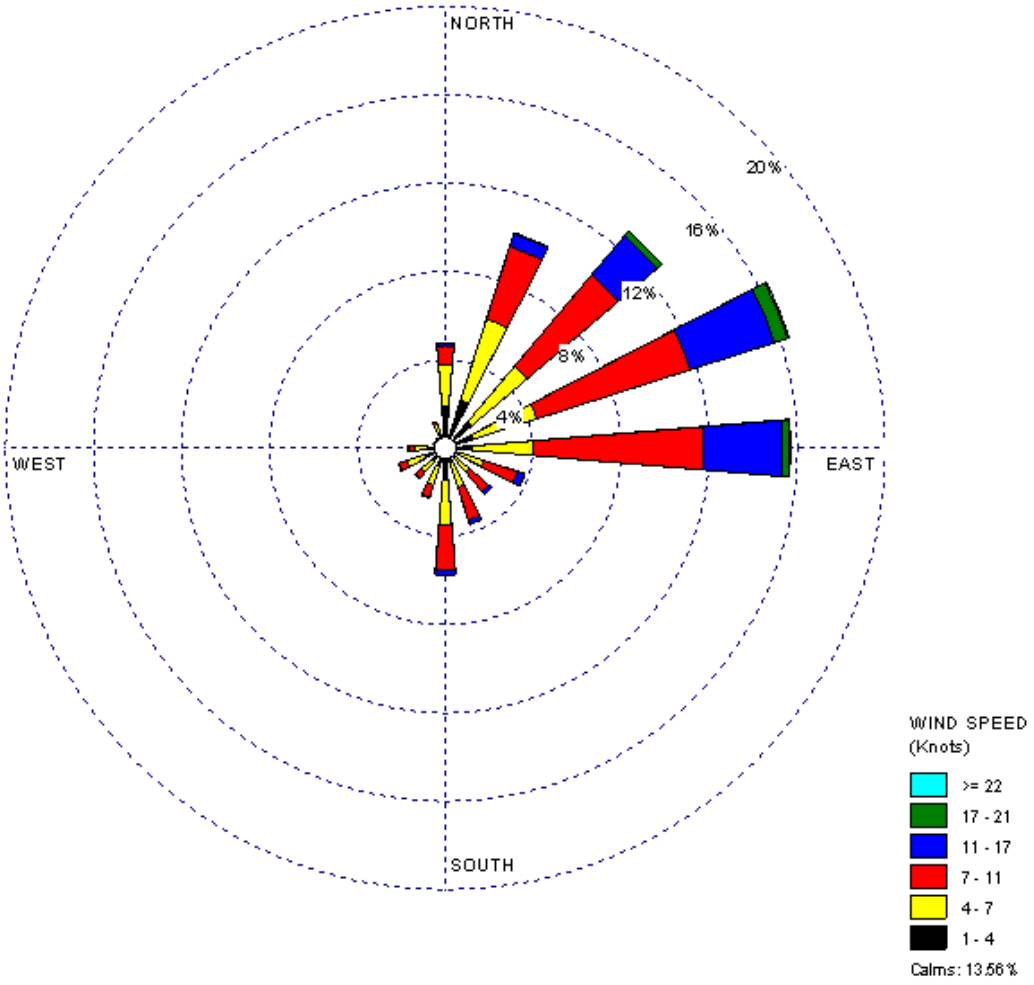
Calm winds were about 30.13% and the average wind speed was 3.14ms^{-1}.

Figure A2: Wind rose showing the variation of wind speed and direction at Dagoretti, Nairobi for 15 years from 1st January 1995 to 31st December 2010.



Calm winds were about 44.68% and the average wind speed was 1.64ms^{-1}

Figure A3: Wind rose showing the variation of wind speed and direction at Jomo Kenyatta Airport, Nairobi for 10 years from 1st January 2001 to 31st December 2010.



Calm winds were about 13.56% and the average wind speed was 3.37ms^{-1}

Figure A4: A scatter plot showing correlation of roadside measurements and rooftop measurements at the CBD site.

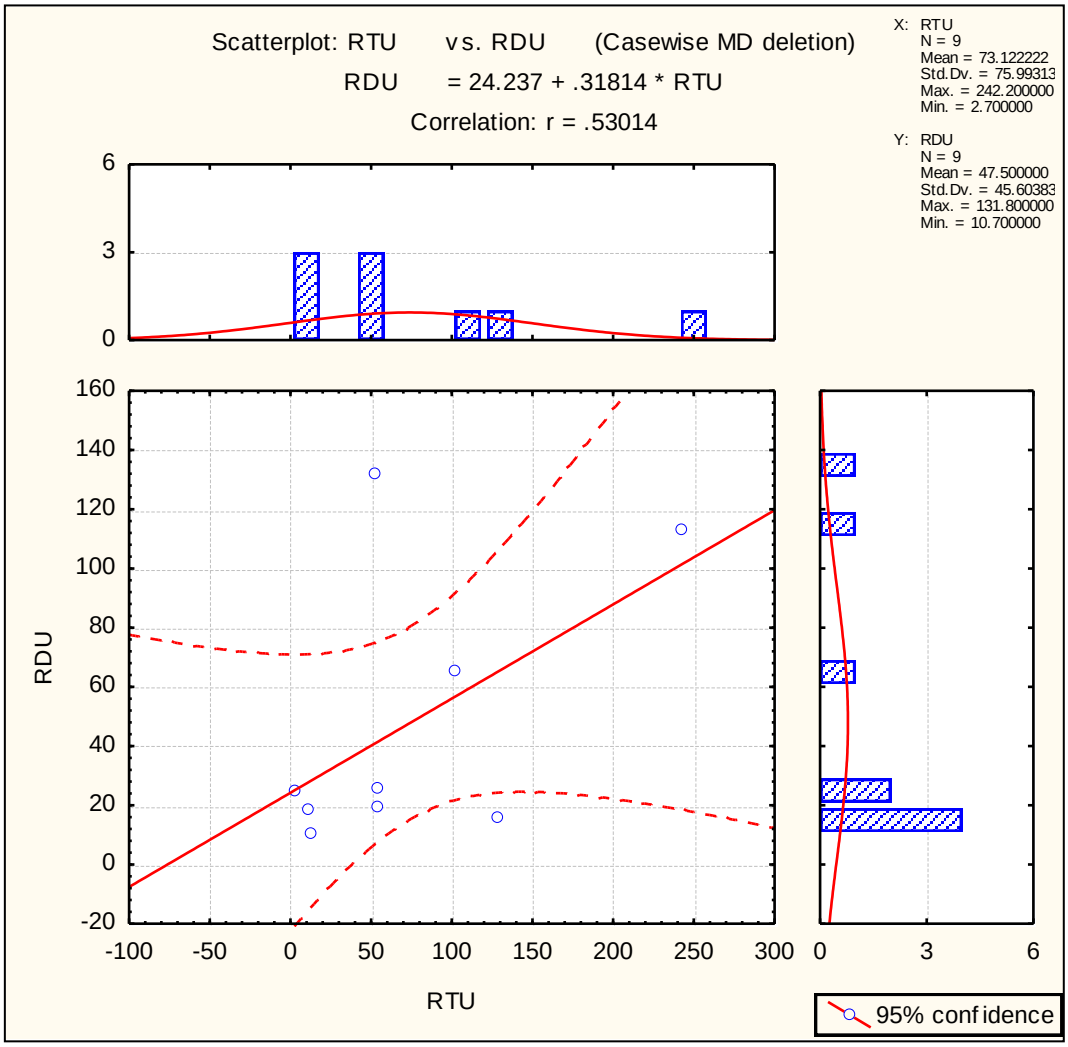


Figure A5: A scatter plot showing correlation of roadside measurements and rooftop measurements at the industrial site.