TEMPORAL AND SPATIAL VARIATIONS OF THE LEVELS OF AMBIENT PARTICULATE MATTER (PM$_{2.5}$ & PM$_{10}$) IN NAIROBI CITY, KENYA

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Temporal and Spatial Variations of the Levels of Ambient Particulate Matter (Pm$_{2.5}$ & Pm$_{10}$) in Nairobi City, Kenya

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DECLARATION

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

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DEDICATION

I dedicate my research to my family and friends. The special feeling of gratitude to my loving husband and our two children, (Agnes and Alex), for encouragement and support. Special thanks go to you for your practical and emotional support as I added the roles of wife and then mother, to the competing demands of business, work, study and personal development. This work is also dedicated to my late dad and mum who have loved me and supported me unconditionally.

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LIST OF ABBREVIATIONS AND ACRONYMS

ICP-OES	Inductive coupled plasma-optical electron spectrometry
ICP-AAS	Inductively coupled plasma-mass spectrometry Atomic Absorption Spectrometry
EC	Elemental carbon
EDRF	Energy Dispersion X-ray Florescence
EMCA	Environmental Management Coordination Act
FDMS	Filter dynamic measuring system
HVS	High volume sampler
IARC	International Agency for Research on Cancer
JICA	Japanese International Cooperation Agency
KEBS	Kenya Bureau of standards
NTSA	National Transport Service Authority
OC	Organic carbon
PM	Particulate matter
RPM	Respirable Particulate Matter
SEM	Scanning electron microscopy
TEOM	Tapered elemental oscillating Micro-balance
UN	United Nations
UNCHS	United Nations Centre for Human Settlements
UNCTED	United Nations Conference on Environment and Development
VOC	Volatile organic compounds
WHO	World Health Organization
XRF	X-ray florescence

ABSTRACT

Air pollution has become a major concern globally as it poses great threats to public health and welfare. In Kenya, studies show that there is increasing threat from poor air quality stemming from rapid urbanization. The factors that contribute to air pollution include transportation, stationary source fuel combustion, industrial processes and solid waste disposal, among others. Particulate matter ($PM_{2.5}$ and PM_{10}) is a major pollutant in cities such Nairobi city. Industrial and vehicular emission are the main sources of particulate matter. This study was conducted in Nairobi city to determine spatial, temporal variation and the particulate matter composition.in the ambient air. Temporal variability was achieved by assessing particulate matter from different location at eight hours' intervals of time (three times) within 24 hrs and different months of the year with different seasons. On the other hand, spatial variability was determined by sampling different locations; residential, controlled and industrial as classified in EMCA Air Quality Regulation 2014. A portable mini-vol was used in sample collection of particulate matter in ambient air. The samples collected were analysed to determine the concentration of heavy metals (i.e., manganese, mercury, lead, arsenic, zinc, cadmium and chromium. The results show that the particulate matter in residential and controlled areas were high during the day. The mean and range values for PM_{10} concentrations in residentials areas were 40.61 ± 18.55 µg/m^3 and 23-86 µg/m^3, respectively, while those for $PM_{2.5}$ were 22.5 ± 7.88 µg/m^3 and 11-41 µg/m^3, respectively. The mean and range values for the PM_{10} concentration in controlled zones were 31.92 ± 23.28 µg/m^3 and 11-45 µg/m^3, respectively, while the $PM_{2.5}$ a ranged between 7.36 to 31 µg/m^3 with a mean value of 19.49 ± 12.59 µg/m^3. The observed range was 11-109 µg/m^3 with average values of 38.77 ± 31.14 µg/m^3 for PM_{10} concentration and 8.36-72 µg/m^3 with a mean of 23.5 ± 16.27 µg/m^3 for $PM_{2.5}$ in the industrial zones. The lead concentration for residential, controlled and industrial area had a mean of 0.066 ± 0.064, 0.336 ± 0.354 and 1.102 ± 0.592 µg/m^3, respectively. These results are useful to planners of urban settlements such as Nairobi City as they provide real and visual perspective of spatial distribution of PM_{10} and $PM_{2.5}$ particulate matter for enhanced safe public health and welfare decision making and planning.

CHAPTER ONE

INTRODUCTION

1.1   Background to the Study

Particulates matter can be defined as minute/tiny particles inform of solid or/and liquids in the air, suspended. Particulate matter can result from natural activities or human related actions. Significant negative and severe effects on both the environment and human can be as result of particulate matter (PM), Zanobetti et al. (2000). From previous research, this has resulted to higher frequency of hospitalization with ailment associated with particulate matter pollutants like coronary artery disease, stroke and other atherosclerotic diseases. The levels of air pollution in sub-Saharan Africa (SSA) have remained high compared to other regions of the world that have witnessed notable improvements.

The deteriorating trend of air quality in SSA countries, has been linked to rapid urbanization, industrialization and the resultant increase in population (Arowosegbe et al., 2021). In Kenya, major sources of particulate matter can be described to be from transportation, stationary fuel combustion, industrial processes, agriculture and waste (Brook et al., 2004). However, industrialisation and motorised transport are main sources of air pollution (Qu, 2013; Tian, 2013; Zhou et al., 2013). More concerns and attentions have been directed towards organic composition of the partculate matter with lesser attention to inorganic matter hence less studies have done on the same. From the human and environmental health point of view inorganic component of the partculate matter is very important aspect. According to Baulig et al. (2004), copper (and possibly iron) are known to be the major contributors to the oxidative stress caused by minute particules in the air (Limbach et al., 2005).

The larger Nairobi municipal extent area, with the current population of 4,397,073, from 2019 censuses report and projected to be more than double by 2030, while the population of the entire metropolitant area is 9,354,580 (Ministry of Nairobi Metropolitan Development, 2008). The city has almost its full capacity in terms of constructions hence can't accommondate any incoming population which has resulted to to growth around the area in the city to support the population that

depends on the city.This growth is as result of rural-urban migration and rapid economic growth.

The population and ecomic growth togethet with poor public transport investiment in the city and inadequate policies has resulted to poor roads and road unworthy motor vehicles which has led to raise of the air pollution which is also accelerated by congestion on the roads (Ministry of Transport and Communications, 2004). Spatially, the development is taking the shape of urban sprawl which, along with growing urban air pollution aggravates some other health riskswhich are directly or indirectly related to particlate air pollution, such as diabetes (Frumkin et al., 2004).

Due to these poor road infrastracture and uncontrolled development due to pooor policies traffic congestion has become the norm where commercial and industrial activities are concentrated especially in the central area of the city. In an attempt to lessen the congestion, extensive road infrastructure projects have commenced within Nairobi metropolitant and more are being planned. Attentions for long-standing enhancements in air quality and health must be taken into account as these projects are planned and implemented. A previous study by the Japanese International Cooperation Agency (JICA) (2006) determined the concentration of partculate matter within the city which provided baseline information on the level pf partculate pollution in the city.

In Kenya, just like other developing countries, air pollution is prevalent in the urban areas where most industrial development is pronounced. These activities are mainly concentrated in most of world cities and other urban area, which today are expected to be holding nearly half of the world's population (UNCHS, 1996). The cities and urban areas, therefore, contain the bulk of people that are most vulnerable to the immediate effects of air pollution. This fact received international recognition when in 1992, the United Nations conference on environment and development (UNCTED) made specific recommendations in its agenda 12 (UN, 1992) with regards to addressing air pollution in cities. The EMCA 2014 Air Quality standard of daily limit of 75 µg/m3 and annual limit of 40µg/m3 (PM_{10}) are less stringent than the World's Health Organization's limit of 45µg/m^3 and annual limit of 15µg/m^3.

The levels of PM$_{10}$ concentration can vary in space and time due to distinct meteorological conditions and anthropogenic sources, such as vehicular, domestic and industrial emissions.

There are significant health effects of road transport ways emissions, specifically for highly exposed persons who resides near pathways and/or for predisposed subgroups that are particularly prone to health effects, such as young ones and the elderly (Pope et al., 2002; Jansen et al., 2005; Ibald-Mulli, 2004). However, fine particular matter is of specific importance,this is because of its size and capability to penetrate in the human body through the lungs aveoli hence causing health problem to human. This is triggered urban development related activities which has resulted to adverse health outcomes for both short-term and long-term average ambient PM2.5 concentrations exposure. High increament in premature and infant mortality rate associed with air pollution causes have been documented. (Woodruff et al., 2006; Dockery et al., 1993; Schwartz, 1994; Samet et al., 2000; Pope et al., 2002. Due to environmental trepidations, the manufacturing industries are required to install and operate dust collection system which are suitable and efficient to control toxic/harmful particulate emissions. These dust collection systems which are recommended and efficient include inertial accumulators (cyclonic separators), fabric filter collectors (baghouses), wet scrubbers, and electrostatic precipitators.

Different sources have been found to contribute to PM$_{10}$ and PM$_{2.5}$ concentration in the air including meteorological conditions. High volume samplers and a quartz fibre filter are used to collect large particles, e.g., PM$_{10}$ particles. The particle size distribution and their chemical constituents are not considered in the set air quality standards although these properties are significant regarding control strategies and of the health risks associated with PM$_{10}$. The fine particles such as PM$_{2.5}$ are brought by into the ambient air through various sources and processes. The main one is the primary source which involves direct emission of particulate matter from industrial processes, constructions, mining and other human activities while the other source is secondary sources which is as result of gaseous chemical reactions in the in the atmosphere. The human lungs structure is made of pipe like air pathways which

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forms minute structure where air is drown to the blood system. At this point only the fine particles, $PM_{2.5}$ are carried along to the human body.

The composition of these tiny particles will dictate the possible health effect through bioaccumulation of those toxic components of the inhaled particles. Apart from the health impacts associated, $PM_{2.5}$ has a tendency to persist in the air for extended periods resulting in reduced visibility. In Kenya there is Environmental Management and Coordination Act 2014 for Air Quality Standards but not sufficient for the current situation. Assessment and classification of particles are important in assessing their outcome on both environment and human health. Particulate matter composition of various chemical substances and particle size range distribution resulting from physical and chemical processes that make $PM_{2.5}$ and PM_{10} difficult to model. Most particles are emitted directly from various industries into the atmosphere while others are formed through different reactions in the air.

Scanty information on levels in ambient air pollution for South Saharan Africa is still a big problem. Air pollution data for most cities is obtained from small discrete monitoring programs rather than established networks, leading to uncertainty about particulate levels (Robert et al., 2016). Projections estimate that Africa's population will double by 2050 from 1·2 billion. More than 80% of that increase will occur in cities, leading to increased traffic and hence air pollution. In an east African study, the change in pollution levels from 1974 to 2018 is illustrated. Without quality historic air pollution data, researchers used visibility to estimate the pollution increase in Addis Ababa (Ethiopia), Nairobi (Kenya), and Kampala (Uganda).

1.2   Statement of the Problem

Air pollution is an undesirable impact of vehicular traffic, and it is especially important in the urban areas. Nairobi being a fast growing city with very high population and many upcoming industries air pollution is expected to be also an emerging issue. Hence there is great need to understand the status of air pollution, in this case the particulate matter (PM_{10} and $PM_{2.5}$). Kenya has recently adapted air quality regulation (2014).

By understanding the status of the particulate matter in Nairobi will explain the increasing health issues associated with air pollution. The new air quality regulation has got some gaps which require improvement hence this research provides data which can be used for improvement of the EMCA air quality regulation 2014 in the country. Data on air quality is crucial to guide policy making and to address the challenges caused by poor air quality.

1.3 Objectives

1.3.1 Main Objective

The main objective of this study is to assess the temporal, spatial and heavy metal composition of the PM_{10} and $PM_{2.5}$ of ambient air in Nairobi County.

1.3.2 Specific Objectives

  i.   To determine the PM_{10} and $PM_{2.5}$ spatial distribution and concentration in the ambient air within Nairobi city.

  ii. To determine the correlation of weather conditions and PM_{10} and $PM_{2.5}$ concentrations in ambient air in Nairobi city.

  iii. To characterize the heavy metals concentration in PM_{10} particulate matter in ambient air within Nairobi City.

1.4 Hypothesis

The particulate air pollutants concentration in Nairobi city are not significantly higher than the permissible levels set by EMCA (Air Quality Regulation 2014), WHO and US-EPA.

1.5 Justification

Generally, all type of environmental degradation like water pollution, noise pollution, in Kenya has been given a lot of attention. However, regular and coordinated monitoring of the ever changing nature of the city and also sharing of the available data officially to the public it's lacking This research provides data that will be used in improving or developing air quality standards, land use and transportation policies. The data can also be used to improve and support in the existing air quality

regulation 2014, and air quality standards respectively in the Kenya especially the fast growing urban cities. In addition, the study results can be used to generate an air pollution level map for Nairobi city. From the new air quality regulations, it will be convenient to determine or to measure its effectiveness and sufficiency from the findings. Finally, the findings of the research will enable the determination of concentration and composition of the ambient air, and one will be able to prospect the impacts on the environment and human health.

1.6   Scope of Study and Limitations

1.6.1 Scope of Study

The main focus of this study was to determine the spatial distribution, concentration and the heavy metal composition of the particulate matter, in the ambient air, Nairobi County under different weather conditions. The sampling sites were determined and categorized into three; Industrial, Residential and Controlled areas in reference to the EMCA Air quality regulations 2014. Nine (9) sampling sites were established from the three categories. Sampling was carried out during the day and night and were analysed for heavy metals. The meteorological data (Humidity, Temperature, wind speed and direction) was collected to determine the effects of weather on the PM_{10} and $PM_{2.5}$ concentrations at different time of the day (Day time and night). This study will inform the existing regulation (EMCA Air Quality Regulation 2014) and the gaps in the regulation.

1.6.2 Limitations

Inadequate reference material on the study area and limited instrumentation especially on data collection was the major challenge during the study. The EPA and EMCA Air Quality Regulation 2014 does not provide permissible levels for synergism conditions, hence the results and the standard cannot be compared for future improvement or recommendation. Possible compounds and health impacts on the environment and human was not carried out. On the other hand, EPA and EMCA Air Quality Regulation 2014 provide the permissible levels of very few metals hence difficult to know what level of certain concentrations has health effects to the

environment. The other challenge was insecurity of the equipment on the site during data collection especially at night and during the raining periods.

CHAPTER TWO
LITERATURE REVIEW

2.1 Background Studies in Nairobi

Nairobi, Kenya is one of the fast growing cities in Africa, located in the trophical in thesub-Saharen Africa. Projections estimate that Africa's population will double by 2050 from 1·2 billion. More than 80% of that increase will occur in cities, leading to increased traffic and hence air pollution. In an east African study, the change in pollution levels from 1974 to 2018 is illustrated. Without quality historic air pollution data, researchers used visibility to estimate the pollution increase in Addis Ababa (Ethiopia), Nairobi (Kenya), and Kampala (Uganda).The daytime Nairobi population is never well documented its estimated to be 4.2 million as in 2009 but during 2019 censuses it was not determined. In India, industrial and vehicular emissions, dust, emissions from biomass burning, open waste burning, household and power sector are major sources of high $PM_{2.5}$ concentrations (Guo et al., 2017; Conibear et al., 2018; Venkataraman et al., 2018).

The population of the city dwellers a is estimated to be 3.2 million in 2009 and 4.3 million in 2019 censuses, with a growth rate of approximately 4% annually (Kenya National Bureau of Statistics (KNBS), 2008). The resident population growth rate is about 3.9% annual from the year 1989 with a population of 1.3 million (East African Statistical Department, 1997) representing a 3.9% annual growth. Correspondingly, the overall proportion of urban dwellers in Kenya has increased from 8% in the 1980s due to rural-urban migration to over 34% in 2003 and is expected to reach 50% by 2020 (KNBS, 2008).

Currently, traffic congestion in Nairobi and second hand vehicles has increased with the estimate number of vehicles in Nairobi by 2012 being 330 000 (approximately 30,000 PSV and 300,000 private cars) which has raised up to 700, 000 vehicles by 2014. The implication of this growth means increased air pollution. The main sources of particulate pollutant have been identified in previous studies to be from vehicular and industrial sources in the city. The population growth in Nairobi has continuously contributed to adverse effects on the transport system and traffic

congestion. The population pressure has been one of the key contributing factors to transport challenges among others which include; increased vehicle ownership, lack of proper traffic control and management, lack of transport planning and inefficient spatial distribution of land use. The fact is that air pollution has not been given any attention despite being the single environmental world disaster due to lack of data hence no policies governing the air quality in Kenya (Zhu and Kung, 2014).

For a long time, there has never been any legislative or administrative framework within which air quality management could be formulated and implemented in Kenya, yet the few relevant studies that have been done show that air pollution continuous adversely affect human health and the environment. For example, occupational asthma silicosis and asbestosis have been reported from industrial workers in battery manufacturing, cement production and mineral processing in Nairobi, Athi River, Thika and Mombasa towns (Kahenya, 1996). The situation can only get worse with the increasing population, growing industrial area, deforestation on the city fringes, increased construction works and increased vehicular traffic.

The sources of dust in the selected zone are; emissions from vehicles, industrial activities, movement of vehicle on unpaved road, wind action on unpaved roads (frequent and prolonged wind events), pedestrians on informal estates and children frequently playing on unpaved roads/grounds is another source of dust. There is open burning of tyres in industrial area at night, and this also affects levels of particulate in air.

Particulate matter PM_{10} country level in Kenya was last measured at 29.63 $\mu g/m^3$ (World Bank, 2009). Particulate matter concentrations refer to fine suspended particulates less than 10μm in diameter (PM_{10}) that are capable of penetrating deep into the respiratory tract and causing significant health damage. Data for countries and aggregates for regions and income groups are urban-population weighted PM_{10} levels in residential areas of cities with more than 4.2 million residents. The estimates represent the average annual exposure level of the average urban resident to outdoor particulate matter. The state of a country's technology and pollution controls is an important determinant of particulate matter concentrations.

2.2   Air Pollution

Air pollution has been identified as one of the major environmental risks to health. Reducing the level of air pollution would lead to reduced burden of diseases like stroke, heart and lung related disease, respiratory diseases, including asthma (Ibald-Mulli et al, 2014). There are 3.5 million premature deaths that occurred in the year 2012 marking the ever highest pre-mature deaths in the world was attributed to ambient air pollution. In other terms these means 160 buses crushing daily with a capacity of 60 passengers with no survivors in the whole year (365 days). The death associated with air pollution in 2012 was distributed as follows, <5 years' children 3% (127,000), >25 years' women 44% (163,2000) and >25 years' men 53% (197,3000) as reported by Burnett et al. (2014). Reducing untreated emissions from industries, motor vehicle, agricultural waste incineration, forest fires and certain agro-forestry activities (e.g., charcoal production) would reduce key rural, peri-urban and urban air pollution sources in developing regions. It would also reduce the concentration of CO_2 and short-lived climate pollutants such as black carbon particles and methane, thus contributing to the near- and long-term mitigation of climate change.

From previous reports done by WHO International Agency for Research on Cancer (IARC) in 2013 established that many incidents of cancer are associated with with the current outdoor air pollution, whereby partculate matter is the main contributor, especially on lung cancer. Similarily cancer of the urinary tract/bladder rise has been association with outdoor air pollution. Air pollution is not considered a serious environmental problem due to adequate air quality, hence, policy makers are not informed on the quality of air or the magnitude of the problem (Bell et al., 2007). The risk factor data for metropolitan areas throughout the United States and combined with vital status for approximately 500,000 adults were linked with air pollution data and cause of death data through December 31, 1998. (C. Arden, III et al. 1999).

2.3 Previous PM measurements in Nairobi

In general, long-term air-quality monitoring in sub-Saharan Africa (SSA) is rare. Correspondingly, there are only limited PM data sets for East African urban areas; where data does exist, estimated concentrations for $PM_{2.5}$ concentrations are approximately 100 µg/m3 compared to < 20 µg/m3 in most European and North American cities (Brauer et al., 2012). This indicates that urban PM air pollution in East Africa could be a significant health concern. In Nairobi, there have been numerous short-term measurements of PM over the last decade (Brauer et al., 2012; Kinney et al., 2011; Ngo et al., 2015; Egondi et al., 2016; Gaita et al., 2016) with only one long-term continuous measurement (Gaita et al., 2014). To date, most measurements have used gravimetric measurement methodologies to record PM mass concentration in the $PM_{2.5}$ and PM_{10} size fractions. Most measurements indicate that PM concentrations in Nairobi regularly exceed the WHO guidelines.

2.4 Air Quality Regulation in Kenya

More than half of African countries, have no air quality management policies. Main reasons for this is inability which includes lack of expertise to formulate air pollution management policies and regulations; low budget priority given to air pollution when compared with other environmental problems; inadequate political will and inappropriate legislative and administrative frameworks in which responsibility for air quality is divided between a number of government ministries and the local administrations, thus complicating policy making.
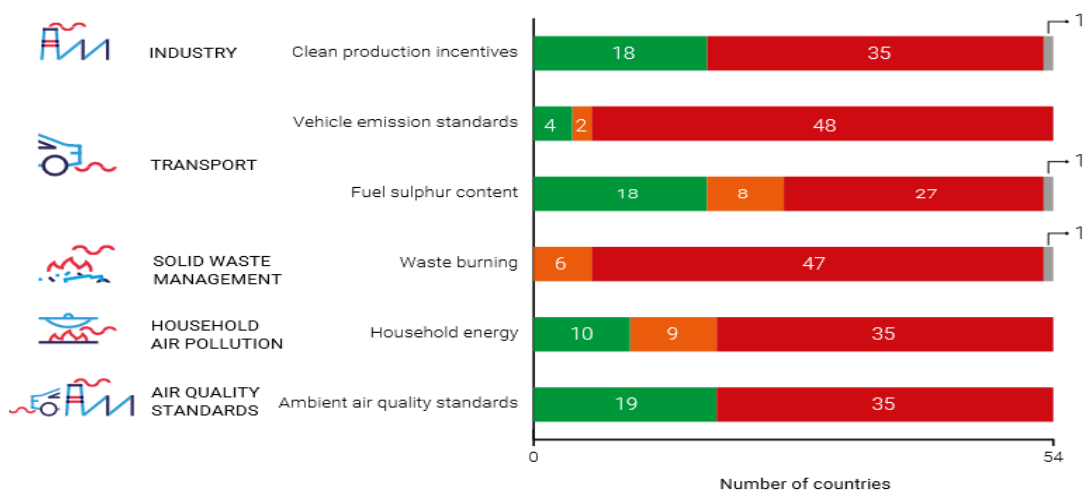
Figure 2.1: Africa progress towards adoption of key actions that can significantly improve air quality in relation to the sources of air pollution. (Source: UNEP Survey data 2020)
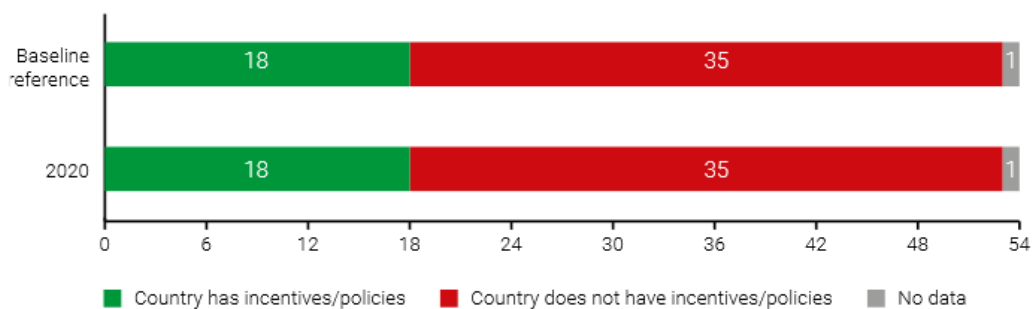
Figure 2.2: Countries with incentives or policies promoting cleaner production, energy efficiency and pollution abatement for industries. (Source: UNEP Survey data 2020)

Due to the transnational nature of air pollution there are many international legislation policies on pollution control; these include the Kyoto and Montreal protocols. In Kenya, there are many pollution control measures, but the widest spread is the use legislation with some acts; The Physical Planning Act 1956, Environmental Management Coordination Act 2014 by National Environmental Management Authority. Other stakeholders in the regulations have come up with many environmental laws that intended to contain the situation on air pollution. The new law has been developed recently that addresses motor vehicle pollution by checking the age and the level of combustion of the vehicle.

The major reason for linadequate air quality management plan in Kenya is the lack of data on air pollution, which often gives the illusion that this is not a serious problem. This is not the reality and only contributes to the cover up of a an emerging vital public health problem, considering that the big population aret urban dwellers. In Kenya, there has never been any legislative or administrative framework for a long time within which air quality management policies and regulation could be formulated and implemented. Yet the few relevant studies that have been done show that air pollution continues to adversely affect human health and the environment.

Environmental management Co-ordination Act Air Quality Regulation 2014 has clearly outlined the permissible levels of air pollutant for the industrial, residential and other area and controlled areas in the ambient air (Table 2.1), EMCA (Air Quality Regulation, 2014).

Table 2.1: Ambient air quality tolerance limits in EMCA 2014

	Pollutant	Time-weighted Mean	Industrial Zones	Residential, rural and other Zones	Controlled Zones***
1	Respirable particulate matter (<10m) (RPM)	yearly mean *	70 g/m^3	50 g/m^3	50 g/m^3
		24 hours**	150 g/Nm^3	100 g/Nm^3	75 g/Nm^3
2	$PM_{2.5}$	yearly mean	35 g/m^3		
		24 hours	75 g/m^3		
3	Lead (Pb)	yearly mean *	1.0 g/Nm^3	0.75 g/Nm^3	0.50 g/m^3
		24 hours**	5 g/m^3	1.00 g/m^3	0.75 g/m^3
		Month average		2.5	

Note; μg- microgram, m^3 – cubic metre, * yearly Arithmetic mean of least 104 recorded in a year taken two times in a week for 24 hourly at constant interval, ** 24 hourly/8 hourly values should be achieved at 98% of the time in a year. However, 2% of the time, it may surpass but not on two sequential days, * the 24-hour limit may not be surpassed more than thrice in one year; ** 24-hour bound may not be surpassed more than thrice in one year micrograms/m3, *** Not to be surpassed more than once per year mean concentration. Whenever and wherever two sequential values surpass the bound specified above for the particular class, it would be considered suitable reason to institute regular/continuous assessment and further research.

The Environment Management Authority and Coordination Act (EMCA), has issued

air quality standards (2014) for public exposure to safe levels of particulate matter suspended in the air. The focus of these standards is the protection of public health and welfare. Particles can range in size from large specks of soot to fine grains of dust with diameters about one-tenth the diameter of a strand of human hair. Fine particles ($PM_{2.5}$) result from fuel combustion in motor vehicles, power generation units, and industrial facilities, as well as from residential fireplaces and wood stoves. Coarse particles (PM_{10}) in general are generated and released from crustal sources, such as dust produced by vehicles travelling on unpaved pathways, material processing, crushing and grinding operations, including natural windblown dust from river gravel bars or other exposed areas.

The EMCA air quality standards focus on "inhalable" size particulates, which are both fine and coarse. These materials can accumulate in the respiratory system and are associated with numerous health-related impacts. Predisposed individuals to coarse partcles (dust) are prone to high occurances of respiratory diseses like asthma and any other associated ailment. The $PM_{2.5}$ has the capability to penetrate Fine particles are more c in our body systems through inhaling polluted air. The individuals exposed to these fine particles have exibited high hospital visits with respiratory complication or related health problem like lung and heart diseases which has led to emergency visits and more hospital admission. This has also increased mortality rate. Sensitive categories of human that seem to be at greatest risk of such effects consist of the aged, individuals affected by cardiopulmonary diseases such as asthma, and children. In addition to health problems, particulate matter is a major cause of reduced visibility in some parts of the country.

To maintain a healthy breathing environment, the EMCA Air Quality Regulations (2014) for $PM_{2.5}$ and PM_{10} are set as 75μg/m^3 and 150 μg/m^3 for a 24-hour average, (one microgram is one-millionth of a gramme) of particulate matter per cubic meter of air, respectively. If air monitoring results show that the concentration of PM_{10} is greater than this amount, EMCA may demand that action is taken to reduce airborne particulate to protect the health of residents.

The amount of particulate matter (PM_{10} and $PM_{2.5}$) concentrations in Nairobi City was measured to define the levels and heavy metal concentrations. This study intended to define the extent of airborne coarse inhalable particulate matter (PM_{10}) and fine particulate matter ($PM_{2.5}$) and heavy metals (cadmium, chromium, manganese, arsenic, mercury and lead). The PM_{10} (reparable particulate matter) samples were subjected to heavy metals analysis to determine their concentration and composition in the ambient air. The selected metals are based on possible emission from vehicles, household and industrial activities.

2.5 Effects of Particulate Air Pollutants on Public Health and Welfare

Particulate matters come from various sources including windblown dust and grinding operations. $PM_{2.5}$ often comes from fuel combustion, power plants, and diesel buses and trucks. Fine particles are so small that they are of health concern because they can easily reach the deepest recesses of the lungs. These fine particles are linked to a series of significant health complications, such as, increased premature mortality, respiratory-interrelated hospital admissions and high frequencies of emergency room visits, intensified asthma, severe respiratory symptoms, including aggravated coughing and difficult or painful breathing, chronic bronchitis, decreased lung function that can be experienced as shortness of breath and work and school absences (Zanobetti et. al., 2000).

The major route by which particles enter the body is through the respiratory tract. Relatively large aprticles are likely to get retained in the nasal cavity and in the pharynx while the small particles are likely to reach the lungs and to be retained by them. The respiratory system may get damaged directly by the particulate material deposited on the lungs or the particles enters the blood system or lymp system through the lungs.The soluable component of the particulaate matter may be transported to the body organs some distance from the lungs and have detrimental effect on the organs. A very strong positive correlation exist between the daily mortality rate and acute episodes of air pollution. Particle that a over 5.0μ in diameter are stpped and deposited mainly at the nose and the throat while the particles that penetrates to the lungs do not go beyond the air duct or brochi and even

these are soon removed by ciliary action.Particulate matter which enters and remains in the lungs can exert a toxic effect in different ways.

Fine particles can remain suspended in the air and move extensive distances that in a few days will affect visibility on the higher altitudes. Some particles are big and dark enough to be seen as smoke depending on the source of the particle. Twenty (20) percent of the problem on dirtiest days in the atmosphere (higher heights) is attributed to smog. Airborne particles can also cause soiling and damage to materials. The intensity of effects of particulate matter on the environment, human and material mainly depends on its chemical composition (source dependent), and the size of the particle dictates the intensity of toxicity. The fine particles that are linked to serious health effects are also a major cause of visibility impairment (Bell et al., 2007). The need for studying air pollution becomes apparent when it is recognised that in 1952, 4000 people in London died from air pollution, but no single pollutant could be cited as the lethal agent. Table 2.2 shows the USEPA air quality standards for both PM_{10} and $PM_{2.5}$

Table 2.2: USEPA air quality standards

Pollutant	Type	Standard	Averaging time
PM_{10}	Primary and secondary	150 μg/m³	24-hour
$PM_{2.5}$	Primary and secondary	35 μg/m³	24-hour
$PM_{2.5}$	Primary and secondary	15 μg/m³	Annual

2.6   Research Gap

The study of particulate matter generally in Africa is great challenge because of the following; there is no routine particulate matter monitoring hence very limited data for reference; there is also limited instrumentation for particulate matter monitoring hence making the study expensive. The sources of the PM_{10} and $PM_{2.5}$ not adequately documented, the particulate matter pollution issues have been given attention in the recent past in Kenya when the Environmental Management Coordination Act 2014 (Air Quality Regulation) it came into effect though with limited knowledge on

monitoring and limited monitoring equipment. The toxicity levels of the inhalable particulate matter not well documented hence not able to compare the results with the toxicity level. The data generated from the study will contribute to the data pool which can be used by the policy makers in strengthening the policies and developing new strategies.

2.7 Conceptual Framework

Currently there is raise of raise of air pollution related diseases globally. In Africa the level and impact of air pollution related diseases is not fully documented. In carrying this research there was need to come up with the main divers. The determination of the PM_{10} and $PM_{2.5}$ concentration setup of the objectives it's the most crucial first step. Objective setup will guide in the development of the hypothesis. The hypothesis was also guided by the previous studies done within the same study area and the current Environmental Management Coordination Act (2014) Air Quality Regulations. The study area in these research was guided by the EMCA 2014 (Air Quality Regulation); The Regulation provides three main categories of areas with different standards, which includes Residential, Industrial and controlled areas. Identification of the sampling sites according to the three categories provided by the Act and instrument setup was the next step for PM_{10} and $PM_{2.5}$ data collection. The weather data was downloaded from the area metrological weather stations and download from National Oceanic Atmospheric Administration (NOAA) weather data and from the meteorological department of Kenya. The different sampling sites (residential, Industrial and Controlled Areas) at different times of the day gave spatial and temporal PM_{10} and $PM_{2.5}$ concentrations. The filter (both PM_{10} and $PM_{2.5}$) with the particulate matter were transported to laboratories for weighing to determine the particulate matter mass and analysis for heavy metal concentration. The next step was to analyse the data and present the results.

CHAPTER THREE
MATERIALS AND METHODS

3.1   Study design

The study was done within Nairobi City County in three categorized areas; Industrial, residential and controlled areas. The samples collected and analysed in laboratories for concentration determination (Gravimetric method) from nine sampling points. Spatial and temporal analysis though QGIS 3.82 to determine the geographical distribution within the county in relation to different times of the day and month. The description focus on achieving the main objective of the study.

3.2   Study Area

The study area is characterised by commercial, industrial and residential area with both paved and unpaved walkways. Nairobi is the capital city of Kenya with erratic and dynamic population. Within the commercial zone there some light industries merchants, move in and transiting population. The population in these commercial zones are not well documented but are very unpredictable. The population has grown from a population of 3.2million to more than 4.7 million, i.e., from 2009 to 2019 census within an area of 684 km^2 (KNBS, 2008). There are no clear boundaries of these three zones, hence you find residential areas (maybe not classified / designated as residential zones) in the industrial zone and vice versa.   Table 3.1 show the sampling sites as categorised in EMCA Air Quality Regulation 2014.

Table 3.1: Sampling sites

Sampling site	EMCA Category	GPS location	Height of installation (M)
Moi avenue primary school	Commercial	$1^o16'48.91''$S; $36^o49'12.99''$E	2.5
Kayole	Residential	$1^o16'36.79''$S; $36^o54'44.08''$E	4
Embakasi	Residential	$1^o19'29.60''$S; $36^o53'47.09''$E	6
Industrial area	Industrial	$1^o19'31.49''$S; $36^o52'03.79''$E	3.5
Museum hill interchanger	Controlled	S 010 16' 30.1"; E 036° 48' 42.6"; Elev. 1667m	4
Pangani round about	Controlled	S 01° 18' 03.2"; E 036° 49' 55.6"; Elev. 1514m	4
Old nation round about (Koja)	Controlled	S 01° 16' 54.0"; E 036° 49' 21.9"; Elev. 1681m	4
Ngara jua kali area	Controlled	S 01° 16' 45.3"; E 036° 49' 51.3"; Elev. 1673m	3.5
Industrial area round about (enterprise road)	Industrial	S 01° 17' 58.3"; E 036° 50' 13.2"; Elev. 1671m	3.5

Figures 3.1 and 3.2 display the sampling points within the study area under the three zones of the city. Since 1899 when the city was established, enormous changes have been observed in the current past with increase of population and also global economic effects. The country is found within trophic with average temperatures of $25o^C$ and relative humidity of 44% and the capital city lies at the southern end of Kenya's agricultural heartland, 1.19^o south of the equator and 36.9^o east of meridian and 1600 to 1850 m above sea level.
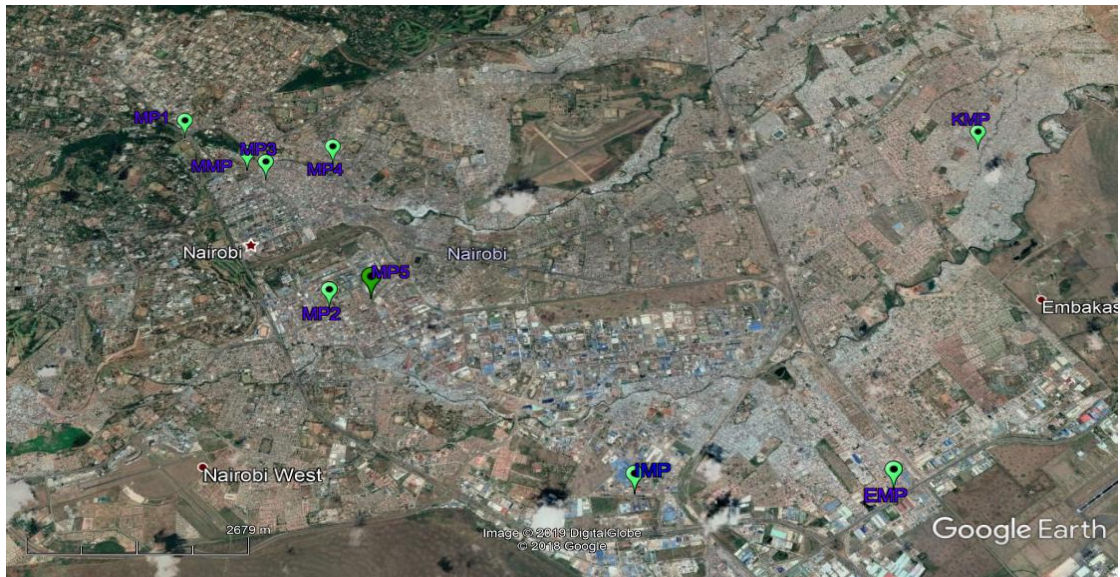
Figure 3:1: Map of Nairobi county showing the study area and points of sampling. In the figure: MP1, Museum Hill Interchanger; MP2, Pangani round about; MMP, Moi Avenue Primary School; MP3, Koja-old Nation round about; MP4, Ngara Jua Kali area; MP5, Roundabout on Enterprise road in Industrial area; IMP, Industrial area road C; EMP, Embakasi; KMP, Kayole

PM_{10} and $PM_{2.5}$ concentration assessment was done at nine sampling locations selected based on above criteria. The sampling locations can be identified as indicated in Table 2.1. The sites from where the samples were collected were categorized into three, Controlled, residential and industrial areas as stipulated in the Environmental Management Coordination Act 2014.
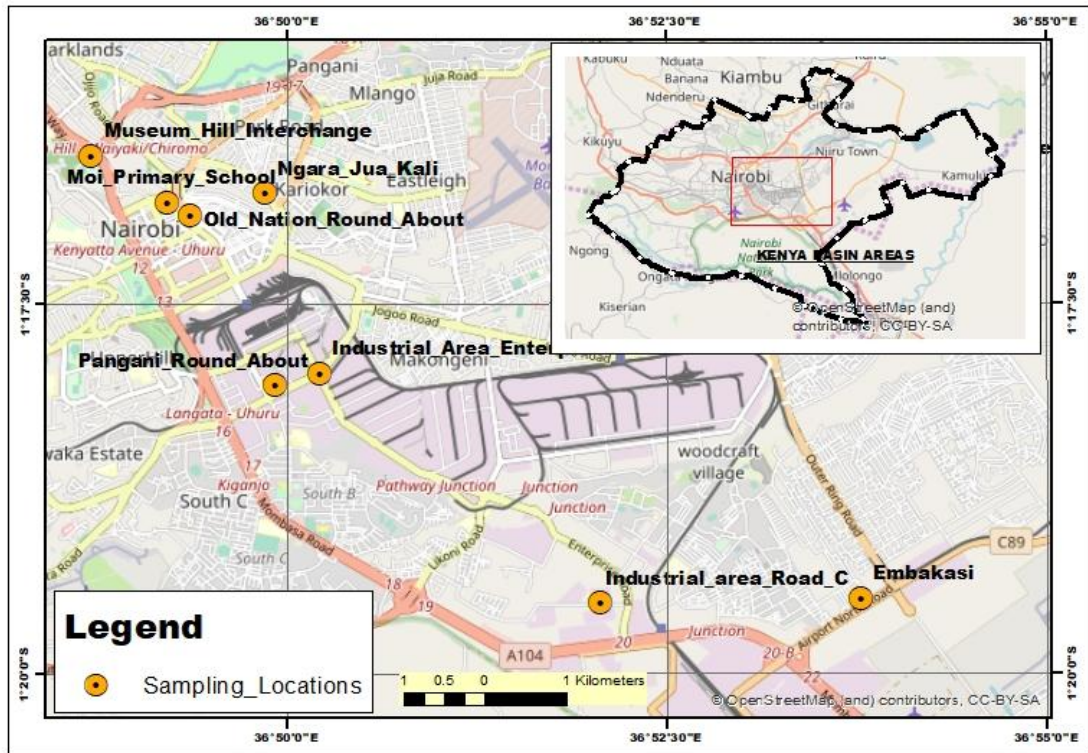
Figure 3:2: Sampling sites

The Figure 3.3 below shows the residential sampling points. The figure shows two residential sampling sites with the red circle indicating the open play grounds in Embakasi and unpaved roads in Kayole which is a contributor to the particulate matter in the ambient air. Nairobi does not have any regular air quality management system yet, and any measurement of air pollution have been done on an ad hoc basis; indeed, out of the mainly developing country cities for a UN study on air quality management capability, Nairobi capacity was rated as the worst (UNEP/WHO, 1996) although in general the current quality of air in Nairobi does not present a critical health or deteriorating.

Figure 3:3: Dust prone emitting unpaved grounds and roads.

3.3 Concentration and Spatial Distribution of PM$_{10}$ and PM$_{2.5}$ in Ambient Air

3.3.1 Experimental Setup

A MiniVol sampler is manufactured by Airmetrics, as illustrated in Figure 3.4 below consists of three basic components: designed inlet, impactors, and a flow rate regulatory system. The particle size characteristics of the inlet and the impactors depend on specified air velocities. A change in velocity results in a change in the nominal particle size collected. The MiniVol's pump draws air at 5 liters/minute through a particle size impactor, then through a 47mm filter.
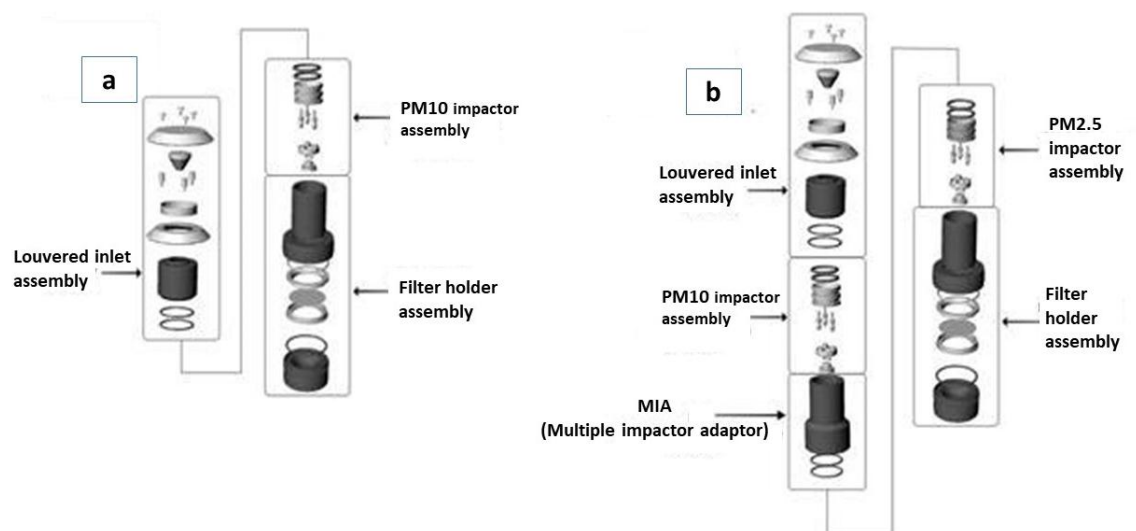
Figure 3:4: Schematic diagram of a MiniVol.

During calibration of the MiniVol, default values are determined from the value in the flow rate field. The first point is 1.5 litres/minute less than the desired flow rate of 5.0 litres/minute. Each point thereafter decreases by 0.5 litres/minute. For a 5.0 litres/minute flow rate, this gives a default range of 6.5 to 4.0 litres/minute as illustrated in Figure 3.4. The figure shows the calibration curve that was used in this study.
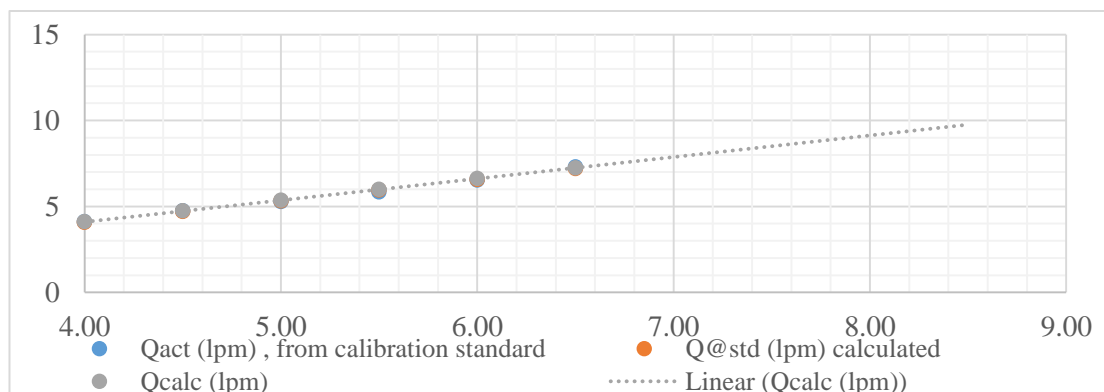
Figure 3:5: Calibration curve for MiniVol.

In reference to Figure 3.4 calibration curve before data collection; Qact is the MiniVol actual flow rate at current ambient conditions; Qstd is the MiniVol's flow rate corrected to EPA standard conditions of 25°C and 760 mmHg, and; Qcalc is the MiniVol's flow rate at standard conditions computed using the newly created calibration line. The difference in flow is expressed as a percentage. This difference is derived using the Qstd and Qcalc values. The colour of this field depends on its value as follows: difference $\geq$ 2% red, 2% > difference $\geq$ 1% yellow, difference < 1% green. Any deviation of 2% or greater may require recalibration.

The MiniVol was mounted to a 5 cm smaller pipe with U-brackets and in other sites on larger posts using the ratchet straps. It was positioned at 270° arc of unrestricted airflow around it and no significant obstruction on the site of concern along the predominant seasonal wind direction. The equipment was placed with the air inlet: facing upward, 2-7 m (6'7" - 23') above ground level (depending on the site) at 30 cm (12") from any obstacle to air flow, two meters (6'7") from walls and architectural features, at least 5 m from natural gas combustion from fuel oil, coal, or solid waste incineration and sampling site name was assigned to each sampling site.

In order to determine the concentration of PM_{10} and $PM_{2.5}$ in ambient air a sample is collected using MinVol sampler. PM_{10} and $PM_{2.5}$ inlets were mounted in two sets of equipment to collect different sizes of particulate matter (PM_{10} and $PM_{2.5}$). PM_{10} and $PM_{2.5}$ inlet and filters were used to trap PM_{10} ($\leq 10\mu g$) and $PM_{2.5}$ ($\leq 2.5\mu g$). The filters are weighed before mounting to the sampler and after trapping the particulate matter.

3.3.2 Data Collection Procedure and Analysis

a) Mini-Vol filter weighing procedure

The filters were held with finger cots or vinyl gloves and placed on the edge in a clean metal file rack and covered with clean white paper towels in climate controlled room during pre-weighing. The filter was allowed to equilibrate for 24 hours at 50% humidity and 15-35°C temperature. Each equilibrated filters were weighed after zeroing the balance then filter numbers were recorded and tare weighted. The weighing process was done repeatedly to ascertain the accuracy of the weighing balance. The impactors are shown in Figure 3.5.

Figure 3:6: PM_{10} and $PM_{2.5}$ impactors.

b) Sampling particulate matter

The equipment used in all selected sites (PM_{10}) for sampling to determine the concentration of airborne dust particles in ambient air was the MiniVol (Hi-Vol) PM_{10} sampler It is a filter-based gravimetric samplers (MiniVol PM sampler. Figure

3.4). The instrument consists of PM_{10} and $PM_{2.5}$ sampling inlet. The sampling followed a three in one sampling schedule for the majority of the time, meaning that a new sample filter was installed and the sampler operated three times for every 24 hours. Before positioning the filter on the filter holder in the sampler, the filters are weighed on a high-precision scale in the laboratory to determine the weight of the filter without any dust deposit. The filter was then positioned on the filter holder of the sampler. Pre-weighed filters were set up for sampling in an office environment. The filter ID number and date were logged on the data sheets and the filters were covered for transport to the field. In the field the sampler flow rate and elapsed time was checked and recorded to complete the data record for the filter that was previously sampled before exchanging the old (now dirty-exposed) filter with the new filter (unexposed). Once the new filter was mounted onto the instrument, the elapsed timer was set to zero and the flow rate re-checked and logged on the log sheets. Ambient air was drawn in through the sampler head and filter media by a pump, similar to a vacuum cleaner motor so that airborne particulates were trapped on the filter papers. The measurement was taken on Sunday, Monday, and Tuesday while others on Friday, Saturday and Sunday twice per selected site in different weather conditions during the February, March and April 2015 and 2016.

Figure 3:7: MiniVol tactical air sampler on sampling site at industrial area.

c) Post-field weighing

Exposed filters were returned to the laboratory for post sampling weighing and analysis of heavy metals the filters with the sample were taken back to laboratory

wrapped in manila folders with clearly printed labels. The filters were carefully removed from their storage container and were placed in the filter cassette. All the filters were weighed and the results recorded on filter weighing form. Note that the weighing was repeated to ascertain the results. The final weight difference was used to calculate the concentration of the particulate matter for PM_{10} and $PM_{2.5}$. The study does not intend to provide information to ascertain daily protection of the individuals who predisposed to dust, but rather to document dust problems. Figure 3.5 shows the sampling and analysis process flow diagram.

Objective 1	Objective 2	Objective 3
• **Input** • Installation of the sampler • Characterisation of Sampling Sites -industrial, residential and controlled sampling site • Pre-field weighing of the filter papers and labelling, and Post-field weighing of the fielter with partculate matter. • **Output** • Filter paper exposed to particulate matter (PM_{10} & $PM_{2.5}$) • Calculation of the mass of the partculate matter (PM10 and PM2.5 Conc) • Spatial maps	• **Input** • Recording of the temparature relative humidity and wind speed parameters • Particulate matter concentration • **Output** • Metereological data and correlation with the PM concentration	• **Sample analysis (PM_{10})Preparation** • Metal Concentration analysis • Acid extraction method of the heavy metals from the filters • mercury - Cold vapour • Arsenic - hydride generation • **Output** • Heavy metal concentration

Figure 3:8: Flow diagram for sampling and analysis process.

d) Filter media selection and gravimetric determination

The filter media was weighed before mounting it on the filter holder and after use to determine the gained weight (mass) whereas the total air volume sampled was generated from the flow rate and the sampling time corrected to EPA standard conditions (25EC and 760NM Hg). The mass of the particle collected was divided by the volume of the air sample to get the concentration of the total particulate matter. The room conditions were 25EC ± 10EC and relative humidity 50% ± 5%.

The procedure for the sample collection and determining the mass of PM_{10} and $PM_{2.5}$ is simple. The particulates are drawn through the inlet selectively with the air which passes through the filter media. The PM_{10} and $PM_{2.5}$ with corresponding diameters less than the provision of the inlet are collected on the filter surface. The weight difference of the used filter and the after unexposed filter is used to calculate the

mass of the particulate matter. The concentration of the PM_{10} and $PM_{2.5}$ was determined by dividing the weight gained after sampling by the volume of the air sampled. The principal procedure for $PM_{10,}$ air is drawn through the filter at rate of 5l/min by the sampler, similarly $PM_{2.5.}$ MinVol samplers with a size-selective inlet, a filter, and a means of pulling air through the system; however, the $PM_{2.5}$ samplers have some exceptional features. The size selective inlet is encompassed of two separate size selective entry point of the particles: the first is a PM_{10} entry point to eliminate all the larger particulates (greater in diameter than 10μg) then the $PM_{2.5}$ selective inlets follows to eliminate the particulates greater in diameter than 2.5μg.

e) Computation of PM concentrations

The aggregate volume of air was calculated using the equation (3.1) where *V* is the cumulative volume of air drawn through the sampler, *Qa* is mean sampler flow rate across the sampling time and *t* is over-all elapsed sampling period in minutes (per sample collected).

$$V = Q_a t \qquad (3.1)$$

To determine the 24-hours concentration of $PM_{2.5}$ and PM_{10}, the weight gain (mass) is divided by the as displayed in equation 3.1 volume calculated in equation 3.2. In the equation, PM_{10} is PM_{10} mass concentration, 10^6 is conversion factor for grams to micrograms, W_f is final weight of exposed filter, W_i is initial weight of unexposed filter and *V* is volume of air sampled. The PM_{10} and $PM_{2.5}$ masses on the filter were determined gravimetrically. The filters were conditioned at 20^oC and fifty percent relative humidity preceding weighing.

$$PM_{10} = (W_i - W_f)10^6 / V \qquad (3.2)$$

The initial weight of filter was taken before digestion, the filter was then put in a 100ml glass beaker and about 30mls HCl was added. This solution was then digested in a hot plate at 70^oC for 1 hour to almost half the volume. The sample was then removed from the hot plate after 1 hour, cooled to room temperature, and then filtered into 50ml volumetric flask using a No.40 Whatman filter paper. The solution in the volumetric flask was topped up to the mark with deionized water which was used for analysis. For arsenic and mercury, analysis was done through the Hydride generation and cold Vapour Generating Accessory respectively (HCL and Sodium

boro-hydride were employed). In the equation below, CR is corrected reading, IR is instrument reading, B is blank control sample, DV is dilution volume and SW is sample weight.

$$CR(ppm) = ((IR - B)DV)/SW \tag{3.3}$$

The equation above is the standard process used to calculate the concentration of the PM_{10}, and $PM_{2.5}$ (particulate matter). The weight difference between the filter after sample collection and before sample collected is determined in order to calculate the particulate matter concentration for both PM_{10} and $PM_{2.5}$. The main objective of the study was determining concentration of the PM_{10}, $PM_{2.5}$ and different heavy metals was determined from different sampling points.

The spatial objective of the study was achieved by considering and sampling different points as categorised by EMCA Air Quality Regulation 2014 while temporal aspect was realized through regular constant interval sample collection within 24-hours within the sampling period. Finally, the PM_{10} samples collected from different categories were subjected to heavy metal analysis to determine their concentration. EMCA Air Quality Regulation 2014 was used as guideline to select the sampling sites, which enabled the development of spatial distribution and mapping of the PM_{10} and $PM_{2.5}$ concentrations (particulate matter). A total of nine sampling points were used for study guided the EMCA 2014 regulation during section. How this sampling points were selected and determined was to achieve the objective of the study that is; particulate matter concentration, chemical composition of the particulate matter and how the concentrations are affected by different weather parameters. Daily computation of PM_{10} and $PM_{2.5}$ concentrations was done to demonstrate the time variation (temporal variation).

Figure 3:9: Particulate collected on PM$_{10}$ filter.

3.4 Effect of Weather Conditions on PM$_{10}$ and PM$_{2.5}$ Concentrations

The study explored the impact of meteorological aspects on PM$_{10}$ and PM$_{2.5}$ concentrations in Nairobi city. Weather conditions; temperature, relative humidity (RH) and wind speed were determined using the Min Vol Sampler. The sampler records the conditions and Correlation analysis between the PM$_{10}$, PM$_{2.5}$ and meteorology factor were conducted for the whole period of monitoring.

3.5 Concentration of Heavy Metal in PM$_{10}$ in Ambient Air

3.5.1 Analytical Procedures

Atomic absorption spectrometry (AAS), is a fairly universal analytical method for determination of metallic elements in both trace and major concentrations. Atomic absorption methods measure amount of energy (in the form of photons of light, and thus a change in the wavelength) absorbed by the sample, a detector measures the wavelengths of light transmitted by the sample (the "after" wavelengths), and compares that to the wavelengths, which originally passed through the sample (the "before" wavelengths). A signal processor integrates the changes in wavelength, which appear in the readout as peaks of energy absorption at discrete wavelengths. Atomic absorption analysis involves measuring the absorption of light by vaporized ground state atoms and relating the absorption to concentration in the sample.

The sample, either a liquid or a solid, is atomized in either a flame or a graphite furnace. Upon the absorption of ultraviolet or visible light, the free atoms undergo

electronic transitions from the ground state to excited state. A common method is to introduce a liquid sample into a flame. Upon introduction, the sample solution is dispersed into a fine spray, the spray is then desolvated into salt particles in the flame and the particles are subsequently vaporized into neutral atoms, ionic species and molecular species. All of these conversion processes occur in geometrically definable regions in the flame. The light produced by the hollow-cathode lamp is emitted from excited atoms of the same element which is to be determined. Therefore, the radiant energy corresponds directly to the wavelength which is absorbable by the atomized sample. This method provides both sensitivity and selectivity since other elements in the sample will not generally absorb the chosen wavelength and thus, will not interfere with the measurement. Equipment calibration was done for the metals which were analysed. All the PM_{10} samples collected were subjected to analysis for manganese, lead, arsenic, mercury chromium, cadmium, zinc and nickel.

Atomic absorption spectrometry standard solutions for Hg, Cd, Pb, Cr and As were used to build up calibration curves. They were prepared from a stock solution of 1000 mg/L for each metal by successive dilutions. Aqueous solutions of reagents and standards were prepared using a Milli-RO 12 plus Milli-Q purification system for water (Millipore, Bedford, MA).

a) Determining concentration of lead, manganese, cadmium and chromium

The PM_{10} samples were digested using 2ml of concentrated Nitric acid and 5ml of Hydrochloric acid. The solutions were heat on electric hot plate at a temperature of 90 – 95 0c until the volume was 15 – 20ml the solution was allowed to cool and adjusted to 100ml with distilled water. The concentrations of lead, cadmium, manganese and chromium were determined using Atomic Absorption spectrometer. The instrument was calibrated before analysis was done.

To obtain a sample with particles containing the sample analytes of the heavy metals a known volume of ambient air was drawn through the filter and then dissolved in HNO_3 and H_2O_2 for digestion by hot plate. Calibration of the low range, for the

metals concentration determination standards of 0.00, 0.05, 0.1, 0.2, 0.3, 0.4, and 0.5 ppm were used. A blank calibration solution is also used for a zero calibration.

b) Determining concentration of mercury

The mercury standard was attuned by changing the volume of the standard used. A blank calibration solution is also used for a zero calibration. Calibration of the low range, for the metals concentration determination standards of 0.00, 0.05, 0.1, 0.2, 0.3, 0.4, and 0.5 ppm were used. The accurate, precise, and automated determination of mercury in samples is complex, not only because of the numerous oxidation states of mercury (i.e., 0, I and II), but also because of biotic and abiotic methylation and the volatility of several forms of mercury (I and II). Mercury is unique among the metals because of its large vapour pressure at ambient conditions. Acid mixture (1.5% HNO_3 and 1.5% H_2SO_4) of 9 mL were added to 1 mL of the digested sample. Mercury was determined using an aqueous solution of 3% (w/v) NaBH4 in a 1% (w/v) NaOH solution freshly prepared and filtered as reducing agent. Mercuric ions in solution can be reduced by tin (II), or sodium borohydride to produce volatile elemental mercury, referred to as the cold vapour process. One to two drops of silicone antifoaming was dispensed into a reaction flask before introducing any solution. All solutions were stabilized by adding 500μL of 5% $KMnO_4$ solution before starting the determination. An electrodeless discharge lamp was used. The mercury is swept out of solution with a carrier gas (in the gas of sodium borohydride, the by-product is hydrogen) into the cell (or torch) where the atomic absorption is measured. The cold vapour technique removes the mercury from the sample matrix, concentrates the mercury in the analytical sample into a small plug of carrier gas, and provides for a relatively long residence time.

c) Determining concentration of arsenic

The calibrations of the AAS for arsenic was carried out with certified reference standard solutions covering the desired concentration range of the analyte in the sample. Auto calibrateable transfer pipettes of 0.5-5 mL volume range from E. Merck (Germany) and volumetric flasks were used. All the acid digestion and dilution work was carried out in a cleaned laminar flow bench equipped with a

proper ventilation system. Nitric acid (69%) and hydrochloric acid (35%) were purified by Sub–boiling distillation using quartz glass device, potassium iodide, sodium hydroxide, ascorbic acid, hydrogen peroxide (35%) and sodium borohydride (99%). As present in trace amounts in the acid were further removed by distillation. After distillation, these sub–boiled Nitric acid and hydrochloric acid were used as reagent for *As* determination to avoid background contamination of *As*.

Concentrated HCl (1 mL) and 1 mL of 5% (w/v) KI-ascorbic acid were added to 1mL of digested sample. After 45 min at room temperature, the mixture was diluted to 10mL with water. The reducing agent was an aqueous solution of 0.2% (w/v) NaBH4 in a 0.05% (w/v) NaOH solution freshly prepared and filtered. Standard addition was required and cell temperature was set at 900°C. An electrodeless discharge lamp was used.

3.5.2   Data Analysis

This study used the quantitative statistical methods to analysis the collected data. Microsoft Excel Package, GIS and Statistical Package for Social Sciences (SPSS) was used to analyse all the quantitative data collected. The study also used the *Cochran* variant of the t-test to analyse the collected data. It is reliable when the standard deviations of the independent sets (PM$_{10}$ and PM$_{2.5}$) differ significantly.

$$t_{cal} = \frac{\left|\overline{x_1} - \overline{x_2}\right|}{\sqrt{\dfrac{s_1^2}{n_1} + \dfrac{s_2^2}{n_2}}}$$

(3.4)

Equation (3.5) was used to determine an alternative critical *t*-value. Means, minimum, maximum and percentages were generated for collected data, and results presented using tables, bar graphs and line charts to discuss data and information on various issues addressed by the study objectives. *t-test* was used to test the study.

$$t_{tab} = \frac{t_1 \dfrac{s_1^2}{n_1} + t_2 \dfrac{s_2^2}{n_2}}{\dfrac{s_1^2}{n_1} + \dfrac{s_2^2}{n_2}}$$

(3.5)

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1   Characterisation of Sampling Sites

Based on the current local air quality regulation (EMCA 2014), Nairobi County has been divided into three (3) zones namely: Industrial zone, Residential zone and Controlled zone

The sampling sites were classified into three categories (industrial, residential and controlled) as defined in the EMCA Air quality regulation 2014 (Table 4.1) and charaterised accordingly.

Table 4.1: Characterization of sample sites

EMCA Air Quality Regulation 2014 Categories	Category definition	Identified sampling sites	Site description
Industrial area	Designated Zones for Industrial	Road C in Industrial area Enterprise road in Industrial Zone	Manufacturing zone, Unpaved roads, Big trucks on the road
Residential, rural and other Areas	Designated Zones for Residential	Kayole and Embakasi	Unpaved Roads, tall residential buildings, Burning tyres, High traffic
Controlled Areas	Residential areas, Hospitals, National Parks, Reserves and Sanctuaries, conservation areas, conservation areas, Central Business Districts Any other area declared by the Authority from time to time	Moi Avenue Road -Moi Avenue Primary School	Tall building, traffic congestion, few unpaved areas, high day and low night population,
		Old Nation Round about (Koja), Ngara Jua Kali Area, Pangani Round About, Museum Hill Interchanger.	Unpaved roads, temporally buildings, tall buildings and high traffic.

4.2   Spatial and Concentration Levels of PM$_{10}$ and PM$_{2.5}$ in Ambient Air

4.2.1   PM$_{10}$ and PM$_{2.5}$ Concentration Levels

a)   Residential Areas

(i)   PM$_{10}$ concentration levels

Figure 4.1 shows the PM$_{10}$ concentration levels obtained for residential areas which are compared with both EMCA and EPA guidelines. The minimum mean of PM$_{10}$ concentration level was 24µg/m^3 recorded at the commencement of sampling day (night) while the maximum level was 74.5µg/m^3 registered on the last day of sampling (afternoon). All the measured values were within the required standards by EMCA Air Quality Regulation 2014 and EPA standards. Generally, afternoons registered higher PM$_{10}$ concentrations levels than nights and mornings. Being a residential area which are near industrial area, this can be associated with more many activities during the day from unpaved roads, traffic and also particulate matter blown from the industrial area. At night few activities are going in the residential and the neighbouring industrial area hence low PM$_{10}$ concentrations were recorded.
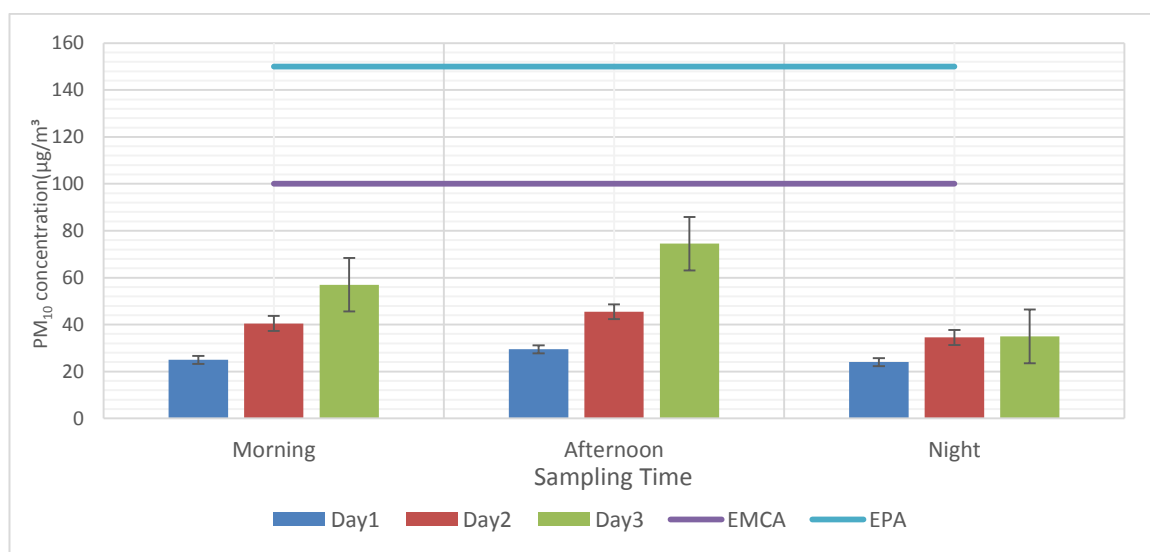
Figure 4:1: Concentration levels of PM$_{10}$ in residential areas during the day and night.

(ii)   PM$_{2.5}$ concentration levels

The mean concentrations levels of PM$_{2.5}$ for residential areas are illustrated in Figure 4.2. The results display that the highest and lowest levels were 38µg/m on Day 3 (afternoon) and 13µg/m^3 on Day 1 (night), respectively. The PM$_{2.5}$ concentrations

were within the EPA permissible standards in 24 hours (35 $\mu g/m^3$) except the afternoon of Day 3, however, there is no clear guideline in the EMCA Air Quality Regulation 2014. Being a residential area it means that there is a big population exposed to this concentration throughout their life. This result can be used to prospect the associated impact of $PM_{2.5}$ to public health and welfare. This translates to health effects on the sensitive group of persons. There is no clear guideline on the permissible levels of $PM_{2.5}$ in residential area by EMCA 2014.
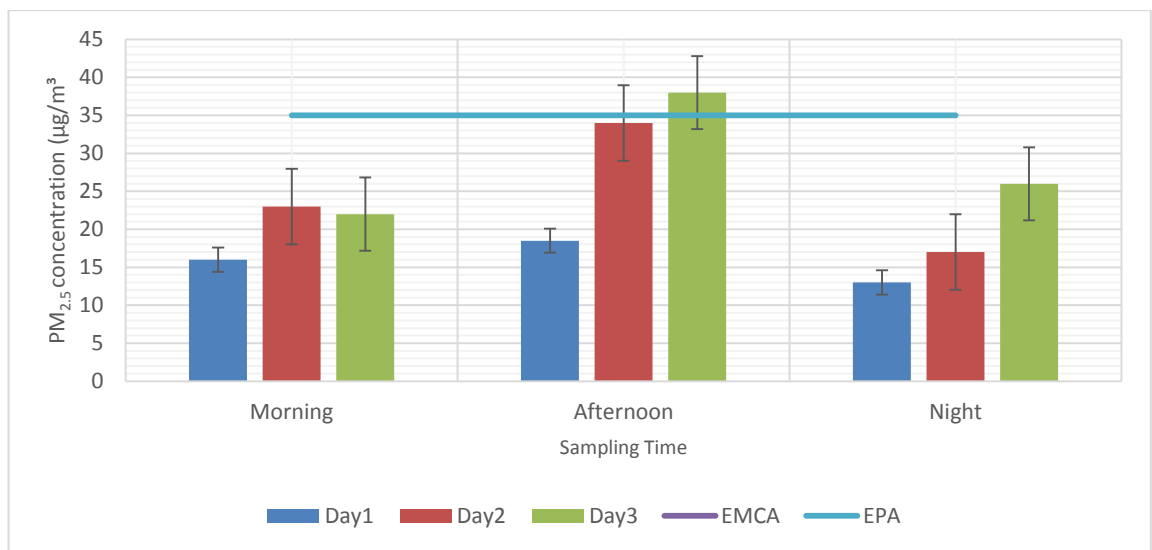
Figure 4:2: Concentration levels of $PM_{2.5}$ in residential area during the day and night.

b) Controlled Areas

(i) PM_{10} concentration levels

The EMCA Air Quality Act 2014 has listed the controlled areas as indicated in Table 4.1. This study considered 5 sampling sites; Moi Avenue Primary School, Museum Hill Inter-change, Pangani Round About, Ngara Jua Kali and Koja old Nation Round About as controlled areas. All these areas are within the central business district (CBD) of Nairobi. The maximum and minimum mean values of PM_{10} concentration are $35\mu g/m^3$ recorded in the afternoon of Day 2 and $16.8\mu g/m^3$ recorded at night on Day 2, respectively (Figure 4.3). Generally, there was no significant deviation of PM_{10} concentration across the sampling days). This observation can be associated with the days of sampling (weekends) and constant stable weather condition. This results to low and stable PM_{10} concentrations across the sampling days. The levels of

PM_{10} recorded in the controlled area were within the permissible levels for both EPA and EMCA. Being the CBD, the sampling site is characterized with paved pathways and slow moving automobiles meaning that little dust is released to the air. The CBD sampling site is also dominated by a massive number of buildings which act as wind breakers which reduce wind speed thereby dwindling any substantial effect of wind on the concentration of dust particles, this translates to very low concentrations rerecords for $PM_{2.5}$ and PM_{10} in air.
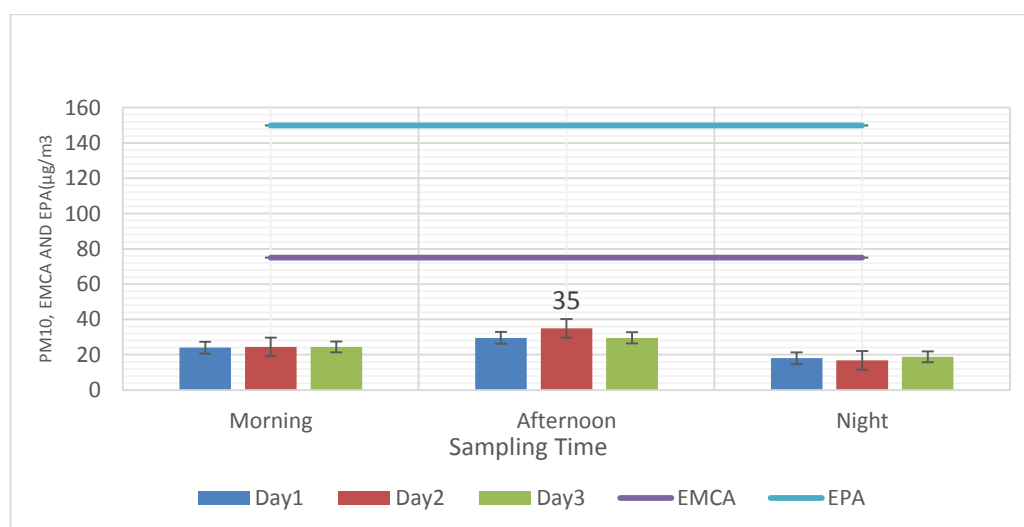
Figure 4:3: Concentration levels of PM_{10} in controlled areas during the day and night.

(ii) $PM_{2.5}$ concentrations levels

The average values of $PM_{2.5}$ concentration levels in the controlled areas during the day and night for three days are shown in Figure 4.4. The maximum and minimum mean values are $32.64\mu g/m^3$ recorded in the afternoon of Day 1 and $11.54\mu g/m^3$ recorded at night of Day 3. The PM2.5 levels were within the EPA ($35\mu g/m^3$) set standards. Caroline kiai et al. reported a range of $34.42 \mu g/m^3$ to $155.58 \mu g/m^3$ in the CBD. These values are higher than the EPA and EMCA recommended standard of $25\mu g/m^3$. The site is dominated by high pedestrian and vehicular traffic, shops, street vendors, and other businesses. Kinney et al. reported values ranging from 75.6 to $98.1\mu g/m^3$ within the CBD. There is no clear guideline provided by EMCA 2014 for the $PM_{2.5}$ concentrations. The concentrations ($PM_{2.5}$) were considerably high in the first day of sampling and low in the third day. Generally, high concentration levels were recorded in the afternoons for all the three days of sampling while low values

were registered at night. The high concentration levels recorded in the afternoons are associated the numerous activities (e.g., heavy traffic flow) that were observed to occur at this time of the day unlike at night.
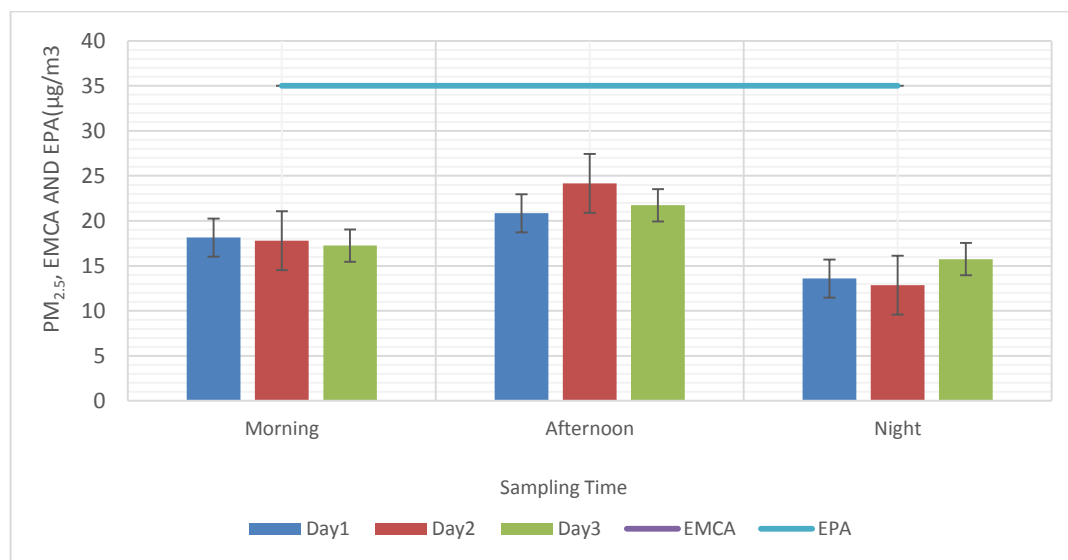
Figure 4:4: Concentration of PM$_{2.5}$ in controlled areas during the day and night.

c) Industrial Areas

(i) PM$_{10}$ concentration levels

Figure 4.5 presents the PM$_{10}$ concentration levels that were recorded for industrial areas which show that the maximum and minimum mean levels were $67\mu g/m^3$ on Day 1 (afternoon) and $19\mu g/m^3$ on Day 3 (night). The levels are within the permissible levels set by the EMCA Air Quality Regulation (2014) and the set standards by EPA. High concentrations were recorded during the day and week days while low values were recorded at night and weekends. Highest concentration levels were observed in the afternoons of the three days of sampling. The implications are that: in consideration to dynamic weather conditions and dispersion of particulate matter, it means that any emission from the industrial area will have different receptor sites which might be a protected or residential area. Despite the PM$_{10}$ concentration being within the permissible levels (Industrial category) set by EMCA 2014, PM$_{10}$ particulate matter being the inhalable particles the workers in industrial area and the neighbouring residential areas (with lower permissible set levels of PM$_{10}$) will be exposed to the high concentrations which leads to negative health

impacts since air flow have no boundaries due to its nature of dispersion, hence the same impact can be felt in the controlled areas and residential areas.
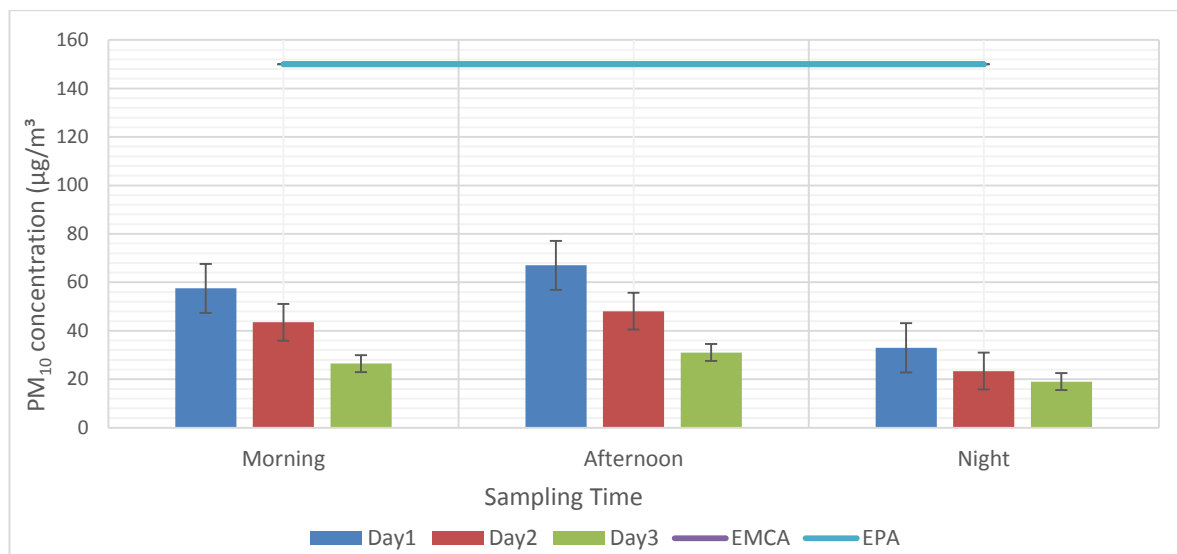
Figure 4:5: PM$_{10}$ concentration in industrial areas at different times of the day.

(ii) PM$_{2.5}$ concentration levels

The recorded PM$_{2.5}$ concentration levels in the industrial area are presented in Figure 4:6. The results show that the levels ranged from 12 to 30 μg/m³ for most samples taken, which are within the EMCA (Air Quality Regulation 2014) set standards and EPA permissible levels except for day one (afternoon) which recorded a level of 46.82 μg/m³, a value that is within EMCA but above the EPA standards. Across the three days of sampling the lowest level was recorded at night and highest in the afternoons. This change is associated with the change in production in the industrial area and also the metrological dynamic changes during different times of the day.
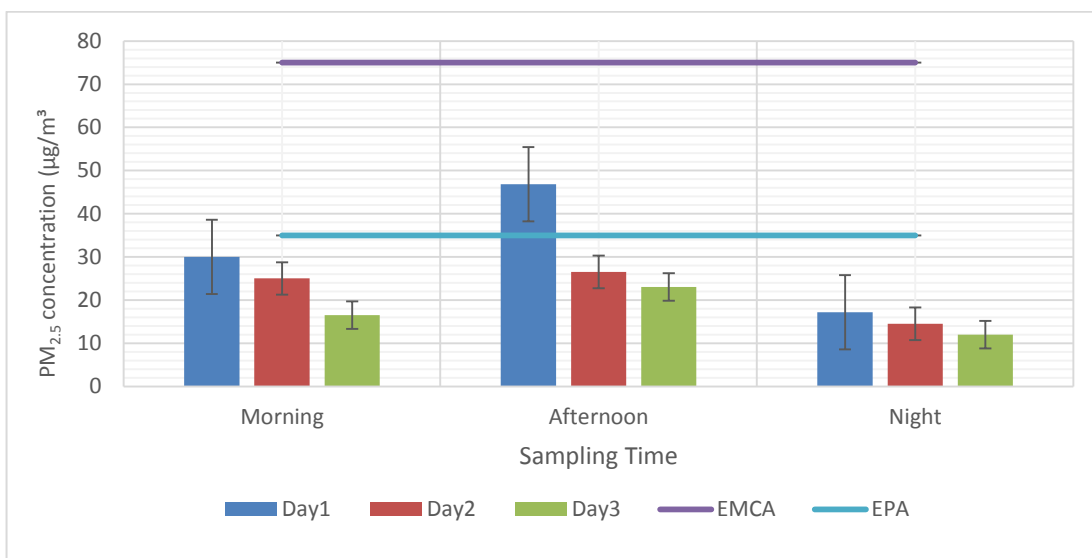
Figure 4:6: Industrial area, PM$_{2.5}$ concentration during the day and night.

Figure 4.7 displays the average values of PM$_{10}$ and PM$_{2.5}$ concentration levels for the various sampling sites. The results demonstrate that the highest PM$_{10}$ concentration level of 109µg/m^3 occurred in the afternoon in the Industrial Area Road C; this was followed by a concentration level of 86µg/m^3 which was recorded at Kayole in the afternoon. The highest PM$_{2.5}$ concentration levels of 72µg/m^3 were observed at the Industrial Area Road C occurred in the afternoon. The lowest recorded concentration for PM$_{10}$ and PM$_{2.5}$ in all the sampling sites were 11µg/m^3 and 7.36µg/m^3 in Industrial Enterprise Road and Ngara Jua kali, respectively at night. The controlled sampling sites were within the CBD where there are high height buildings hence acting as wind breakers at the peripheral of the sampling site. Moi Avenue Primary School (Categorised as controlled area) recorded concentration levels of PM$_{10}$ and PM$_{2.5}$ ranging from 41-18 and 31-13µg/m^3, correspondingly. The uppermost recorded PM$_{10}$ and PM$_{2.5}$ concentration levels are above the acceptable bounds allowed by the EMCA Air Quality Regulation 2014. The particulate matter concentration level for the Industrial area were high during week days when production is at optimum registering a maximum value while they were low at night and weekends due to low production. For the sampled residential areas, Kayole recorded the highest PM$_{10}$ concentration levels of 86 µg/m^3 while the Industrial Area Road C recorded highest PM$_{10}$ concentration of 109µg/m^3 of all the industrial

sampling sites. Museum hill interchange recorded the maximum concentrations of $45\mu g/m^3$ of the controlled zones sampled.
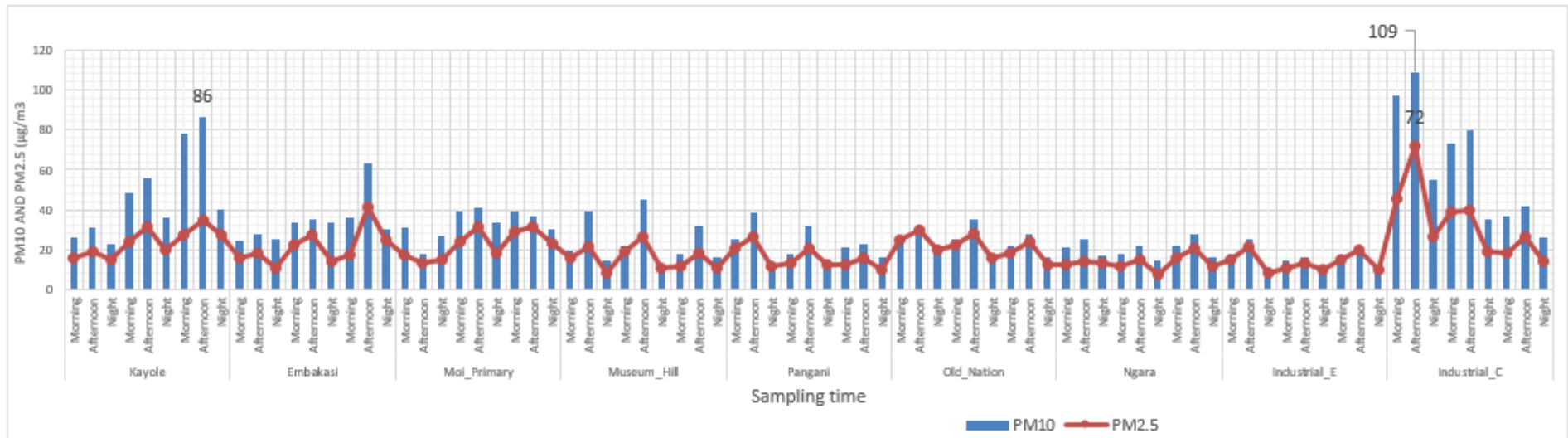
Figure 4:7: Mean PM$_{10}$ and PM$_{2.5}$ concentration levels for various sites during the day and night.

In general, long term air quality monitoring within SSA countries is rare, there are inadequate particulate matter data sets for East Africa Urban zones; where data does exist, projected concentrations of $PM_{2.5}$ concentrations are approximately 100 compared to less than $20\mu g/m^3$ in most European countries and North America (Brauer et al., 2012). A study by Gitari et al., (2014) showed a concentration of 11-21 $\mu g/m^3$ for $PM_{2.5}$ and varies from $26\mu g/m^3$ to $59\mu g/m^3$ for PM_{10} in controlled areas (schools) with Nairobi City County. The particulate matter can also be compared with concentration data observed in other cities. In Accra Ghana average $PM_{2.5}$ levels along the roadsides range from 39-53 $\mu g/m^3$ (Dianisio et al., 2010). It may be reasonable to suppose that if measurements in Accra study were taken along the pathways, as in this study that higher concentration may have been recorded. A study done in North America along the walkways air quality monitoring was conducted in Harlem. High $PM_{2.5}$ levels were recorded for 5 days with an average of 42 $\mu g/m^3$ (Kinney et al., 2000) similar to Nairobi study samples taken about shoulder-level using portable MinVol Sampler. In Europe annual average of $PM_{2.5}$ concentrations is 11.6 $\mu g/m^3$. In Nairobi there have been short-term measurements of particulate matter over the last decade. Kinnney et al. (2011) investigated the impact of vehicular emission in Nairobi on the concentration of $PM_{2.5}$, recording a range of 45-85 $\mu g/m^3$ for 24hrs sampling time. This is faintly higher in comparison with the recorded values in this study, with a concentration range of 11-60 $\mu g/m^3$. In 2012 the yearly mean for $PM_{2.5}$ levels in South Africa oscillated between 4.9-43.3$\mu g/m^3$, the levels of $PM_{2.5}$ concentrations from this study does not vary (11-60 $\mu g/m^3$) much from different classes of sampling points. The variance can be presumed to be brought about by the difference in the sampling points and various weather conditions.

4.2.2 PM_{10} and $PM_{2.5}$ Spatial Distribution in Ambient Air

Figures 4.8-4.11 displays the PM_{10}, $PM_{2.5}$ spatial distribution and heavy metals concentrations respectively. In reference to Figures 4.8 and 4.9, the PM_{10} and $PM_{2.5}$ illustrates concentrations ranges of 14-100 $\mu g/m^3$ and 7-60 $\mu g/m^3$, respectively, for the sampling period in all the sampling points (i.e., residential, controlled and industrial zones). During the morning hours the PM_{10} and $PM_{2.5}$ concentrations

ranged from 14-100 µg/m^3 and 11-60 µg/m^3, respectively. These levels result to poor air quality as per the air quality index for 24- and 1-hour presented in Table 4.2. In the afternoon the ranges were similar to those in the morning hours while at night the range of PM$_{10}$ and PM$_{2.5}$ were from 11-50 µg/m^3 and 7-30 µg/m^3, this can be interpreted as fair air quality as tabulated in Table 4.2. In the Kenyan set-up, most activities are carried out during the day in the city hence high concentrations are recorded in the morning and afternoon in all the sampling categories. Only few industries are operated at night with minimal activities in the residential and controlled areas hence the low concentrations were recorded in these areas at night. This means that average concentrations of PM$_{2.5}$ and PM$_{10}$ which are $\geq$ 37.5 and $\geq$75 µg/m^3, respectively, will cause serious problem to human health which is classifies as very poor air quality by the EPA. This is observed in the three sampling categories which raises health alert to everyone and much more to the sensitive group of persons.
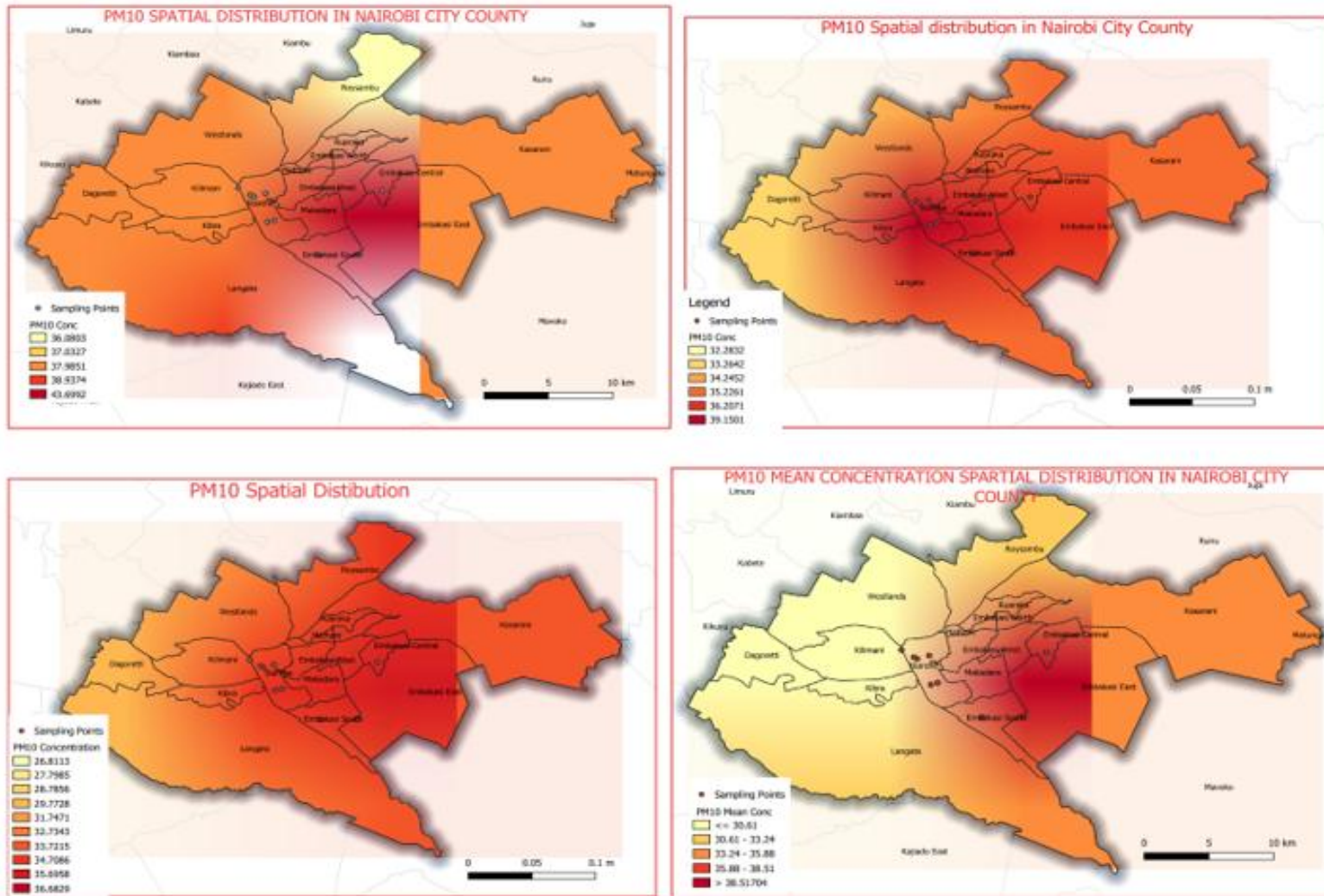
Figure 4:8: Spatial distribution for PM$_{10}$ concentration at different times during study period.
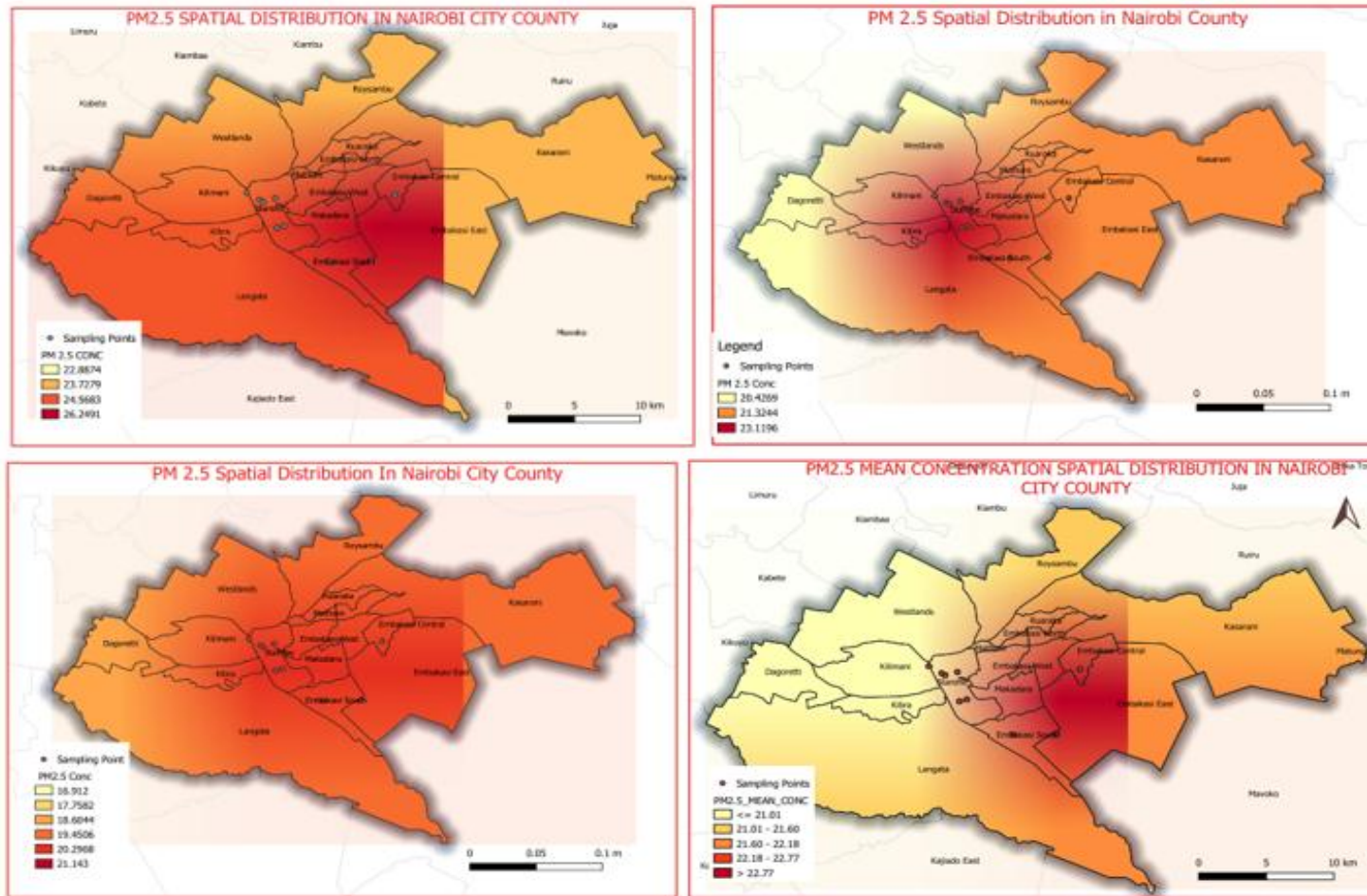
Figure 4:9: Spatial distribution for PM$_{2.5}$ concentration at different times during study period.

Figure 4.10 shows spatial distribution of 5 heavy metal concentrations (namely, manganese, chromium, cadmium, lead and arsenic). Manganese concentration was much more significant with more than 75% concentration of each sample in most of the sampling sites both in the morning and at night. Chromium was also significant with more than 40% concentration of the parameters analysed at night in the industrial area and controlled areas. Five (5) out of 9 sampling sites recorded highest lead concentrations at night (3 in controlled areas and 2 in industrial areas). High concentration levels were recorded in the industrial areas while the residential areas recorded the minimum levels of heavy metals.

The major factors that contributed to variance in PM_{10}, and $PM_{2.5}$ concentrations were meteorological factors which includes temperature, humidity, cloud coverage, precipitation and wind, these impacted directly or indirectly to the primary and secondary sources (local pollution emission, external pollution propagation) of particulate matter (local pollution emission, external pollution propagation). Spatial-temporal variation of PM_{10}, $PM_{2.5}$ concentrations is a result of meteorological factors impacts causing conglomeration and diffusion of particulate matter. A sampling day with high temperatures and low relative humidity, high concentrations of the PM_{10} and $PM_{2.5}$ were recorded. The particles in the ambient air when there is high temperature and low relative humidity, the potential energy is converted to kinetic energy hence increased movement of the particles. This will result to high concentration of the particulate matter while the dispersion rate will be and the receptor site far from the source and much more accelerated by windy weather. If the temperatures are high with high relative humidity (especially wet weather) the particulate matter concentration will be high but the dispersion distance shorter because of the strong bonds between the particles.
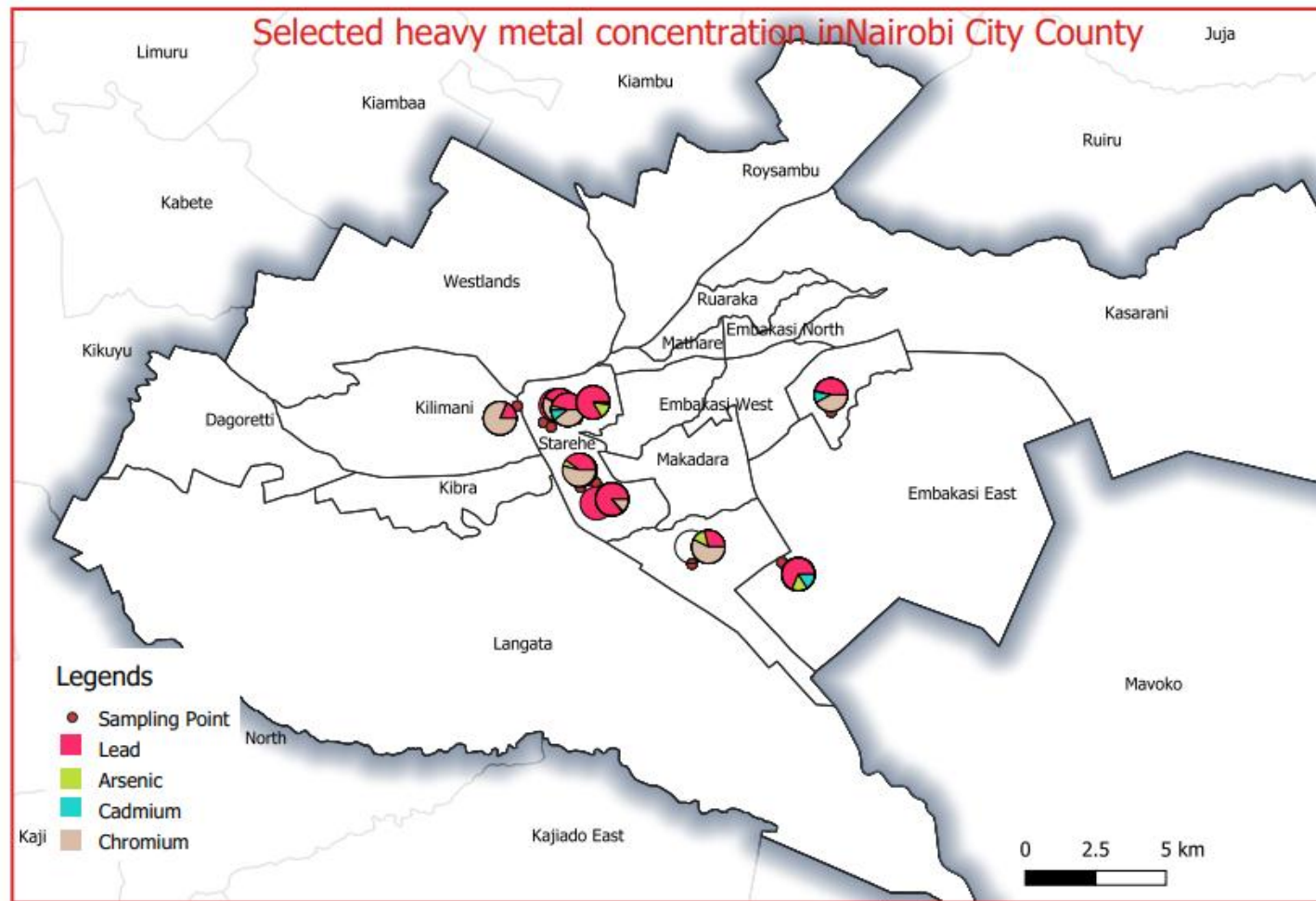
Figure 4:10: Heavy metals Spatial distribution mean concentrations in selected sites in Nairobi County.
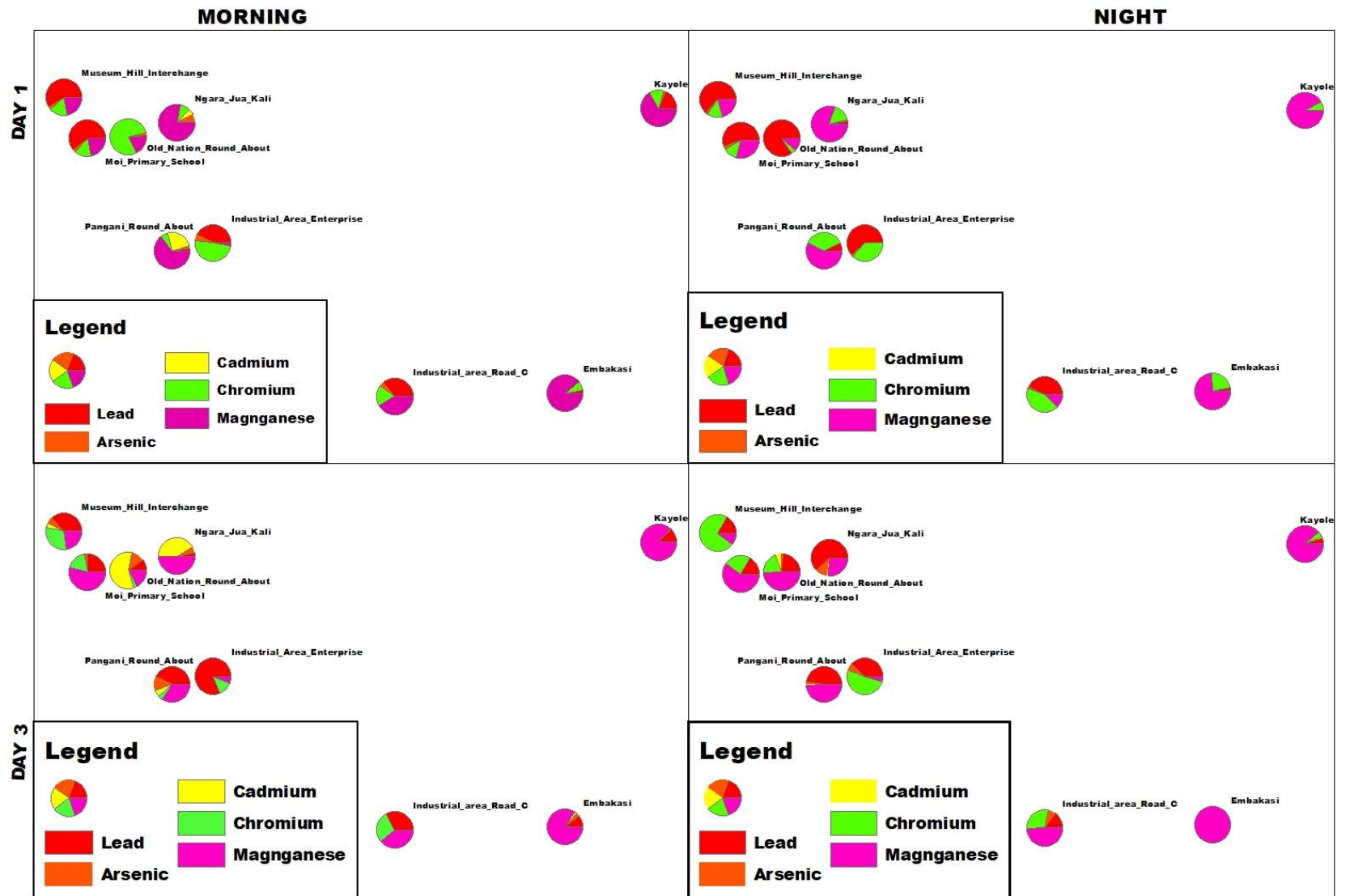
Figure 4:11: Heavy metals Spatial distribution during the day and night.

Table 4.2: Air quality index for 24-hour PM$_{10}$ and PM$_{2.5}$

Air quality Class	24-hour PM$_{2.5}$ µg/m3	One-hour PM$_{2.5}$ µg/m3	24-hour PM$_{10}$ µg/m^3	One-hour PM$_{10}$ µg/m^3	Meaning
Very good	0–8.2	0–13.1	0–16.4	0–26.3	Air quality is satisfactory posing little or no risk
Good	8.3–16.4	13.2–26.3	16.5–32.9	26.4–52.7	Acceptable levels but there are health concerns of the unusual sensitive persons
Fair	16.5–25.0	26.4–39.9	33–49.9	52.8–79.9	Health effects on the sensitive group of persons
Poor	25.1–37.4	40–59.9	50–74.9	80–119.9	Everyone will experience health problems and much more serious to the sensitive group
Very poor	37.5 or greater	60 or greater	75 or greater	120 or greater	Serious effects on everyone, health alerts.

Source: EPA

Table 4.3 shows the statistical correlation coefficient r of the elements in PM$_{10}$ samples. The results indicate that there are insignificant correlations between PM$_{10}$ concentration levels and elements.

Table 4.3: Correlation of average concentrations of elemental composition of PM$_{10}$ in selected sampling sites in Nairobi City

	PM10	PM2.5	Pb	Cd	Cr	Mn	Wind Speed	Temperature (0C)	Relative humidity (%)
PM10.	1								
PM2.5	0.86	1							
Pb	-0.26	-0.33	1						
Cd	-0.11	0.08	-0.27	1					
Cr	-0.23	-0.23	0.73	-0.22	1				
Mn	0.31	0.37	-0.10	-0.14	-0.11	1			
Wind Speed	-0.11	0.22	0.12	0.16	0.15	-0.02	1		
Average temperature (0C)	0.35	0.42	0.00	0.18	0.03	0.03	-0.11	1	
Relative humidity (%)	-0.25	-0.32	0.04	-0.20	0.04	-0.11	-0.09	-0.85	1

4.2.3 Discussion

Results of this study are comparable to those from a similar study done in the city of Accra. We observed overlaps in concentration ranges for both PM_{10} and $PM_{2.5}$ particularly for background locations. Average particulate concentrations from Accra study ranged from 57.9 µg/m3 to 93.6µg/m^3 PM_{10} and 22.3 µg/m^3 to 40.2 $PM_{2.5}$ (Raphael E. Arku et al. 2008) and Dar es Salaam 86-108µg/m^3 PM_{10} and 26.8-38µg/m^3 $PM_{2.5}$ (Robert M. Njee et. al, 2016) which compares well with the range of 11-109µg/m^3 PM_{10} and 8.36 - 72µg/m^3 $PM_{2.5}$ in Nairobi city sampling sites from my study. Even though the PM_{10} levels in two of the three Accra sites were substantially lower than we measured in Nairobi City. The urban PM_{10} concentration we measured were in range of annual averages reported for Latin America, Caribbean (30-118µg/m^3), and Asian cities (50- 130µg/m^3) but higher than reported for Europe (26.3-32µg/m3), North America i.e. in USA (14-63 µg/m^3), and Canada (20-28µg/m^3). Conversely, $PM_{2.5}$ concentrations we measured were higher than those that are being reported from Dutch cities: 17 - 20µg/m^3 for Amsterdam, (de Hartog, J.J. et al., 2005, Timonen, K.L. et al., 2006.). 16.8µg/m^3 Rotterdam urban, and 16.9µg/m^3

an average for many cities mitigation measured targeting vehicular sources are necessary to reduce public health consequences of ambient pollution in Sub-Sahara African cities. (Eeftens, M., Beelen, R., et al., 2012, Eeftens, M., Tsai, M., et al., 2012)

4.3 Effect of Weather Conditions on PM_{10} and $PM_{2.5}$ Concentration in Ambient Air

When the humidity is low, because of hygroscopic growth, $PM_{2.5}$ concentration increases. When the humidity is high enough, the particles grow too heavy to stay in the air. Therefore, dry deposition occurs; particles fall to the ground. As a result, particle numbers reduce and $PM_{2.5}$ concentration decreases. Another reason for high $PM_{2.5}$ in warmer seasons may be related to air temperature. Air temperature can influence chemical processes that manipulate $PM_{2.5}$ components. High $PM_{2.5}$ episodes occurred more frequently in warmer day. Precipitation can effectively decrease $PM_{2.5}$ mass concentrations through wet deposition. Precipitation can effectively remove atmospheric particulate matter, especially of small size.

4.3.1 Impact of Weather Conditions on PM_{10} and $PM_{2.5}$ Concentrations in Residential Areas

The physical plan for the city it's not clear on the boundaries of the three categories considered in this study. There are no boundaries of air movement yet the residential, commercial and industrial have different set standards by EMCA Regulations 2014. In this case the residential are the main receptor of the particulate matter emitter from the industrial and commercial zones. The movement of these particulate matter from the point of emission is aided by weather conditions among other factors as displayed in Figures 4.12-4.14. The Embakasi and Kayole (classified as residential areas) borders the industrial area closely. Different weather factors were considered to have different influence on the concentration of particulate matter. The weather factors influence the receptor sites of the particulate matter from the source. Depending on the source the wind strength and direction can dictate the landing/down falling of the particulate matter. The residential zone maybe the intermediary receptors of the particulate matter blown by the wind from the industrial zone. Depending on the

direction of the wind and the speed, the PM_{10} and $PM_{2.5}$ measured have likely emanated from the industrial area and also from the nearby unpaved roads.

Figure 4.12 displays negative correlation between PM_{10} and $PM_{2.5}$ concentration and relative humidity in residential zones suggesting that as relative humidity rises the concentration of particulate matter drops. Weak correlation is displayed between the PM_{10} Concentration and relative humidity with a coefficients of determination, $R^2 = 0.45$ while that between $PM_{2.5}$ concentration and relative humidity is very weak ($R^2 = 0.24$).

Figure 4.12: Correlation between particulate matter concentration and relative humidity in residential areas.

$R^2 \geq 0.75$-very strong correlation; $0.5 \leq R^2 < 0.75$-strong correlation; $0.25 \leq R^2 < 0.5$-weak correlation; $R^2 < 0.25$-very weak correlation

Positive correlation is demonstrated between the PM_{10} and $PM_{2.5}$ concentration and temperature, though not strong because there are other contributing factors which may bring down or elevate the particulate matter concentration. Holding the factors constant Increase of temperatures increase the mobility of the particulate matter. The correlation between PM_{10} and temperature is weak ($R^2 = 0.3565$) while that between $PM_{2.5}$ and temperature is very weak ($R^2 = 0.1981$). In the residential area there are other factors which were not considered during the study that could have influenced particulate matter concentration.
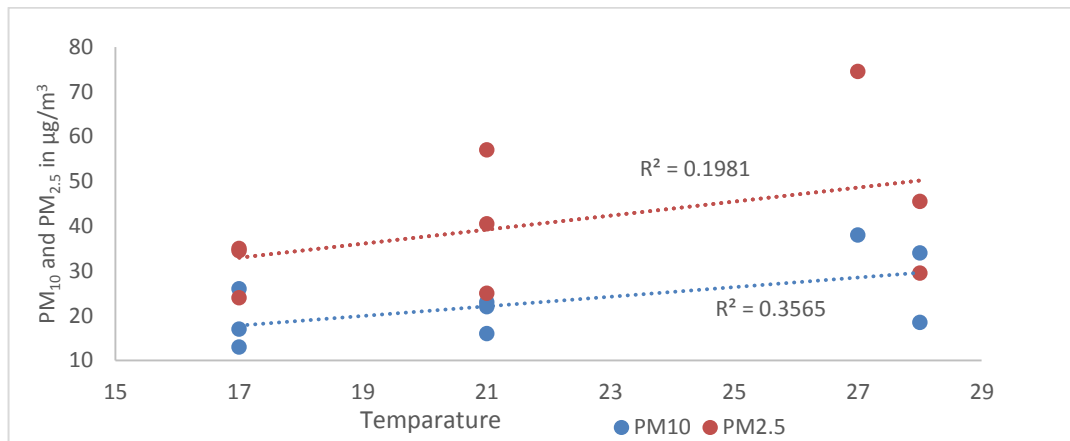
Figure 4:13: Correlation between particulate matter concentration and temperature in residential areas.

Relationship of two or more variables is referred to be very strong when its greater than 0.75, while between 0.45 to 0.69 is considered to be strong and any values below 0.45 is referred to be weak. In this case the effects of wind speed to the particulate matter concentration is very weak ($R^2 < 0.25$) positive relationship. This means the variation of particulate matter concentration it's not caused by wind speed but other meteorological factors among others. The relationship between PM_{10} and $PM_{2.5}$ concentration and wind speed is presented in Figure 4.14 indicating that there a positive correlation between particulate matter (PM_{10} and $PM_{2.5}$) and wind speed though the correlation is very week ($R^2 < 0.25$). This is well demonstrated in the Figure 4.14.
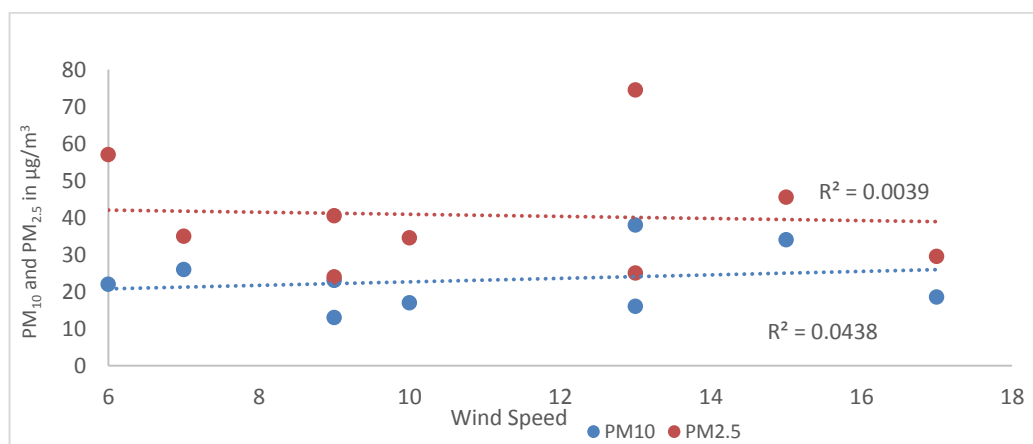
Figure 4.14: Correlation between particulate matter concentration and wind speed in residential areas.

4.3.2 Effect of PM_{10} and $PM_{2.5}$ Concentrations in Controlled Areas

Like the other areas the controlled zones had more or less characterization of the various meteorological factors on the particulate matter as illustrated in Figures 4.15-4.17. The effects of standalone weather factor were analysed in the sampling points. The results in Figure 4.15 show that there a negative correlation between particulate matter (PM_{10} and $PM_{2.5}$) concentration and relative humidity and that the correlation is very strong ($R^2 > 0.75$). This implies that relative humidity has very high influence on the particulate matter concentration in the controlled areas despite the other counteracting weather condition which might also influence the concentrations. High relative humidity causes low mobility of the particulate matter in the ambient air with low temperatures, which shortens the distance of particulate matter dispersion. This will result to low PM_{10} and $PM_{2.5}$ concentrations. Generally, all the nights had low PM_{10} and $PM_{2.5}$ concentrations which were associated with high relative humidity and low temperature, hence, low particle mobility; the nights had also low activities. The temperatures were high in the afternoon while the relative humilities were low over the sampling period and this contributed to high particulate matter concentrations.
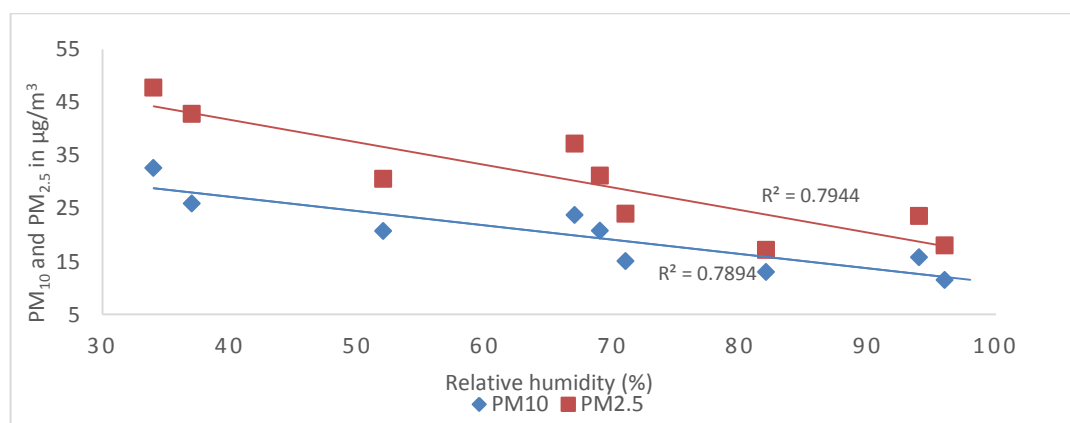
Figure 4.15: Correlation between particulate matter concentration and relative humidity in controlled areas.

$R^2 \geq 0.75$-very strong correlation; $0.5 \leq R^2 < 0.75$-strong correlation; $0.25 \leq R^2 < 0.5$-weak correlation; $R^2 < 0.25$-very weak correlation

On the contrary, the results in Figure 4.16 demonstrates that there is positive correlation between particulate matter concentration (PM_{10} and $PM_{2.5}$) and ambient

air temperature suggesting that increase of temperature increases particulate concentration. The correlation is strong and very strong with a coefficient of $R^2 = 0.71$ and $R^2 = 0.75$ for PM_{10} and $PM_{2.5}$ respectively. This implies that temperature have strong positive influence on the PM_{10} and $PM_{2.5}$ concentrations in the ambient air. This is explained by the high mobility of particles when the temperature is high and low particle mobility when the temperature is low. The results suggest that on sunny and bright days, higher $PM_{2.5}$ and PM_{10} concentration were registered compared to cloudy days with lower ambient air temperatures records.
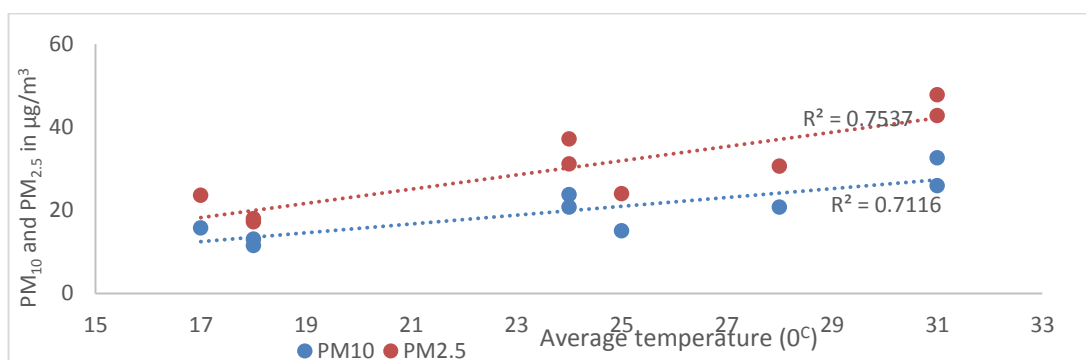
Figure 4.16: Correlation between particulate matter concentration and ambient air temperature in controlled areas.

Figure 4.17 explains the relationship between wind speed and particulate matter (PM_{10} and $PM_{2.5}$) concentration. A weak positive correlation between particulate matter (PM_{10} and $PM_{2.5}$) concentration and wind speed with R^2 values are just above 0.25. This weak relation can be as a result of the influencing weather condition. Generally, the particulate matter concentration at any single point are affected by multiple number of factors which cannot be separated from each other hence no single factors can be said to have a specific relation unless in study done in a controlled environment.
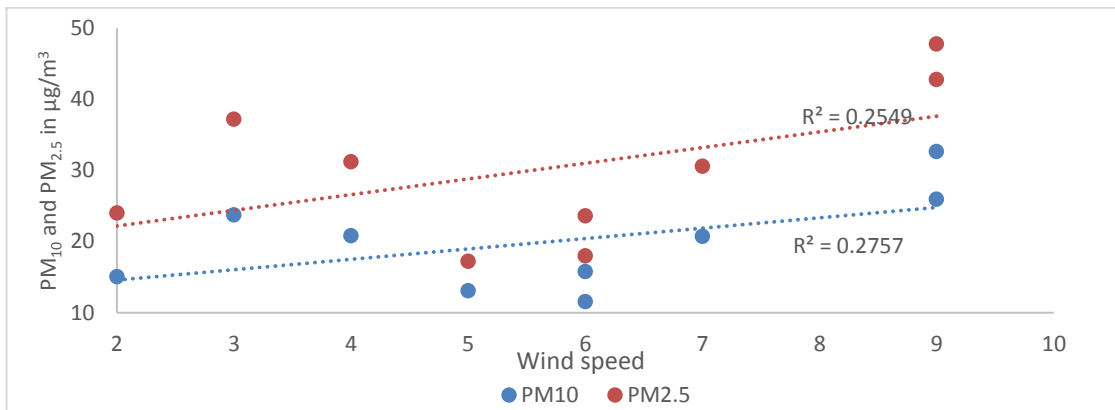
Figure 4:17: Correlation between particulate matter concentrations and wind speed in controlled areas.

4.3.3 Effect of Weather on PM_{10} and $PM_{2.5}$ Concentrations in Industrial Areas

The industrial areas are characterised by various industrial belt with both dry and wet production, few high building and both paved and unpaved roads. Diverse effects were observed on the particulate matter concentrations as a result of different weather conditions under different seasons. This is illustrated in Figures 4.18-4.20 and indicated earlier the correlation between particulate matter (PM10 and PM2.5) and relative humidity negative is weak for both PM_{10} ($R^2 = 0.4507$) and $PM_{2.5}$ ($R^2 = 0.3326$). This implies that the effect of relative humidity on particulate matter concentration is low, hence high or low concentration of the particulate matter was influenced by other factors rather than temperature in industrial areas.
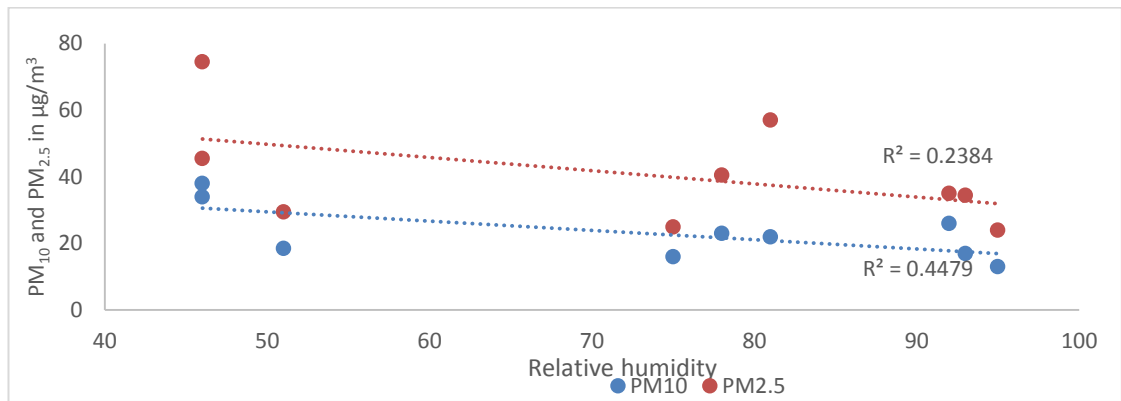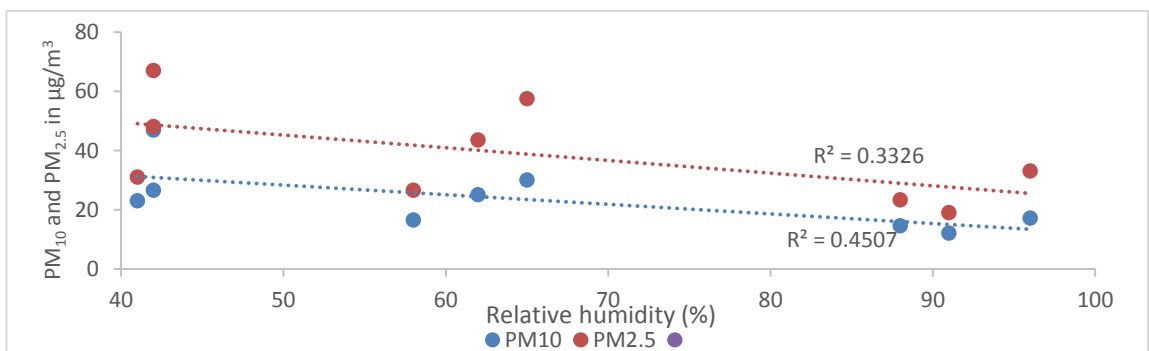

Figure 4.18: Correlation between particulate matter concentration and relative humidity in industrial areas.

$R^2 \geq 0.75$-very strong correlation; $0.5 \leq R^2 < 0.75$-strong correlation; $0.25 \leq R^2 < 0.5$-weak correlation; $R^2 < 0.25$-very weak correlation

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The increase of temperature increases particle kinetic energy and the vice versa is correct. This increase will lead to high concentrations of particulate matter hence strong positive relationship as observed in the figure below 4.19 for both PM_{10} ($R^2 = 0.56$) and PM2.5 ($R^2 = 0.49$). Holding all the other weather factors constant temperature have strong positive effect on the concentration of particulate matter. The synergistic effect of two or more weather conditions on the ambient on particulate matter was not clearly defined.
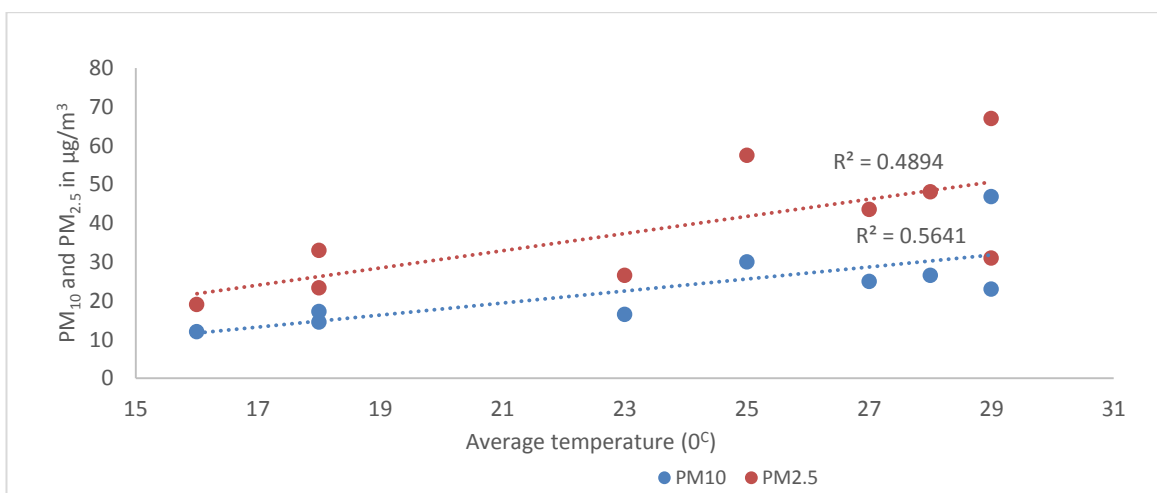
Figure 4.19: Correlation between particulate matter concentration and ambient air temperature in industrial areas.

Though the particulate matter concentration is not strongly affected by the wind speed but at lease there is a strong bond between the particulate matter concentration and the wind speed as displayed in the Figure 4.20 below. This specific parameter is also influenced by other weather conditions which now results to weaker relationship between the particulate matter concentration and the wind speed. In the figure the relationship is denoted by the R2 values, wind speed which is weak the R^2 values lie between 0.25 and 0.5.
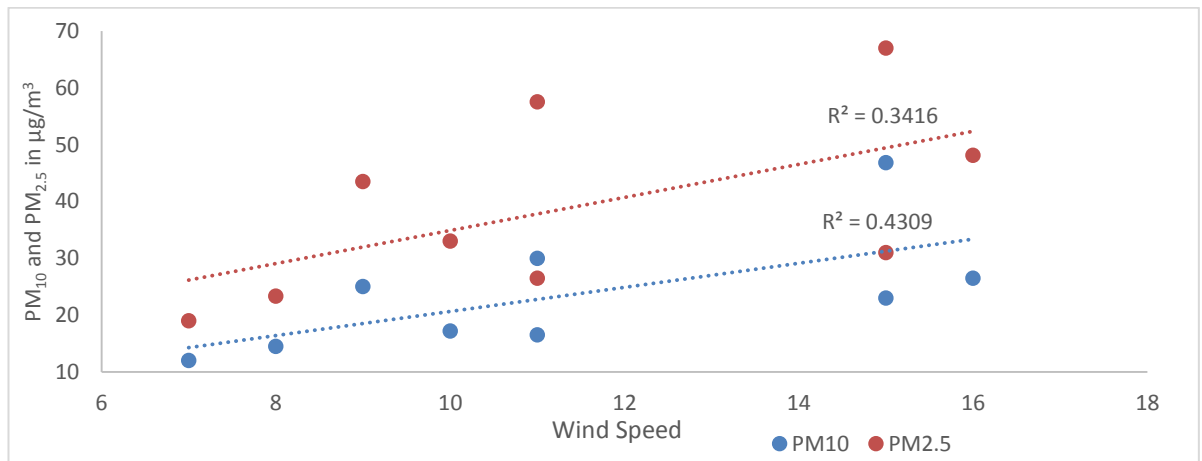
Figure 4.20: Correlation between particulate matter concentration and wind speed in industrial areas.

4.3.4 Effect of Weather Conditions on PM_{10} and $PM_{2.5}$ Concentration

The residential areas were not treated different from the other sampling zones, analysis of the particulate matter (PM_{10} and $PM_{2.5}$) concentration was compared with the weather conditions (ambient air temperature, relative humidity and wind speed) and a weak as the R^2 values obtained are all less than 0.5. This implies that weather conditions have little effect on particulate matter concentrations in these areas. However, there exist a strong correlation between particulate matter concentration and both relative humidity and ambient air temperature in the controlled areas, implying that both these factor have a significant effect on particulate matter concentration in these zones. As for the industrial areas the major weather factor which impacts on PM_{10} and $PM_{2.5}$ concentrations is ambient air temperature though slightly at R^2 value about 0.5.

Low particulate matter concentration was recorded at night when the relative humidity was high, and the temperatures and wind speed were low; which led to low particulate matter mobility. This was associated with less activities during the night. On the other hand, high concentrations of particulate matter were recorded in the afternoon which was associated with high activities, high wind speed, low relative humidity and high temperatures which increased the mobility of the particles. The samples were collected at a range of 20°C-28°C temperature, Kenya lies at the tropical hence temperature extremes are not expected. Temperature is very important

factor when it comes to the particulate matter concentration because, the temperatures determines the kinetic energy in particle hence influencing the mobility of the particles. Temperature variation resulted to the high $PM_{2.5}$ and PM_{10} concentration recording during the day when the temperature averaged 24°C, which is within this range.

When there is high humidity and low temperature the kinetic energy of the particulates is low, hence, the particulates emitted from the area is likely not to travel far. The direction of the receptor site should be towards the surrounding area of the source of emission. As wind speed increases the concentration of PM_{10} and $PM_{2.5}$ increases as well, especially during the operational hours of the day (i.e., in the afternoon). More than 50% of the PM_{10} makes the $PM_{2.5}$ which has higher health impact. The speed and direction of wind dictates the direction of receptor sites for the particulate matter.

Figure 4.21 correlates relative humidity and temperature for combined results for residential, controlled and industrial areas. The results show that there is a very strong negative linear correlation ($R^2 = 0.8862$) between temperature and relative humidity; relative humidity decreases with increase in temperature.
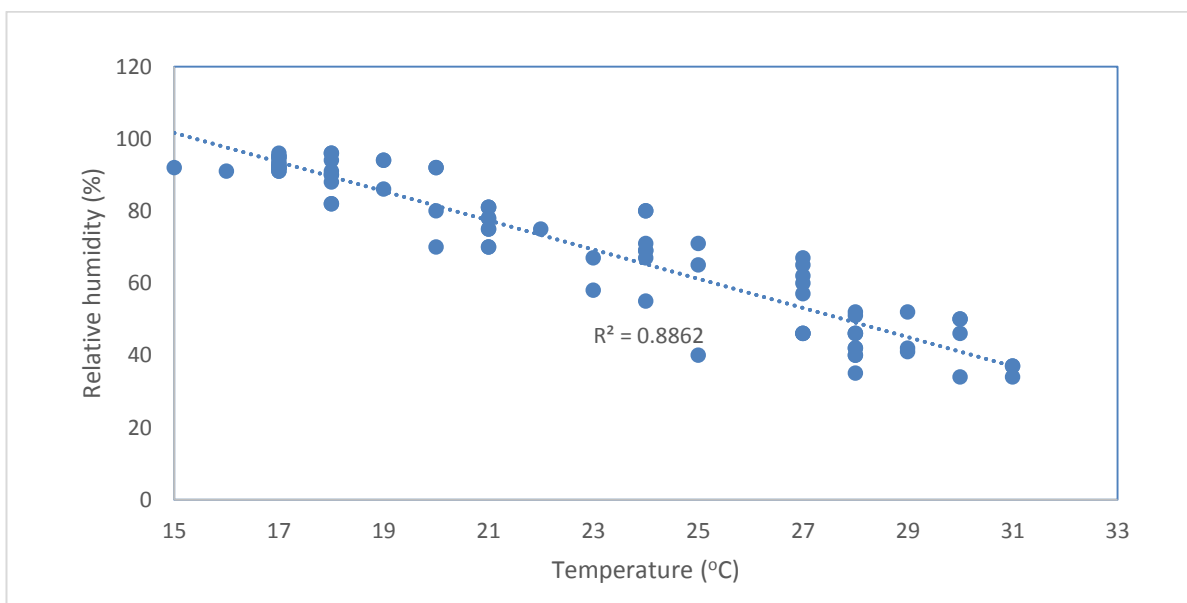
Figure 4.21: Correlation between relative humidity and temperature.

4.3.5 Discussion

The linear regression analysis indicated that the correlation between $PM_{2.5}$ and relative humidity was negative with coefficients of -0.0606 in Canada (Liu, Jane & Cui, Siliang. (2014)). This means that is, the $PM_{2.5}$ concentration decreases with increasing relative humidity this was different with the linear regression coefficient in this study of positive 0.45. A negative correlation between PMs and wind speed lower than 3 m/s was observed and positive correlation between PMs and wind speed higher than 3 m/s. When the wind speed is low, it can blow away the pollutants within a certain geographical range but, when the wind speed is high enough, it can transport large quantities of pollutants from far away.

For meteorological variables which include temperature, humidity and wind speed, the hourly average values, for 24 h during February 2016 to March 2016, were used. This was done because PM_{10} and $PM_{2.5}$ values have the largest range in some days, which allowed for identifying the correlations with meteorological variables. Fairly good correlation coefficients were obtained between PM mass concentrations and wind velocity (–0.49 and –0.33) for fine, and coarse PM, respectively. The correlation coefficient of relative humidity and PMs was positive. The negative sign indicates that, in general, high wind speeds favor the dispersion of atmospheric pollutants and reduce PM concentrations, while low wind speeds allow pollution levels to rise.

In other studies, weather pattern favouring the transport is suggested to indicate that when it was hot, humid, and stagnant with southerly or south-westerly winds, the likelihood of high $PM_{2.5}$ occurrences was high. The Greater Golden Horseshoe and Southwestern Ontario regions had higher $PM_{2.5}$ (6–12 $\mu g/m^3$ annually) than the northern region (4-6 $\mu g/m^3$), (Liu, Jane & Cui, Siliang. (2014)). reflecting combined effects of meteorology, regional transport, and local emissions. This can be compared with the concentration of $PM_{2.5}$ from different sampling sites which were higher in industrial (7.7-72 $\mu g/m^3$,) than the other sampling sites with 13-31 $\mu g/m^3$ concentration of $PM_{2.5.}$

4.4 Heavy Metal Concentration in PM_{10} in Ambient Air

Table 4.4 shows the average concentration of 6 heavy metals in PM_{10}.particulate matter in residential, controlled and industrial areas. The concentration levels for mercury and zinc, were below detectable levels. From the same samples manganese, chromium, cadmium and arsenic was determined to understand the metallic composition of the same samples. These metals analysed are considered to be carcinogenic and significantly high concentration of PM_{10} was analysed. Unfortunately, both globally and nationally no clear regulations or policies which are set to regulate their emission in the environment. This is a very big gap in our policies and regulations.

Table 4.4: Spatial variability of air pollutants in selected points in Nairobi city county

Element	Residential		Controlled		Industrial	
	Mean	Range	Mean	Range	Mean	Range
Lead	0.07	0 - 0.16	0.34	0.001 - 0.988	1.10	0.099 - 1.75
Arsenic	0.01	0 - 0.03	0.03	0.001 - 0.09	0.08	0.004 -0.23
Cadmium	0.007̅	0 - 0.03	0.033	0 - 0.2	0.00	0 -0.0123
Chromium	0.06	0 - 0.18	0.17̅1̅	0 - 0.54	0.86	0.195 - 1.67
Manganese	0.79	0.23 - 2.17	0.347	0.06 - 1.0	0.381	0.001 - 1.55

Global policies and regulation have clearly stated the allowable lead concentrations in the ambient air, this enables the emitters to be regulated and enable them to monitor what amount is emitted in the air. Nationally the EMCA (Air Quality Regulations 2014) has also provided the allowable values of lead and these has enabled the manufacturers who are main emitters to regulate and monitor how much is released to the ambient air while on the other no single mention of arsenic which very poisonous when released in the environment. Lack of the of these policies means Arsenic cannot be monitored, which level is harmful to both human and

environment. When there is no information to show the harmful levels of these carcinogenic components, will translate to increased health issues linked to air pollution which can be very vital. The synergistic effects of the carcinogenic metals and compound have been addressed EPA and EMCA, the synergistic effects of lead in presence of zinc is considered more dangerous in other studies than individual metal effects. The PM_{10} samples collected were analysed for the heavy metals.

Manganese is associated with petroleum products used in transportation. Manganese is released to the environment from industrial emissions and fossil fuel combustion. Almost 80% of industrial emissions of manganese are attributable to iron and steel production facilities (EPA 2003a). Manganese may also be released to the environment through the use of Methylcyclopentadienyl Manganese Tricarbonyl (MMT) as a gasoline additive. Manganese adsorbed to particulate matter in air can be classified by the size of the particles. Fuel combustion from household activities and vehicular emission from fuel additives are the major sources of manganese in residential and controlled areas. Mercury, Nickel and Zinc were below detectable levels.

The concentration of lead in PM_{10} was analysed and the results are presented in Figure 4.22. The levels were mostly above the EPA thresholds but lower than the EMCA standards. The presence of lead in the respirable particulate matter ($< 10\mu m$) poses high risks of health to human in the Nairobi city and its environs.

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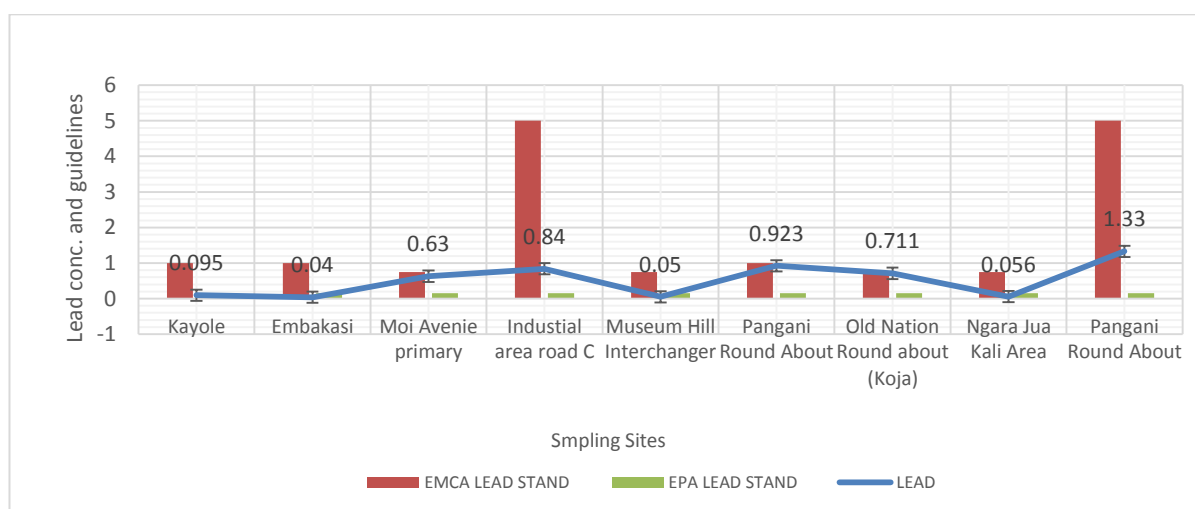
Figure 4.22: Comparing lead concentration in ambient air with EMCA and EPA standards.

The source of the particulate matter will give rough idea of the expected composition of the particulate matter. But understanding the composition of the particulate matter can also direct the possible source of the particulate matter. By determining and understating the trend of the particulate matter, both inorganic and organic can support to in understanding the possible effects on human and environmental health. Global and national policies and regulations have no guidelines for the inorganic components except lead in ambient air. The allowable limits of these carcinogenic components has not been determined hence the harmful level of either individual element or compound is unknown. At this times of economic growth with too many manufacturing industries will translate to increased number of hospitalization and also development of new health complications which are associated with air pollution. The primary and secondary sources of the particulate matter results to particulate matter which composes of multiple organic and inorganic components. The synergistic effects of these multiple carcinogenic element to human and environment it's not defined and some regulation to be set to enable easy monitoring. The Nairobi dwellers and the environ who can be the main receptors will be affected. Through bioaccumulation many organisms might be in danger for future generations. The essence of studying particulate matter is to understand its composition to be able regulate the emission and monitor to mitigate current and future health issues for both human and environment.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

(i) With regard to concentration levels in Nairobi city it was established that: the highest recorded PM_{10} concentration levels were 109 µg/m^3, 86 µg/m^3 and 45µg/m^3 in industrial, residential and in controlled areas, respectively; the $PM_{2.5}$ concentration levels in industrial and residential areas were way above set permissible standards by the EPA; and that the highest level for $PM_{2.5}$ concentrations was 72 µg/m^3 in industrial areas and 41 µg/m^3 in residential areas. In reference to spatial distribution of the PM_{10} and $PM_{2.5}$ concentrations industrial areas recorded the highest values of 109µg/m^3 and 72µg/m^3, respectively, while controlled areas registered concentration levels of 45µg/m^3 and 31µg/m^3, respectively. Residential areas recorded the highest levels 86µg/m^3 and 41µg/m^3 for PM_{10} and $PM_{2.5}$, respectively.

(ii) The weather factors had both positive and negative effect on the particulate matter. Most of individual weather factors have positive correlation the particulate matter concentration but because it's not possible to separate these parameters and test each individually negative or very weak positive relation was observed. The lowest concentration levels of PM_{10} and $PM_{2.5}$ were recorded at night due to low temperatures, high relative humidity and low wind speed as particles had low mobility. The direction of wind dictates the composition while the speed dictates on the receptor site of the particulate matter. The particulate matter concentration was highly impacted, both negatively and positively by metrological weather conditions.

(iii) The high heavy metal concentration in the particulate matter were found in residential, controlled and industrial areas, lead-and manganese were significantly present. Lead concentration levels of 1.33µg/m^3 were beyond the harmful limits set by EPA standards but were within EMCA 2014 standards in controlled sampled areas.

5.2 Recommendations Emanating from the Study

(i) The study established that there are no sufficient set regulations for particulate matter (PM_{10} and $PM_{2.5}$) management. EPA and EMCA 2014 provides clear standards for lead and mercury but no guidelines for other heavy metals. On the other hand, EMCA 2014 has clear standards on the PM_{10} acceptable concentrations but no clear regulation on $PM_{2.5}$ acceptable levels. Hence, there is need for establishment of these standards (locally and globally)

(ii) EMCA 2014 standards provides different standards for different categories, which poses danger in cross-boundary movement of the particulate matter across the categories. From the study the following recommendations are proposed; review, evaluation and improvement of EPA and National (EMCA) policies governing the ambient air quality as soon as possible. PM_{10} which is referred as respirable particulate matter (<10) and its high concentration in the cities poses a threat to human health currently and in the near future. Most of the heavy metals are carcinogenic and other toxic in nature and regulations should provide guiding values for the carcinogenic and other toxic elements and their compound in the respirable particulate matter (<10μm). Industries should develop techniques for the safe disposal of carcinogenic-containing wastes and effluents.

(iii) The set standards for the concentrations of particulate matter should be uniform/harmonized across the residential, Controlled and industrial areas because air knows no boundaries. This will enable easy implementation of the standards across all areas for improved to air quality.

5.3 Areas of Further Studies

(i) Further studies should be carried out on the impacts of specific carcinogenic heavy metals and their compound on public health and welfare.

(ii) Secondly, other factors that contributes to particulate matter concentration other than temperature should be investigated in future studies.

(iii) Finally, there is need for conducting studies on primary sources of each carcinogenic heavy metal and modelling of the possible receptor sites of the main urban areas and impact quantification.

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Appendix I: Computation of PM_{10} Concentration Levels for Embakasi Sampling Site

Table A1: PM_{10} concentration levels computation

Filter #	Before measurement				After measurement				PM_{10} (mg)	PM_{10} (μg)
	WT1	**WT2**	**WT3**	**Ave**	**WT1**	**WT2**	**WT3**	**Ave**		
EMP1	0.08963	0.08963	0.08963	**0.08963**	0.08967	0.08967	0.08967	**0.08967**	**0.04**	**40**
EMP2	0.08995	0.08995	0.08995	**0.08995**	0.08999	0.09000	0.09000	**0.09000**	**0.05**	**47**
EMP3	0.09051	0.09051	0.09050	**0.09051**	0.09060	0.09059	0.09059	**0.09059**	**0.09**	**87**
EMP4	0.09012	0.09012	0.09012	**0.09012**	0.09018	0.09018	0.09018	**0.09018**	**0.06**	**60**
EMP5	0.09022	0.09023	0.09023	**0.09023**	0.09030	0.09030	0.09030	**0.09030**	**0.07**	**73**
EMP6	0.08975	0.08976	0.08976	**0.08976**	0.08987	0.08987	0.08986	**0.08987**	**0.11**	**110**
EMP7	0.09080	0.09080	0.09080	**0.09080**	0.09087	0.09087	0.09087	**0.09087**	**0.07**	**70**
EMP8	0.09076	0.09075	0.09075	**0.09075**	0.09088	0.09088	0.09087	**0.09088**	**0.12**	**123**
EMP9	0.09040	0.09040	0.09040	**0.09040**	0.09050	0.09050	0.09050	**0.09050**	**0.10**	**100**

In the table: EMP, Embakasi

Table A2: PM$_{10}$ MiniVol log sheet

Filter Ref No.	Start Time	Start Elapse Time Reading (hrs)	Flow Rate (l/min)	Finish Time	Finish Elapse Time Reading (hrs)	No of Hours	Total Vol sampled (m^3)	Mass PM$_{10}$ collected (µg)	PM$_{10}$ (ug/m^3)
EMP1	10:15:00	1751	5.0	13:00:00	1757	5.5	1.65	40	24
EMP2	10:30:00	1757	5.0	18:30:00	1762	5.5	1.65	47	28
EMP3	13:30:00	1762	5.0	06:00:00	1774	11.5	3.45	87	25
EMP4	12:00:00	1774	5.0	12:00:00	1780	6.0	1.80	60	33
EMP5		1780	5.0	19:00:00	1787	7.0	2.10	73	35
EMP6		1787	5.0	06:00:00	1798	11.0	3.30	110	33
EMP7		1798	5.0	12:30:00	1804	6.5	1.95	70	36
EMP8		1804	5.0	19:00:00	1811	6.5	1.95	123	63
EMP9		1811	5.0	06:00:00	1822	11.0	3.30	100	30

Table A3: PM$_{2.5}$ concentration levels computation

Filter #	Before measurement				After measurement				PM$_{2.5}$ (mg)	PM$_{2.5}$ (µg)
	WT1	WT2	WT3	Ave	WT1	WT2	WT3	Ave		
EMP1	0.09090	0.09090	0.09090	**0.09090**	0.09092	0.09093	0.09093	**0.09093**	**0.03**	**27**
EMP2	0.09089	0.09089	0.09089	**0.09089**	0.09092	0.09092	0.09092	**0.09092**	**0.03**	**30**
EMP3	0.09088	0.09088	0.09088	**0.09088**	0.09091	0.09092	0.09092	**0.09092**	**0.04**	**37**
EMP4	0.09089	0.09089	0.09089	**0.09089**	0.09093	0.09093	0.09093	**0.09093**	**0.04**	**40**
EMP5	0.09090	0.09090	0.09090	**0.09090**	0.09095	0.09096	0.09096	**0.09096**	**0.06**	**57**
EMP6	0.09087	0.09087	0.09087	**0.09087**	0.09091	0.09092	0.09092	**0.09092**	**0.05**	**47**
EMP7	0.09091	0.09090	0.09090	**0.09090**	0.09094	0.09093	0.09094	**0.09094**	**0.03**	**33**
EMP8	0.09091	0.09091	0.09091	**0.09091**	0.09099	0.09099	0.09099	**0.09099**	**0.08**	**80**
EMP9	0.09088	0.09089	0.09089	**0.09089**	0.09097	0.09097	0.09097	**0.09097**	**0.08**	**83**

Table A4: PM$_{2.5}$ MiniVol log sheet

Filter Ref No.	Start Time	Start Elapse Time Reading (hrs)	Flow Rate (lpm)	Finish Time	Finish Elapse Time Reading (hrs)	No of Hours	Total Vol sampled (m^3)	Mass PM$_{2.5}$ collected (µg)	PM$_{2.5}$ (µg/m^3)
EMP1	10:15:00	1457	5.0	13:00:00	1462	5.5	1.65	27	16
EMP2	10:30:00	1462	5.0	18:30:00	1468	5.5	1.65	30	18
EMP3	13:30:00	1468	5.0	06:00:00	1479	11.5	3.45	37	11
EMP4	12:00:00	1479	5.0	12:00:00	1485	6.0	1.80	40	22
EMP5		1485	5.0	19:00:00	1492	7.0	2.10	57	27

EMP6		1492	5.0	06:00:00	1503	11.0	3.30	47	14
EMP7		1503	5.0	12:30:00	1510	6.5	1.95	33	17
EMP8		1510	5.0	19:00:00	1516	6.5	1.95	80	41
EMP9		1516	5.0	06:00:00	1527	11.0	3.30	83	25

Table A6: Arsenic concentration in PM$_{10}$ computation

Filter Ref No.	mass of sample (µg)	As (mg/kg)	mg	µg	volume sampled	Concentration µg/m^3
EMP1	40.00000	0.04000	0.00000	0.00	1.65	0.0010
EMP2	47.00000		0.00000	0.00	1.65	0.0000
EMP3	87.00000	0.08000	0.00001	0.01	3.45	0.0020
EMP4	60.00000		0.00000	0.00	1.80	0.0000
EMP5	73.00000		0.00000	0.00	2.10	0.0000
EMP6	110.00000		0.00000	0.00	3.30	0.0000
EMP7	70.00000	0.72000	0.00005	0.05	1.95	0.0258
EMP8	123.00000		0.00000	0.00	1.95	0.0000
EMP9	100.00000	0.00000	0.00000	0.00	3.30	0.0000

Table A7: Cadmium concentration levels in PM$_{10}$ computation

Filter Ref No.	mass of sample (µg)	Cd (mg/kg)	mg	µg	volume sampled	Concentration µg/m^3
EMP1	40.00000	0.00000	0.00000	0.00	1.65	0.0000
EMP2	47.00000		0.00000	0.00	1.65	0.0000
EMP3	87.00000	0.07000	0.00001	0.01	3.45	0.0018
EMP4	60.00000		0.00000	0.00	1.80	0.0000
EMP5	73.00000		0.00000	0.00	2.10	0.0000
EMP6	110.00000		0.00000	0.00	3.30	0.0000
EMP7	70.00000	0.73000	0.00005	0.05	1.95	0.0262
EMP8	123.00000		0.00000	0.00	1.95	0.0000
EMP9	100.00000	0.00000	0.00000	0.00	3.30	0.0000

Table A8: Chromium concentration levels in PM$_{10}$ computation

Filter Ref No.	mass of sample (µg)	Cr (mg/kg)	mg	µg	volume sampled	Concentration µg/m^3
EMP1	40.00000	1.49000	0.00006	0.06	1.65	0.0361
EMP2	47.00000		0.00000	0.00	1.65	0.0000
EMP3	87.00000	7.07000	0.00062	0.62	3.45	0.1783
EMP4	60.00000		0.00000	0.00	1.80	0.0000
EMP5	73.00000		0.00000	0.00	2.10	0.0000
EMP6	110.00000		0.00000	0.00	3.30	0.0000
EMP7	70.00000	0.00000	0.00000	0.00	1.95	0.0000
EMP8	123.00000		0.00000	0.00	1.95	0.0000
EMP9	100.00000	0.00000	0.00000	0.00	3.30	0.0000

Table A9: Lead concentration levels in PM$_{10}$ computation

Filter Ref No.	mass of sample (µg)	Pb (mg/kg)	mg	µg	volume sampled	Concentration µg/m^3
EMP1	40.00000	0.41000	0.00002	0.02	1.65	0.0099
EMP2	47.00000		0.00000	0.00	1.65	0.0000
EMP3	87.00000	1.04000	0.00009	0.09	3.45	0.0262
EMP4	60.00000		0.00000	0.00	1.80	0.0000
EMP5	73.00000		0.00000	0.00	2.10	0.0000
EMP6	110.00000		0.00000	0.00	3.30	0.0000

EMP7	70.00000	3.17000	0.00022	0.22	1.95	0.1138
EMP8	123.00000		0.00000	0.00	1.95	0.0000
EMP9	100.00000	0.00000	0.00000	0.00	3.30	0.0000

Table A10: Manganese concentration levels in PM$_{10}$ computation

Filter Ref No.	mass of sample (µg)	Mn (mg/kg)	mg	µg	volume sampled	Concentration µg/m^3
EMP1	40.00000	15.72000	0.00063	0.63	1.65	0.3811
EMP2	47.00000		0.00000	0.00	1.65	0.0000
EMP3	87.00000	23.51000	0.00205	2.05	3.45	0.5929
EMP4	60.00000		0.00000	0.00	1.80	0.0000
EMP5	73.00000		0.00000	0.00	2.10	0.0000
EMP6	110.00000		0.00000	0.00	3.30	0.0000
EMP7	70.00000	24.47000	0.00171	1.71	1.95	0.8784
EMP8	123.00000		0.00000	0.00	1.95	0.0000
EMP9	100.00000	7.44000	0.00074	0.74	3.30	0.2255

Table B1: PM$_{10}$ concentration levels computation

Filter #	Before measurement				After measurement				PM$_{10}$ (mg)	PM$_{10}$ (µg)
	WT1	WT2	WT3	Ave	WT1	WT2	WT3	Ave		
KPM1	0.09090	0.09090	0.09090	**0.09090**	0.09097	0.09095	0.09098	**0.09097**	**0.07**	**67**
KPM2	0.09070	0.09070	0.09070	**0.09070**	0.09079	0.09078	0.09078	**0.09078**	**0.08**	**83**
KPM3	0.09088	0.09088	0.09087	**0.09088**	0.09097	0.09097	0.09097	**0.09097**	**0.09**	**93**
KPM4	0.09092	0.09092	0.09091	**0.09092**	0.09102	0.09102	0.09103	**0.09102**	**0.11**	**107**
KPM5	0.09077	0.09077	0.09077	**0.09077**	0.09089	0.09090	0.09089	**0.09089**	**0.12**	**123**
KPM6	0.09090	0.09090	0.09090	**0.09090**	0.09107	0.09107	0.09108	**0.09107**	**0.17**	**173**
KPM7	0.09085	0.09085	0.09085	**0.09085**	0.09101	0.09100	0.09100	**0.09100**	**0.15**	**153**
KPM8	0.09095	0.09095	0.09095	**0.09095**	0.09108	0.09108	0.09108	**0.09108**	**0.13**	**130**

In the table: KMP, Kayole

Table B2: PM$_{10}$ MiniVol log sheet

Filter Ref No.	Start Time	Start Elapse Time Reading (hrs)	Flow Rate (lpm)	Finish Time	Finish Elapse Time Reading (hrs)	No of Hours	Total Vol sampled (m^3)	Mass PM$_{10}$ collected (μg)	PM$_{10}$ (μg/m^3)
KMP1	10:15:00	1457	5.0	18:00:00	1464	7.2	2.16	67	31
KMP2	10:30:00	1464	5.0	06:00:00	1476	12.1	3.63	83	23
KMP3	13:30:00	1476	5.0	12:30:00	1483	6.4	1.92	93	48
KMP4	12:00:00	1483	5.0	18:30:00	1489	6.4	1.92	107	56
KMP5		1489	5.0	06:00:00	1501	11.5	3.45	123	36
KMP6		1501	5.0	13:00:00	1508	7.4	2.22	174	78
KMP7		1508	5.0	19:15:00	1514	6.0	1.80	154	86
KMP8		1514	5.0	06:00:00	1525	10.8	3.24	130	40

Table B3: PM$_{2.5}$ concentration levels computation

Filter #	Before measurement				After measurement				PM$_{2.5}$ (mg)	PM$_{2.5}$ (µg)
	WT1	WT2	WT3	Ave	WT1	WT2	WT3	Ave	PM$_{2.5}$ (mg)	PM$_{2.5}$ (µg)
KPM1	0.09089	0.09088	0.09088	**0.09088**	0.09091	0.09093	0.09093	**0.09092**	**0.04**	**40**
KPM2	0.09091	0.09091	0.09091	**0.09091**	0.09096	0.09097	0.09096	**0.09096**	**0.05**	**53**
KPM3	0.09088	0.09088	0.09088	**0.09088**	0.09093	0.09092	0.09093	**0.09093**	**0.05**	**47**
KPM4	0.09090	0.09090	0.09091	**0.09090**	0.09097	0.09096	0.09096	**0.09096**	**0.06**	**60**
KPM5	0.09090	0.09090	0.09090	**0.09090**	0.09097	0.09097	0.09097	**0.09097**	**0.07**	**70**
KPM6	0.09088	0.09088	0.09088	**0.09088**	0.09094	0.09094	0.09094	**0.09094**	**0.06**	**60**
KPM7	0.09089	0.09089	0.09089	**0.09089**	0.09095	0.09095	0.09096	**0.09095**	**0.06**	**63**
KPM8	0.09091	0.09091	0.09091	**0.09091**	0.09100	0.09100	0.09099	**0.09100**	**0.09**	**87**

Table B4: PM$_{2.5}$ MiniVol log sheet

Filter Ref No.	Start time	Start elapse time reading (hrs)	Flow rate (lpm)	Finish time	Finish elapse time reading (hrs)	No of Hrs	Total vol sampled (m^3)	Mass PM$_{2.5}$collected (µg)	PM$_{2.5}$ (µg/m^3)
KMP1	10:15:00	1355	5.0	18:00:00	1362	7.2	2.16	40	19
KMP2	10:30:00	1362	5.0	06:00:00	1374	12.1	3.63	53	15
KMP3	13:30:00	1374	5.0	12:30:00	1380	6.4	1.92	47	24
KMP4	12:00:00	1380	5.0	18:30:00	1387	6.4	1.92	60	31
KMP5		1387	5.0	06:00:00	1398	11.5	3.45	70	20
KMP6		1398	5.0	13:00:00	1406	7.4	2.22	60	27
KMP7		1406	5.0	19:15:00	1412	6.0	1.80	63	35
KMP8		1412	5.0	06:00:00	1422	10.8	3.24	87	27

Table B6: Arsenic concentration levels in PM$_{10}$ computation

Filter Ref No.	mass of sample (µg)	As (mg/kg)	mg	µg	volume sampled	Concentration µg/m^3
KMP1	67.00000	0.25000	0.00002	0.02	2.16	0.0078
KMP2	83.00000	0.08000	0.00001	0.01	3.63	0.0018
KMP3	93.00000		0.00000	0.00	1.92	0.0000
KMP4	107.00000		0.00000	0.00	1.92	0.0000
KMP5	123.00000		0.00000	0.00	3.45	0.0000
KMP6	173.00000	0.28000	0.00005	0.05	2.22	0.0218
KMP7	154.00000		0.00000	0.00	1.80	0.0000
KMP8	130.00000	0.06000	0.00001	0.01	3.24	0.0024

Table B7: Lead concentration levels in PM$_{10}$ computation

Filter Ref No.	mass of sample (µg)	Pb (mg/kg)	mg	µg	volume sampled	Concentration µg/m^3
KMP1	67.00000	3.10000	0.00021	0.21	2.16	0.0962
KMP2	83.00000	0.00000	0.00000	0.00	3.63	0.0000
KMP3	93.00000		0.00000	0.00	1.92	0.0000
KMP4	107.00000		0.00000	0.00	1.92	0.0000
KMP5	123.00000		0.00000	0.00	3.45	0.0000
KMP6	173.00000	2.00000	0.00035	0.35	2.22	0.1559
KMP7	154.00000		0.00000	0.00	1.80	0.0000
KMP8	130.00000	3.20000	0.00042	0.42	3.24	0.1284

Table B8: Chromium concentration levels in PM$_{10}$ computation

Filter Ref No.	mass of sample (µg)	Cr (mg/kg)	mg	µg	volume sampled	Concentration µg/m^3
KMP1	67.00000	2.16000	0.00014	0.14	2.16	0.0670
KMP2	83.00000	2.28000	0.00019	0.19	3.63	0.0521
KMP3	93.00000		0.00000	0.00	1.92	0.0000
KMP4	107.00000		0.00000	0.00	1.92	0.0000
KMP5	123.00000		0.00000	0.00	3.45	0.0000
KMP6	173.00000	0.15000	0.00003	0.03	2.22	0.0117
KMP7	154.00000		0.00000	0.00	1.80	0.0000
KMP8	130.00000	2.93000	0.00038	0.38	3.24	0.1176

Table B9: Manganese concentration levels in PM$_{10}$ computation

Filter Ref No.	mass of sample (µg)	Mn (mg/kg)	mg	µg	volume sampled	Concentration µg/m^3
KMP1	67.00000	10.87000	0.00073	0.73	2.16	0.3372
KMP2	83.00000	26.06000	0.00216	2.16	3.63	0.5959
KMP3	93.00000		0.00000	0.00	1.92	0.0000
KMP4	107.00000		0.00000	0.00	1.92	0.0000
KMP5	123.00000		0.00000	0.00	3.45	0.0000
KMP6	173.00000	14.18000	0.00245	2.45	2.22	1.1050
KMP7	154.00000		0.00000	0.00	1.80	0.0000
KMP8	130.00000	54.25000	0.00705	7.05	3.24	2.1767

Appendix III: Computation of PM_{10} and $PM_{2.5}$ Concentration Levels for Moi Avenue Primary School Sampling Site

Table C1: PM_{10} concentration levels computation

Filter #	Before measurement				After measurement				PM_{10} (mg)	PM_{10} (µg)
	WT1	WT2	WT3	Ave	WT1	WT2	WT3	Ave		
MMP1	0.08960	0.08960	0.08960	**0.08960**	0.08966	0.08966	0.08966	**0.08966**	**0.06**	**60**
MMP2	0.09021	0.09021	0.09021	**0.09021**	0.09023	0.09023	0.09024	**0.09023**	**0.02**	**23**
MMP3	0.09054	0.09054	0.09055	**0.09054**	0.09065	0.09065	0.09064	**0.09065**	**0.10**	**103**
MMP4	0.08950	0.08950	0.08950	**0.08950**	0.08957	0.08957	0.08957	**0.08957**	**0.07**	**70**
MMP5	0.08978	0.08978	0.08978	**0.08978**	0.08987	0.08987	0.08986	**0.08987**	**0.09**	**87**
MMP6	0.09175	0.09175	0.09175	**0.09175**	0.09186	0.09186	0.09186	**0.09186**	**0.11**	**110**
MMP7	0.08995	0.08995	0.08995	**0.08995**	0.09002	0.09003	0.09003	**0.09003**	**0.08**	**77**
MMP8	0.09082	0.09082	0.09082	**0.09082**	0.09090	0.09089	0.09089	**0.09089**	**0.07**	**73**
MMP9	0.08922	0.08922	0.08922	**0.08922**	0.08932	0.08932	0.08932	**0.08932**	**0.10**	**100**

In the table: MMP, Moi Avenue Primary School

Table C2: PM_{10} MiniVol log sheet

Filter Ref No.	Site Reference ID	Start Time	Start elapse time reading (hrs)	Flow rate (lpm)	Finish time	Finish elapse time reading (hrs)	No of hrs	Total Vol sampled (m³)	Mass PM_{10} collected (µg)	PM_{10} (µg/m³)
MMP1	RUN1	10:15:00	1852	5.0	13:40:00	1858	6.5	1.95	60	30.8
MMP2	RUN2	10:30:00	1858	5.0	18:00:00	1862	4.3	1.29	23	17.8
MMP3	RUN3	13:30:00	1862	5.0	06:30:00	1875	12.5	3.75	103	27.5
MMP4	RUN4	12:00:00	1875	5.0	12:00:00	1881	6.0	1.80	70	38.9
MMP5			1881	5.0	19:00:00	1888	7.0	2.10	87	41.4
MMP6			1888	5.0	06:00:00	1899	11.0	3.30	110	33.3
MMP7			1899	5.0	12:30:00	1905	6.5	1.95	77	39.5
MMP8			1905	5.0	19:00:00	1912	6.5	1.95	73	37.4
MMP9			1912	5.0	06:00:00	1923	11.0	3.30	100	30.3

Table C3: PM$_{2.5}$ concentration levels computation

Filter #	Before measurement				After measurement				PM$_{2.5}$(mg)	PM$_{2.5}$ (µg)
	WT1	WT2	WT3	Ave	WT1	WT2	WT3	Ave		
MMP1	0.09088	0.09088	0.09088	**0.09088**	0.09092	0.09091	0.09091	**0.09091**	**0.03**	**33**
MMP2	0.09090	0.09090	0.09090	**0.09090**	0.09091	0.09092	0.09092	**0.09092**	**0.02**	**17**
MMP3	0.09084	0.09084	0.09084	**0.09084**	0.09089	0.09090	0.09090	**0.09090**	**0.06**	**57**
MMP4	0.09087	0.09087	0.09087	**0.09087**	0.09091	0.09091	0.09092	**0.09091**	**0.04**	**43**
MMP5	0.09091	0.09091	0.09091	**0.09091**	0.09098	0.09098	0.09097	**0.09098**	**0.07**	**67**
MMP6	0.09086	0.09086	0.09086	**0.09086**	0.09092	0.09092	0.09092	**0.09092**	**0.06**	**60**
MMP7	0.09089	0.09089	0.09089	**0.09089**	0.09094	0.09095	0.09095	**0.09095**	**0.06**	**57**
MMP8	0.09084	0.09084	0.09084	**0.09084**	0.09090	0.09090	0.09090	**0.09090**	**0.06**	**60**
MMP9	0.09082	0.09082	0.09082	**0.09082**	0.09090	0.09090	0.09089	**0.09090**	**0.08**	**77**

Table C4: PM$_{2.5}$ MiniVol log sheet

Filter Ref No.	Start Time	Start elapse time reading (hrs)	Flow rate (lpm)	Finish time	Finish elapse time reading (hrs)	No of hrs	Total Vol sampled (mµ)	Mass PM10 collected (µg)	PM$_{2.5}$ (µg/m^3)
MMP1	10:15:00	1852	5.0	13:40:00	1858	6.5	1.95	33	17
MMP2	10:30:00	1858	5.0	18:00:00	1862	4.3	1.29	17	13
MMP3	13:30:00	1862	5.0	06:30:00	1875	12.5	3.75	56	15
MMP4	12:00:00	1875	5.0	12:00:00	1881	6.0	1.80	43	24
MMP5		1881	5.0	19:00:00	1888	7.0	2.10	66	31
MMP6		1888	5.0	06:00:00	1899	11.0	3.30	60	18
MMP7		1899	5.0	12:30:00	1905	6.5	1.95	57	29
MMP8		1905	5.0	19:00:00	1912	6.5	1.95	60	31
MMP9		1912	5.0	06:00:00	1923	11.0	3.30	77	23

Table C6: Arsenic concentration levels in PM$_{10}$ computation

Filter Ref No.	mass of sample (μg)	As (mg/kg)	mg	μg	volume sampled	Concentration μg/m^3
MMP1	60.00000	1.51000	0.00009	0.09	1.95	0.0465
MMP2	23.00000		0.00000	0.00	1.29	0.0000
MMP3	103.00000	1.81000	0.00019	0.19	3.75	0.0497
MMP4	70.00000	1.48000	0.00010	0.10	1.80	0.0576
MMP5	87.00000		0.00000	0.00	2.10	0.0000
MMP6	110.00000	0.08000	0.00001	0.01	3.30	0.0027
MMP7	77.00000		0.00000	0.00	1.95	0.0000
MMP8	73.00000		0.00000	0.00	1.95	0.0000
MMP9	100.00000		0.00000	0.00	3.30	0.0000

Table C7: Cadmium concentration levels in PM$_{10}$ computation

Filter Ref No.	mass of sample (µg)	Cd (mg/kg)	mg	µg	volume sampled	Concentration µg/m^3
MMP1	60.00000	0.00000	0.00000	0.00	1.95	0.0000
MMP2	23.00000		0.00000	0.00	1.29	0.0000
MMP3	103.00000	0.00000	0.00000	0.00	3.75	0.0000
MMP4	70.00000	0.00000	0.00000	0.00	1.80	0.0000
MMP5	87.00000		0.00000	0.00	2.10	0.0000
MMP6	110.00000	0.00000	0.00000	0.00	3.30	0.0000
MMP7	77.00000		0.00000	0.00	1.95	0.0000
MMP8	73.00000		0.00000	0.00	1.95	0.0000
MMP9	100.00000		0.00000	0.00	3.30	0.0000

Table C8: Chromium concentration level in PM$_{10}$ computation

Filter Ref No.	mass of sample (µg)	Cr (mg/kg)	mg	µg	volume sampled	Concentration µg/m^3
MMP1	60.00000	7.62000	0.00046	0.46	1.95	0.2345
MMP2	23.00000		0.00000	0.00	1.29	0.0000
MMP3	103.00000	7.80000	0.00080	0.80	3.75	0.2142
MMP4	70.00000	9.31000	0.00065	0.65	1.80	0.3621
MMP5	87.00000		0.00000	0.00	2.10	0.0000
MMP6	110.00000	7.18000	0.00079	0.79	3.30	0.2393
MMP7	77.00000		0.00000	0.00	1.95	0.0000
MMP8	73.00000		0.00000	0.00	1.95	0.0000

MMP9	100.00000		0.00000	0.00	3.30	0.0000

Table C9: Lead concentration levels in PM$_{10}$ computation

Filter Ref No.	mass of sample (µg)	Pb (mg/kg)	mg	µg	volume sampled	Concentration µg/m3
MMP1	60.00000	30.70000	0.00184	1.84	1.95	0.9446
MMP2	23.00000		0.00000	0.00	1.29	0.0000
MMP3	103.00000	33.57000	0.00346	3.46	3.75	0.9221
MMP4	70.00000	12.54000	0.00088	0.88	1.80	0.4877
MMP5	87.00000		0.00000	0.00	2.10	0.0000
MMP6	110.00000	5.23000	0.00058	0.58	3.30	0.1743
MMP7	77.00000		0.00000	0.00	1.95	0.0000
MMP8	73.00000		0.00000	0.00	1.95	0.0000
MMP9	100.00000		0.00000	0.00	3.30	0.0000

Table C10: Manganese concentration levels in PM$_{10}$ computation

Filter Ref No.	mass of sample (µg)	mn (mg/kg)	mg	µg	volume sampled	Concentration µg/m^3
MMP1	60.00000	11.16000	0.00067	0.67	1.95	0.3434
MMP2	23.00000		0.00000	0.00	1.29	0.0000
MMP3	103.00000	17.61000	0.00181	1.81	3.75	0.4837
MMP4	70.00000	27.32000	0.00191	1.91	1.80	1.0624
MMP5	87.00000		0.00000	0.00	2.10	0.0000
MMP6	110.00000	18.91000	0.00208	2.08	3.30	0.6303
MMP7	77.00000		0.00000	0.00	1.95	0.0000
MMP8	73.00000		0.00000	0.00	1.95	0.0000
MMP9	100.00000		0.00000	0.00	3.30	0.0000

Table C11: Mercury concentration levels in PM$_{10}$ computation

Filter Ref No.	mass of sample (µg)	Hg(mg/kg)	mg	µg	volume sampled	Concentration µg/m^3
MMP1	60.00000	0.00000	0.00000	0.00	1.95	0.0000
MMP2	23.00000		0.00000	0.00	1.29	0.0000
MMP3	103.00000	0.00000	0.00000	0.00	3.75	0.0000
MMP4	70.00000	0.00000	0.00000	0.00	1.80	0.0000
MMP5	87.00000		0.00000	0.00	2.10	0.0000
MMP6	110.00000	0.00000	0.00000	0.00	3.30	0.0000
MMP7	77.00000		0.00000	0.00	1.95	0.0000
MMP8	73.00000		0.00000	0.00	1.95	0.0000
MMP9	100.00000		0.00000	0.00	3.30	0.0000

Appendix IV: Computation of PM_{10} and $PM_{2.5}$ Concentration Levels for Industrial Area Sampling Site

Table D1: PM_{10} concentration levels for industrial area

Filter #	Before measurement				After measurement				PM_{10} (mg)	PM_{10} (μg)
	WT1	WT2	WT3	Ave	WT1	WT2	WT3	Ave		
IMP1	0.09070	0.09070	0.09070	**0.09070**	0.09089	0.09089	0.09089	**0.09089**	**0.19**	**190**
IMP2	0.09055	0.09055	0.09055	**0.09055**	0.09070	0.09071	0.09071	**0.09071**	**0.16**	**157**
IMP3	0.09100	0.09100	0.09100	**0.09100**	0.09121	0.09120	0.09120	**0.09120**	**0.20**	**203**
IMP4	0.09054	0.09054	0.09054	**0.09054**	0.09069	0.09068	0.09068	**0.09068**	**0.14**	**143**
IMP5	0.09052	0.09053	0.09052	**0.09052**	0.09064	0.09064	0.09065	**0.09064**	**0.12**	**120**
IMP6	0.08949	0.08949	0.08949	**0.08949**	0.08962	0.08962	0.08962	**0.08962**	**0.13**	**130**
IMP7	0.09060	0.09060	0.09060	**0.09060**	0.09067	0.09066	0.09067	**0.09067**	**0.07**	**67**
IMP8	0.09080	0.09081	0.09081	**0.09081**	0.09088	0.09088	0.09087	**0.09088**	**0.07**	**70**
IMP9	0.09060	0.09060	0.09060	**0.09060**	0.09069	0.09069	0.09070	**0.09069**	**0.09**	**93**

Table D2: PM$_{10}$ MiniVol log sheet

Filter Ref No.	Start Time	Start Elapse Time Reading (hrs)	Flow Rate (lpm)	Finish Time	Finish Elapse Time Reading (hrs)	No of Hours	Total Vol sampled (m^3)	Mass PM$_{10}$ collected (ug)	PM$_{10}$ (ug/m^3)
IMP1	10:15:00	1945	5.0	14:00:00	1951	6.5	1.95	190	97
IMP2	10:30:00	1951	5.0	18:45:00	1956	4.8	1.44	157	109
IMP3	13:30:00	1956	5.0	07:00:00	1968	12.3	3.69	203	55
IMP4	12:00:00	1968	5.0	13:30:00	1975	6.5	1.95	143	73
IMP5		1975	5.0	18:30:00	1980	5.0	1.50	120	80
IMP6		1980	5.0	07:00:00	1992	12.5	3.75	130	35
IMP7		1992	5.0	13:00:00	1998	6.0	1.80	67	37
IMP8		1998	5.0	18:30:00	2004	5.5	1.65	70	42
IMP9		2004	5.0	06:30:00	2016	12.0	3.60	93	26

Table D3: PM$_{2.5}$ concentration levels computation

Filter #	Before measurement				After measurement				PM$_{2.5}$ (mg)	PM$_{2.5}$ (µg)
	WT1	WT2	WT3	Ave	WT1	WT2	WT3	Ave		
IMP1	0.09085	0.09085	0.09085	**0.09085**	0.09093	0.09094	0.09094	**0.09094**	**0.09**	**87**
IMP2	0.09088	0.09088	0.09089	**0.09088**	0.09098	0.09099	0.09099	**0.09099**	**0.10**	**103**
IMP3	0.09089	0.09089	0.09090	**0.09089**	0.09099	0.09099	0.09099	**0.09099**	**0.10**	**97**
IMP4	0.09087	0.09087	0.09087	**0.09087**	0.09094	0.09095	0.09095	**0.09095**	**0.08**	**77**
IMP5	0.09090	0.09090	0.09090	**0.09090**	0.09096	0.09096	0.09096	**0.09096**	**0.06**	**60**
IMP6	0.09088	0.09088	0.09088	**0.09088**	0.09095	0.09095	0.09095	**0.09095**	**0.07**	**70**
IMP7	0.09090	0.09090	0.09090	**0.09090**	0.09093	0.09093	0.09094	**0.09093**	**0.03**	**33**
IMP8	0.09080	0.09081	0.09081	**0.09081**	0.09085	0.09085	0.09085	**0.09085**	**0.04**	**43**
IMP9	0.09090	0.09090	0.09090	**0.09090**	0.09095	0.09095	0.09095	**0.09095**	**0.05**	**50**

Table D4: PM$_{2.5}$ MiniVol log sheet

Filter Ref No.	Start Time	Start Elapse Time Reading (hrs)	Flow Rate (lpm)	Finish Time	Finish Elapse Time Reading (hrs)	No of Hours	Total Vol sampled (m^3)	Mass PM10 collected (µg)	PM10 (µg/m^3)
IMP1	10:15:00	1588	5.0	14:00:00	1595	6.5	1.95	87	45
IMP2	10:30:00	1951	5.0	18:45:00	1956	4.8	1.44	103	72
IMP3	13:30:00	1956	5.0	07:00:00	1968	12.3	3.69	97	26
IMP4	12:00:00	1968	5.0	13:30:00	1975	6.5	1.95	77	39
IMP5		1975	5.0	18:30:00	1980	5.0	1.50	60	40
IMP6		1980	5.0	07:00:00	1992	12.5	3.75	70	19
IMP7		1992	5.0	13:00:00	1998	6.0	1.80	33	18
IMP8		1998	5.0	18:30:00	2004	5.5	1.65	43	26
IMP9		2004	5.0	06:30:00	2016	12.0	3.60	50	14

Table D6: Arsenic concentration levels in PM$_{10}$ computation

Filter Ref No.	mass of sample (µg)	As(mg/kg)	mg	µg	volume sampled	Concentration µg/m^3
IMP1	190.00000	1.33000	0.00025	0.25	1.95	0.1296
IMP2	157.00000		0.00000	0.00	1.44	0.0000
IMP3	203.00000	0.81000	0.00016	0.16	3.69	0.0446
IMP4	143.00000		0.00000	0.00	1.95	0.0000
IMP5	120.00000		0.00000	0.00	1.50	0.0000
IMP6	130.00000		0.00000	0.00	3.75	0.0000
IMP7	67.00000	0.10000	0.00001	0.01	1.80	0.0037
IMP8	70.00000		0.00000	0.00	1.65	0.0000
IMP9	93.00000	1.80000	0.00017	0.17	3.60	0.0465

Table D7: Cadmium concentration levels in PM$_{10}$ computation

Filter Ref No.	mass of sample (μg)	Cd(mg/kg)	mg	μg	volume sampled	Concentration μg/m^3
IMP1	190.00000	0.00000	0.00000	0.00	1.95	0.0000
IMP2	157.00000		0.00000	0.00	1.44	0.0000
IMP3	203.00000	0.00000	0.00000	0.00	3.69	0.0000
IMP4	143.00000		0.00000	0.00	1.95	0.0000
IMP5	120.00000		0.00000	0.00	1.50	0.0000
IMP6	130.00000		0.00000	0.00	3.75	0.0000
IMP7	67.00000	0.07000	0.00000	0.00	1.80	0.0026
IMP8	70.00000		0.00000	0.00	1.65	0.0000
IMP9	93.00000	0.00000	0.00000	0.00	3.60	0.0000

Table D8: Cadmium concentration levels in PM$_{10}$ computation

Filter Ref No.	mass of sample (μg)	Cr(mg/kg)	mg	μg	volume sampled	Concentration μg/m^3
IMP1	190.00000	6.89000	0.00131	1.31	1.95	0.6713
IMP2	157.00000		0.00000	0.00	1.44	0.0000
IMP3	203.00000	28.17000	0.00572	5.72	3.69	1.5497
IMP4	143.00000		0.00000	0.00	1.95	0.0000
IMP5	120.00000		0.00000	0.00	1.50	0.0000
IMP6	130.00000		0.00000	0.00	3.75	0.0000
IMP7	67.00000	8.30000	0.00056	0.56	1.80	0.3089
IMP8	70.00000		0.00000	0.00	1.65	0.0000
IMP9	93.00000	7.56000	0.00070	0.70	3.60	0.1953

Table D9: Lead concentration levels in PM$_{10}$ computation

Filter Ref No.	mass of sample (µg)	Pb(mg/kg)	mg	µg	volume sampled	Concentration µg/m^3
IMP1	190.00000	13.79000	0.00262	2.62	1.95	1.3436
IMP2	157.00000		0.00000	0.00	1.44	0.0000
IMP3	203.00000	28.17000	0.00572	5.72	3.69	1.5497
IMP4	143.00000		0.00000	0.00	1.95	0.0000
IMP5	120.00000		0.00000	0.00	1.50	0.0000
IMP6	130.00000		0.00000	0.00	3.75	0.0000
IMP7	67.00000	9.79000	0.00066	0.66	1.80	0.3644
IMP8	70.00000		0.00000	0.00	1.65	0.0000
IMP9	93.00000	3.84000	0.00036	0.36	3.60	0.0992

Table D10: Manganese concentration levels in PM$_{10}$ computation

Filter Ref No.	mass of sample (µg)	Mn(mg/kg)	mg	µg	volume sampled	Concentration µg/m^3
IMP1	190.00000	15.90000	0.00302	3.02	1.95	1.5492
IMP2	157.00000		0.00000	0.00	1.44	0.0000
IMP3	203.00000	7.92000	0.00161	1.61	3.69	0.4357
IMP4	143.00000		0.00000	0.00	1.95	0.0000
IMP5	120.00000		0.00000	0.00	1.50	0.0000
IMP6	130.00000		0.00000	0.00	3.75	0.0000
IMP7	67.00000	11.46000	0.00077	0.77	1.80	0.4266
IMP8	70.00000		0.00000	0.00	1.65	0.0000
IMP9	93.00000	12.79000	0.00119	1.19	3.60	0.3304

Table D11: Mercury concentration levels in PM$_{10}$ computation

Filter Ref No.	mass of sample (µg)	Hg(mg/kg)	mg	µg	volume sampled	Concentration µg/m^3
IMP1	190.00000	0.00000	0.00000	0.00	1.95	0.0000
IMP2	157.00000		0.00000	0.00	1.44	0.0000
IMP3	203.00000	0.00000	0.00000	0.00	3.69	0.0000
IMP4	143.00000	0.00000	0.00000	0.00	1.95	0.0000
IMP5	120.00000		0.00000	0.00	1.50	0.0000
IMP6	130.00000	0.00000	0.00000	0.00	3.75	0.0000
IMP7	67.00000		0.00000	0.00	1.80	0.0000
IMP8	70.00000		0.00000	0.00	1.65	0.0000
IMP9	93.00000		0.00000	0.00	3.60	0.0000

Appendix V: PM$_{10}$ computation for CBD

Table E1: MP1, Museum Hill Interchanger

Filter Ref No.	Start Date	Finish Date	PM10 (µg/m3)
PS 1	2nd April. 2015	3rd April. 2015	24
PS 2	3rd April. 2015	4th April. 2015	26
PS 3	4th April. 2015	5th April. 2015	22
PS 4	5th April. 2015	6th April. 2015	27

Table E2: MP2, Pangani Round About

Filter Ref No.	Start Date	Finish Date	PM10 (µg/m3)
PS 5	2nd April. 2015	3rd April. 2015	25
PS 6	3rd April. 2015	4th April. 2015	22
PS 7	4th April. 2015	5th April. 2015	20

Table E3: MP3, Old Nation Round about (Koja)

Filter Ref No.	Start Date	Finish Date	PM10 (µg/m3)
PS 9	2nd April. 2015	3rd April. 2015	24
PS 10	3rd April. 2015	4th April. 2015	25
PS 11	4th April. 2015	5th April. 2015	22
PS 12	5th April. 2015	6th April. 2015	25

Table E4: MP5, Industrial Area Round About (Enterprise Road)

Filter Ref No.	Start Date	Finish Date	PM10 (µg/m3)
PS 17	6th April. 2015	7th April. 2015	18
PS 18	7th April. 2015	8th April. 2015	14
PS 19	8th April. 2015	9th April. 2015	16
PS 20	9th April. 2015	10th April. 2015	15

Table E6: MP1, Museum Hill Interchanger

locations	Filter Ref No.	manganese	units
Museum Hill Interchanger	PS 1	0.31	µg/m3
	PS 2	0.33	µg/m3
	PS 3	0.35	µg/m3
	PS 4	0.08	µg/m3

Table E7: MP2, Pangani Round About

locations	Filter Ref No.	manganese	units
Pangani Round About	PS 5	0.33	µg/m3
	PS 6	0.35	µg/m3
	PS 7	0.09	µg/m3
	PS 8	0.33	µg/m3

Table E8: MP3, Old Nation Round about (Koja)

locations	Filter Ref No.	manganese	units
Old Nation Round about (Koja)	PS 9	0.06	µg/m3
	PS 10	0.06	µg/m3
	PS 11	0.06	µg/m3
	PS 12	0.29	µg/m3

Table E9: MP4, Ngara Jua Kali Area

locations	Filter Ref No.	manganese	units
Ngara Jua Kali Area	PS 13	0.07	µg/m3
	PS 14	0.09	µg/m3
	PS 15	0.06	µg/m3
	PS 16	0.05	µg/m3

Table E10: MP5, Industrial Area Round about (Enterprise Road)

Locations	Filter Ref No.	manganese	units
Industrial Area Round About (Enterprise Road)	**PS 17**	0.10	**µg/m3**
	PS 18	0.001	**µg/m3**
	PS 19	0.10	**µg/m3**
	PS 20	0.11	**µg/m3**