UNIVERSITY OF NAIROBI

DEPARTMENT OF METEOROLOGY

SCHOOL OF PHYSICAL SCIENCES

ANTHROPOGENIC CONTRIBUTION TO AIR POLLUTION WITH BACKGROUND EMISSIONS; CASE OF NAIROBI, MOMBASA AND KISUMU

By

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Reg No: I54/83387/2015

A MASTER'S PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN CLIMATE CHANGE SCHOOL OF PHYSICAL SCIENCES, UNIVERSITY OF NAIROBI.

2018

DECLARATION

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

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Acknowledgements

I thank the Almighty God for giving me strength and resources that have enabled me to pursue this MSc in Climate Change degree course.

This research project would not have been successful without the support and guidance of a number of people who made their contribution in various ways.

I would like to express my thanks and appreciation to my supervisors Prof. Muthama, Prof. Onwonga and Dr. Ngaina of the University of Nairobi for their support, patience, motivation, critique, being with me and for all the long hours they took to review this project at the expense of their busy schedule.

I would also like to thank my family for being very supportive. Thanks for being with me during the difficult times, for your love, inspiration and encouragement.

DEDICATION

To my late Dad, Mum, My brothers and Sisters, My wife and baby Sheryl….

Your support I cannot measure.

ABSTRACT

This study aimed at assessing the contribution of human beings to pollution levels in Nairobi, Kisumu and Mombasa; and helping understand the pollution trends in changing climate. The study followed a Driver-Pressure-State-Impact and Response (DPSIR) framework where cause-effect-response model was adopted. Mt Kenya Global Atmosphere Watch (GAW) station was used as background station with the assumption of natural pollution occurrence. The pollutants that were studied include Particulate Matter ($PM_{2.5}$), Sulphur dioxide (SO_2) and Carbon dioxide (CO_2). The pollution dataset was sourced from Modern-Era Retrospective Analysis for Research and Application (MERRA – 2) while wind data was sourced from Kenya meteorological department (KMD) from 2000 to 2016. Time series and correlation analysis were used to describe data characteristics while cross-sectional analysis was done to ascertain spatial behavior of pollutants. Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) and Wind Rose plotting (Wrplot) were used to determine wind trajectory and wind frequency

The study found that $PM_{2.5}$, SO_2 and CO_2pollution levels varied in both time and space based on the position of the Inter-Tropical Convergence Zone (ITCZ). The amounts of the pollutant however had close resemblance for seasonal cycles. The winds in all the three cities exhibited variable tendencies that were also based on the position of the sun. When the sun is in the northern hemisphere, the winds showed moderate to strong south-southerly in most stations and northeasterly to easterly during southern summer.

Within the MAM and SON seasons dominant winds were light to moderate easterlies and sometimes southeasterly. However, the spatial and temporal interactions with different scales bring in a different flow characteristics of wind. This differential scale otherwise known as inhomogenity, is seen in most stations that have built canopy particularly in urban centers. Moreover, the densely populated built structures that alter the flow of pollutants complicate the nature of flow. Northeasterly and easterly winds correlated with higher levels of pollutants in all stations while southerly winds contributed to pollutants though the levels were low.CO_2 did not show high variation except for Mombasa station while there were correlations of more pollutants during dry seasons of the year. The pollutants were dispersed beyond 50 km within short periods with least dispersion occurring during the long rain season.

The findings of this study indicate that background emission is increasing at a lower rate compared to increases at station located in urban areas due to human activities. The main contributors to the burden of pollutants in the near surface atmosphere are thus human activities followed by wind and other natural factors. Therefore, the study recommends for a consultative planning process of the management of urban centers that accounts not only for the expected increased human activities but also for the observed wind characteristics and other natural factors over the towns.

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Acronyms

DPSIR : Driver-Pressure-State-Impact and Response

EMCA : Environmental Management Coordination Act

GAW : Global Atmospheric Watch

GHGs : Greenhouse Gases

HAP : Household Air Pollution

IPCC : Inter-Governmental Panel for Climate Change

ITCZ : Inter-Tropical Convergence Zone

KNBs : Kenya National Bureau of Statistics

NEMA : National Environmental Management Authority

OECD : Organization of Economic Cooperation and Development

UNDP : United Nations Development Program

UNEP : United Nations Environmental Program

URTI : Upper Respiratory Tract infection

VOCs : Volatile Organic Compounds

WHO : World Health Organization

CHAPTER ONE: INTRODUCTION

1.0 Background

Human beings need clean air as a basic requirement for good human health and his well-being (WHO 2012). Yet, air pollution remains a serious threat to life. A report by the World Health Organization (WHO, 2012) gave a worrying figure in terms of global air pollution contribution to mortality. The data released attributed seven million deaths to poor air quality in 2012 and double the figure released in 2004. These values show a reduction of desirable quality of air globally with two million premature deaths attributed to exposure to urban outdoor pollution and indoor pollution mostly as a result of burning of the solid fuel. What is more striking is the fact that most of this happens in the developing countries (WHO 2012).

Sulphur dioxide(SO_2), nitrogen oxide (NO) and nitrogen dioxide (NO2), carbon dioxide (CO_2), carbon monoxide (CO), and particulate matter (PM) are the critical pollutants that cause environmental and air pollution. These critical pollutants undergo chemical transformation in the atmosphere, leading to formation of secondary pollutants with the example of Sulfuric acid (H_2SO_4 - acid deposition) and ozone (O_3) (WHO, 2014). When these pollutants are spread by winds, they have a residency time of few days in the lower troposphere to several years in the uppers stratosphere. Normally within the lower troposphere, CO_2 stays for up to 5 days depending on the rate at which it is removed from the atmosphere while $SO_2$and PM stays up to two and 3 days respectively. Most of the pollutants are spread far off the origin depending on the mass and other chemical attributes and causing problems in some areas resulting to additional trans-boundary pollution problems (Hunter et al., 2002).

Due to this, there is a probability of environmental stress that is occasioned by population increase and this has an inherent health effect to the ecosystem, (State of the Environment, 2012). From this analogy, it is important to know the substance of pollutants and their significant distribution within the urban cities in Kenya. The main polluters emanate from industries and traffic, the vehicles with the motorbikes being the most contributors because of their increasing need in ballooning population (Hung, 2010). With this in mind, anthropogenic pollution is a significant contributor to poor air quality within developing nations(Hung, 2010).

Air pollution occurs partly as results of natural forces and human induced forces, and is exacerbated by anthropogenic activities. Volcanic eruptions, forest fires and dust are some of the examples of natural causes whilst industrial smoke, motor vehicle smoke constitute a continuous serious human induced pollution problem. The reason as to why this human induced pollution has a more influence is the fact that it occurs in human densely populated environments meaning the first-hand effects is on the inhabitants. Nairobi, the capital city, Mombasa the tourist hub, and Kisumu the Lakeside city are such areas in Kenya.

Dealing with air pollution is an issue that affects some more than others and with this in mind, there a probability of more effect to developing countries than the already developed. The developing countries have a poor strategy in dealing with air quality which makes them to be slave of the process of industrialization. Within this area a huge challenge emanates in balancing between which types of development, one that offers more economic abundance and another that favors the sustainability and cares about the environment; hence there is an out weighing of pollution mechanisms policies with short-term policies that have accrued benefits because of increased production and creation of jobs. Now, this overlooked important air management capabilities in these regions means pollution data apathy hence giving an assumption that all is well. This is on the contrary to the real case and only further shows the major pollution crisis in the developing world (Omanga et al., 2014).

Air pollution adversely impacts the environment and the magnitudes of the effects are mostly spread far beyond certain geographical boundaries. From the establishment of the United Nation Environmental Program (UNEP) in 1972, having its headquarters in Nairobi, there has been increased focus in terms of attention on national and international pollution effects. However, with this increased interest in pollution, a lot of efforts have been put towards reducing water related pollution and leaving the effects caused by air pollution still gaping, the negative effects of increased industrialization and resultant pollutant (Omanga et al., 2014).

Global perspective of the pollutants shows a varying trend, particularly for SO_2 and $PM_{2.5}$. Estimates of SO_2 are found from the historical records of the fossil, imports and industrial processing outputs dating back to 1850. Industrialization led to a different point in SO_2 magnitude which was occasioned with burning of Sulfur fuels. From this perspective, Europe led followed by North America in the rise of SO_2, which continued well in the 19^{th} and 20^{th} century. The trend of SO_2 emissions peaked in 1970 and 1980 in Europe and South America respectively with North America showing the lowest SO_2 emission than any other time in the 20^{th} century, and then a downward trend has been experienced in these areas (Klimont et al., 2013).

PM2.5 has a serious effect on respiratory tracts and even with the ease of having this pollutant measured at the ground level; there is still a challenge in sufficient monitoring network to do so globally. However, best estimates have been developed to come up with pollution estimation using combination of satellite data, air transport models and local meteorological conditions-this helps in giving global-level coverage of local air quality (Brauer, et al., 2016). From the global perspective, it was estimated that over 3.7 million die annually on premature deaths as at 2012 (WHO, 2012) and most the causes are the Particulate matter exposures.

In Kenya, air quality is deteriorating over the years which have manifested itself in increased Upper Respiratory Tract infection (URTI) particularly in urban centers. From this, Provisions of air quality regulations draft, (2014) was drafted to come up with a framework that helps in reducing the impacts of air pollution and also appropriate control technologies in pollution. There is general trend of increasing pollutant in Africa while the same cannot be said of developed states in Europe and America (Klimont et al., 2013, Brauer et al., 2016), with this there is lack of better framework in monitoring and management of pollution (Henne et al., 2008).

1.1Background Emissions

Background emissions can be defined as total concentration of pollutant which comprises those from explicit local emission devoid of human contribution, (Wang et al., 2011). In many ways the background emissions represent a significant or dominant proportion of the total pollution concentration; hence the addition concentration is assumed to be human induced. The areas that are assumed to have less effect of human activities are the oceans and heavily forested areas. As part of the Mt. Kenya National Park the whole mountain area is protected and there are no local anthropogenic emissions, making the site suitable for continuous observations of the background free tropospheric composition.

Mt. Kenya GAW station is located in eastern equatorial Africa it is largely unaffected by direct African biomass burning emissions that are most prominent in the western parts of the continent but insignificant in Kenya. This station was used to differentiate natural emissions from non-natural sources. The immediate surroundings to GAW is generally free from anthropogenic emission and makes atmospheric baseline measurements possible. The DJF season maximum was caused by advection of northern hemispheric air that is enriched in pollutants during the boreal winter. In contrast, JJA maximum was observed during advection of southern hemispheric air loaded with emissions from biomass burning in southern part of the region; however, these emissions were slightly low. Inter-annual variability in summer time pollutants could mostly be explained by a combination of changes in transport patterns and biomass burning intensity.

1.2 Problem Statement

The effect of anthropogenic pollution is with no doubt a cause to worry. Nature does not forgive if its limit is stretched to points where it breaks. To understand to leanings of pollution and its occurrence, a great depth of literature is needed particularly for the developing countries. There is a gap in understanding pollution in Kenyan urban cities, particularly with regard to health effects, built environment and ecosystem in general (Mulaku and Kariuki, 2001,Gatariet al., 2001,Gatari et al., 2004). However, with developed countries increasingly adding on pollution literature, there is still inadequate literature on Kenyan context on how to deal with (Cohen et al., 2004). The inception of the act that deals conservation of the environment (Kenya Government, 1999) and enacting of National Environmental Management Authority (NEMA), led to improved management of air quality to some extent. However, this still drags behind with professional capacity and framework still being an issue needed to urgently to spur the need to accurately monitor pollution.

To sum up all the aforementioned gaps, the main problem that we face is having no elaborate framework for monitoring of the anthropogenic pollution within cities in Kenya (Henne et al., 2008). With fewer studies concentrating on space-time distribution of emission, there is another gap in understanding the contribution trend and concentration of emission within urban centers. To understand the contribution of human induced air quality will help improve our understanding of anthropogenic contribution to air pollution over cities in Kenya and build a framework in its monitoring.

1.3Objectives of the study

The objective of this study is to examine anthropogenic contribution to air pollution with background emissions under changing climate.

The specific objectives are to:

i. Analyze spatial-temporal characteristics of SO_2, $PM_{2.5}$ and CO_2 in Nairobi, Mombasa and Kisumu.
ii. Study spatial-temporal characteristics of Winds in Nairobi, Mombasa and Kisumu.
iii. Evaluate the relationship between meteorological variables and air pollutants as indicator of air quality in Nairobi, Mombasa and Kisumu.
iv. Determine anthropogenic contribution to air quality in Nairobi, Mombasa and Kisumu.

1.4 Research Questions

i. What are the spatial-temporal characteristics of SO_2, $PM_{2.5}$ and CO_2 in Nairobi, Mombasa and Kisumu?
ii. What are the spatial-temporal characteristics of winds in Nairobi, Mombasa and Kisumu?
iii. What is the relationship between winds and air pollutants as the indicator of air quality in Nairobi, Mombasa and Kisumu?
iv. What is the anthropogenic contribution to air quality in Nairobi, Mombasa and Kisumu?

1.5 Significance of the study

Sustainable Development goals, goal number three which is specific with health issues talks about improvement of air quality and cities and human settlements (Goal 3). UNEA-1 resolution which strengthens the functions of UNEP in promoting and improving air quality affirms the importance of strong framework and support for clean air. In this regard, UNEP has promoted the use of affordable monitoring of air quality technology. This technology is effective in dealing with management of air quality and its effects to humans. Based on this, assessment of ambient air in determining trends and contributions are key to modeling pollution scenarios. It will be of great importance to note biomass burning effect to background emission.

Another twist will be the contribution of SO_2, CO_2, and $PM_{2.5}$ together with others contributing to the changing climate. This brings a different perception of urban emission which leads to urban heat island. It will be imperative to add to literature on anthropogenic contribution to emission trends.

Finally, the area of urban pollution in majority of African cities is still a grey area, as articulated by $PM_{2.5}$ exposure index (WHO 2012). Statistics show only less than 10% of the monitoring stations are in Africa, which begs the question of how best we are able to monitor pollution within our cities. Compared to other developed nations like France that has well elaborate monitoring system, we are far off in monitoring pollution. This study is important in understanding the current and future pollution in urban settlements in Kenya.

1.6 Study Area

Kenya lies on the eastern side of African continent within coordinates 4^o N and 4^o S, and 34^o and 41^o east. The weather and climate of this place is highly controlled by mesoscale and synoptic scales that is the land-sea breezes and Inter-Tropical Convergence Zone (ITCZ), monsoon wind systems, and the Inland lakes which provide local sources of moisture. Kenya has a total area of 582,646 km^2 (KNBS 2010).This research on pollution contributed by urbanization is based on three main cities in Kenya: Nairobi, Mombasa, and Kisumu.

Kenyan climate is controlled by micro scale, mesoscale and synoptic features that are responsible for weather and climatic phases. The Inter-Tropical Convergence Zone (ITCZ) and the monsoons are the large scale contributors with local winds also having localized contribution to the weather (Asnani, 1993; Slingo et al., 2005). The seasonal displacement of the ITCZ leads to the variation of the monsoon winds which in turn affect the abundance of pollutants being transported. Throughout boreal winter, the ITCZ is assumed to be lying between (10-15^o S) having the effect extending all the way from northern Madagascar to the south of Tanzania and then northwards to Lake Victoria. At this time East Africa is dominated with north-easterly monsoon transporting northern air to Kenya, and this is assumed to be rich in pollutants (Novelli et al., 1998a, 2003). When the ITCZ starts to migrate northwards, it is occasioned with long rains and this occurs from March-April-May season to the beginning of June. At this time clean air from the Indian Ocean is transported to Kenya. Together with the large scale circulations, Kenya is also affected with Land/ Sea breezes particularly in Mombasa and Kisumu, Mountain wind in Kisumu and Mt. Kenya region and effect of Urban Heat Island within the three cities: Nairobi, Mombasa and Kisumu (Ongoma et al., 2013).

Nairobi is the capital city and serves as a center of administration, politics, economy, and culture within its administrative area of approximately 692 km^2at coordinates (1° 9'S, 1° 28'S and 36° 4'E, 37° 10'E). This city accounts for half the proportion of employment and also provides over 50% to GDP. The population of Nairobi increases at a very high rate due to rural urban migration and reproduction. According to the past population census that was conducted late 2009, Nairobi had the population of excess of 3 million, which is around 8% of the national population (KNBS, 2010). Opijah et al. (2007), gives an account of winds in Nairobi that shows predominant easterlies accompanied by rainfall driven from the Indian Ocean. They give a seasonal distribution of winds during the DJF, which shows more predominant Northeast monsoons while JJA season showed southeasterly monsoons that are generally associated with rainfall. The general air quality condition of Nairobi has continuously deteriorated over the past decades while the population of the city continues to grow.

Mombasa happens to be the second largest city in Kenya which lies on the southeast of the Kenyan coast with coordinates (3°80', 4º10'S and 39º60' and 39º80'E). The city has an area of 295 km^2 and an increasing number of inhabitants at more than 0.9 million (KNBS, 2010). Mombasa, on the other hand, is a tourism and port city. This means it has a considerable population that depends and carries out their daily activities. The other reason why the study is important, this city has predominantly offshore and onshore winds, which will be important in interrogating contribution of meteorological variables.

The lakeside city of Kisumu is located over the western region with coordinates (0°6'S, 0.1°S and 34°45', 34.75°E) and having elevation of 1,131 m above sea level, and is estimated to have over 0.9 million people (KNBS, 2010). Kisumu comes third in terms of coverage at 417 Km^2, with over two-thirds (297 Km^2) being dry land with the rest of the area covered with water. Kisumu is a lakeside city and it will be important to also analyze the emission trends and meteorological trends within this city. Finally, Mt. Kenya GAW region data will be used for background emissions.

The sources of atmospheric pollution come from the motor vehicle and industries with some portion being because of household emissions. Because of this pattern, the source proximity and wind regime also play a part of problem in terms pollution distribution. With difference on location of these cities, there is a differential increase of pollutants and this forms a basis of this paper.

1.7 Limitation of the study

The success of this study was pegged on the availability of accurate and consistent data. To achieve this requires a great deal of instrumentation and time to override the challenge. First, this research required more data samples to well analyze space-time patterns of distribution of pollutants. However, this is a big challenge not only in Kenya but most developing states meaning it was not possible to get more consistent data samples. This challenge though was overridden by coming up with averaged monthly data. To address the spatial aspect of data, cross-sectional analysis of data within the four stations was analyzed comparatively.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

This chapter evaluates literature that has been advanced in pollution and particularly contributed by human activities. This study bases its research on contribution of anthropogenic pollution in Nairobi, Mombasa and Kisumu as compared with background emission in changing climate. The chapter follows five different segments; First, global perspective of pollution is discussed then local pollution and the environment thereof. Background emission and climate forcing with wind attribute is discussed. Finally, the conceptual and theoretical framework to show the step and the constructs that border on the problem of study is discussed.

Human induced greenhouse gas otherwise known as anthropogenic GHGs, from the time before industrialization have been having an upward trajectories effect on pollutants like global warming gases like Carbon dioxide, Methane, Particulate matter and Nitrous Oxide. A total of CO_2 atmospheric emissions of 957 ± 145 ppm of CO_2has been observed globally. With this almost a half of the pollutants (40%) remain suspended and caused the quality of air to be compromised. The remaining 60% of these pollutants are deposited on land and in oceans after being washed from the atmosphere. Now of importance is the fact that about half of the human induced emissions within the period (1750-2011) actually occurred in the last 40 years (IPCC, 2014a).

Spread of anthropogenic emissions globally corresponds to areas with human habitation with 88% of the population participating in the exacerbation of pollution. This emission that is due to biomass burning has an equal distribution in almost all the habitations (Dentener et al., 2011). The environmental assessment report (IPCC, 2014), states that the contributions of pollutants in the atmosphere occasioned by human activities have been significantly increasing. This part of literature contravenes the efforts put in place to mitigate increasing pollution trends. A view of the CO_2 levels of pollution in 2010 shows significant levels 23 ± 2.1 ppm of CO_2eq/yr. this is 78% increase of between 1970 to 2000, the same proportionate percentage also can be attributed to CO_2 during the 2000-2010 period (IPCC, 2014a).

Globally, the need to have food on the table has been the major driver of emissions, increase in population and economic adjustments have been the main contributor of CO_2 from fossil fuel combustion and other GHGs. The population increase has shown a near and constant growth between 2000 to 2010, this likened to the previous three decades. According to this, the values contrast; there is an opposite taste of reality showing data from economic growth that shows sharp rise in economic activities. From this assessment, the increased use of fossil fuels like coal has taken back the efforts that have been put in place to decarbonizes or keeping the intensity of carbon energy low from the main world supply of energy (IPCC, 2014b).

Since 2000, sectoral pollutants have been gradually increasing in most sectors with the exception of Agriculture, Forestry and land use, with the energy sector taking 35% of the total GHG emissions (IPCC, 2014a). Pollution from industries; suffice to say within the urban setting, negatively affects the employees and the neighboring people's health and still has a potential to affect adverse population if this population has limited information about how to mitigate themselves and defend against punishing conditions. The effects of these pollutants again are not just limited to the urban environment but have a probability to be transported downwind to the rural communities that practice farming. These rural communities are often overlooked in policy formulation that is meant to help them. The lack of environmental health awareness together with the deficiency of programs that are environmentally sustainable are major problems in developing countries (WHO, 2015).

The main pollutants that are associated with biomass burning in the atmosphere include GHGs, Carbon monoxide and the Volatile Organic Compounds (VOCs) that are abundant in the tropics and subtropics. Most of these compounds have a higher effect to the ecosystem, as they also interact with other compounds to cause complex pollutants. (Koppman et al., 2005), posits that anthropogenic emissions are accounting to almost 90% of the total as a result of biomass burning. To have a better insight of how the atmospheric pollutants interact and indicate abundance, a study on the photochemical system was conducted and showed70% of Hydroxyl (OH) radicals in the background atmospheric emission reacts with CO (Crutzen and Andreae, 1990).

Anthropogenic activities like the landfill also contribute to gas emissions. They act as sole contributor source of methane, precursor emitter to carbon dioxide. These gases are important for their primary greenhouse gas. Other gases are also emitted within the landfills but don't form a significant portion of the GHGs. These emitted gases are as a result of waste decomposition process of waste and landfill technologies used (Abushammala et al., 2009). Tire burning also contributes emissions. Uncontrolled sources are open tire fires occurring in incomplete combustion and release the products directly into the atmosphere. Controlled sources happen with controlled environment and in this case boilers and kilns are used where some conditions can be varied (Reisman, 1997).

Because of the variability of conditions in the controlled sources their emissions are slightly lower often than not, but also these sources also have some pollution capabilities so they do have appropriate air pollution control equipment to reduce on the severity that comes from them these sources (Reisman, 1997). Significant pollution comes from uncontrolled sources which mostly give rise to percentage of black carbon which is normally classified as PM2.5 The reason to this is because the amounts of air that is used in combustion is not limited hence the rise in black carbon.

2.1 Air Quality situation in Kenya

Kenya Constitution, Article 42 and in chapter 4 which talks about the Bill of rights grants every citizen of Kenya un fettered right to clean and healthy environment (GoK, 2010). To operationalize this right, the Environmental Management and Coordination Acts (EMCA) which the law that guides prevention of pollution was enacted. Under the law, the National Environment Management Authority (NEMA),was established to conduct general supervision and coordination over all matters that are of environmental importance. Within EMCA, ambient air quality regulations exist which is referred as "The Environmental Management and Coordination (Air Quality) Regulations, 2014". The original Air Quality Regulations, 2008, did not set any air quality guidelines but instead proposed their formulation. This was updated in 2014 to include limit values. Guidelines for Assessment of Air Quality in the 2014 regulations seek to, among other things, ‘establish source contributions to ambient concentrations of pollutants' and ‘assess the environmental benefit of measures to reduce and maintain air quality within limit values'. Whereas there has been significant progress in formulating guidelines, there is no national air quality monitoring program is in place. Air Quality monitoring is limited to urban areas where ad hoc monitoring is done in response to air pollution complaints and short-time research campaigns initiated by academic institutions.

The major serious problem of pollution is the fact that it emanates from both outdoor and indoor sources. Sulphur dioxide, particulate matter and Carbon dioxide together with others not discussed in this study like ozone, nitrogen dioxide and nitrogen oxide are the major players of pollution. The air quality within the country is affected by differential emitted pollutants from scattered sources. These numerous sources include activities that are as a result of generation of power, industrial processes generating emissions, disposal of harmful wastes, fumes from transportation machineries, burning of biomass and fuel burning, wastewater treatment and agricultural products, which in them have anthropogenic and natural contributions(The State of Environment, 2012). To understand this, in a nutshell, it is imperative that the two faculties of air quality are briefly described here.

Pollution from indoor sources can be said to be found in the earlier times when human beings had to find a way out of the coldness in order to keep themselves warm, for cooking and lighting. The fire meant increased levels of pollution, and this is evidenced by soot within the prehistoric caves (Albalak, 1997). World Bank (2008) posits that a greater proportion of the world's population will suffer the effects of pollution because of the reliance on biomass that is unprocessed in the form of residues that emanate from plants and animals. The bulk of this is burnt within closed doors or poorly performing stoves. Because of this, there is high amounts of pollution to the people close to the source and majorly the women who do the cooking.

The primary cause of indoor air quality comes from the indoor sources and this has a tendency to grow with poor ventilation. These sources will tell whether the pollution will diffuse or it will deposit. Indoor air pollution includes the combustion of fuels that is of use within homes such as coal, paraffin, wood products, tobacco smoke amongst other household products. Common air pollution has been so much and is much occasioned with outdoor sources. However with this in mind the poor and most vulnerable are the most affected and it means the developing countries bore the brand of being most affected particularly with indoor sources (Abushammala et al., 2009).

There are different kinds of definition about ambient air. As regard to this study, is the physical and chemical measurement of the concentrations of pollutants that is in contact with the population hence being exposed. Ambient air quality in most developing countries has a serious downward development, and this occurs mostly in urban setting. Since most of the population prefers staying in the urban setting, there is a greater population that is exposed to pollution levels above the expected limits (UNEP 2002). The other type of pollution is the outdoor pollution, which is perceived to be more serious than indoor pollution. The reason for this is that outdoor pollution has elevated concentration of certain pollutants, which are perceived to cause more health and environmental effects. With these effects, there have been many environmental responses from the national and international community even to the local setting with the aim of improving air quality (The State of Environment, 2012).

In matters pollution, there is a twofold sector that is of interest. The indoor air pollution which comprises products of solid fuels that result from combustion of solid fuels in open fires or sometimes in stoves in households, which in the end lead to household kind of pollution (HAP) (Noubiap et. al. 2015). However, with all its importance in pollution, it is more localized and contributes slightly lower to global emissions as outdoor emissions. Outdoor pollution is no doubt a global phenomenon because of global circulation. The ever-increasing growth of urban centers and movement of population to these centers, industrialization growth and use of motor vehicles has exacerbated the levels of pollution. Trans-boundary transport of pollutants and dispersion then thereafter deposition has a substantial effect of the levels of pollution within an area around the source and also far off the source (UNEP, 2016). According to Muthama et al. (2012), another contribution of pollution but this is more of a natural occurrence, volcanic eruptions. All these emissions have had an effect to climate change and this has been manifested in more notable features in the continent.

Human induced or natural sources contribute to air pollution. The natural sources of air pollution include Volcanoes that are responsible for the production of Sulphur, chlorine and particulate matter (WHO, 2012). Due to this, wildfires emanate and cause smoke, carbon dioxide and carbon monoxide. Now with volcanoes being the main producer of natural emission, we still have other natural causes that include animal products like cattle that have methane as their products without forgetting Volatile organic compounds coming from pines. On the other hand, we have human induced pollution and are the reason we have significant levels of pollutants in the atmosphere. Fossil fuels burning that are used in the industrial processes, products from electric generation, and pollutants from vehicle, aircraft and also domestic products that contain persistent organic pollutants, biomass burning and waste incineration. Air pollution is either particulate or gaseous in nature but both pose negative impacts to the economies and African livelihoods. The major source of outdoor emissions includes motor vehicle and industrial sources with power generation and household combustion of solid fuels (Muthama et. al.2015).

2.2 Indicators and Sources of poor air quality in Kenyan Cities

Human induced emissions within the three major cities in Kenya are the main contributors of pollutants. The examples of these pollutants are carbon dioxide (CO_2), carbon monoxide (CO), particulate matter (PM), oxides of nitrogen (NO_x), tropospheric ozone (O_3) and sulfur dioxide (SO_2). The air quality has no uniform distribution within these cities. It is localized and some of the areas have more concentration while others have less (Beukes et al., 2013). This can be partly because of the wind attributes and the source of the pollutant.

Nairobi according to National Environmental Management Authority (NEMA) is considered as a pollution density zone meaning it is a hot spot, experiencing poor air quality. Whenever the concentration of pollutants gets higher than those within the ambient air quality standards, health risk sets in Muindi (2017)research showed pollution spikes on the roads of Nairobi.“The pollution is uncontrolled and particularly deadly in slum districts and for drivers, street vendors and traffic police,” she says. This adds to the pollution trends particularly in highly populated places in Nairobi.

Gatari, (2016) predicts the country will have "a very sick population in years to come”. Even with limited data, he suggests that Nairobi will be 30 times worse than in London, and that Kenya is building up an immense health problem. His research is based on scenario simulation of increasing population with industrialization. He concludes his finding that thirty percent more diesel is being burned in Nairobi in 2016 compared with five years ago. Without a doubt, the pollution will have a huge economic and health impact. We will see more and more cancers and heart disease, many more asthma cases, and respiratory diseases."

Particulate matter ($PM_{2.5}$), mostly coming from motor vehicles by burning of fuels has been heavily linked with health effects within urban cities. Studies show a whopping increase of number of deaths around the world, with the figure being quoted to exceed 800,000 (Cohen et al., 2004; Pope and Dockery, 2006). With this groundbreaking figure, we still challenged by little information that exists about this PM2.5 levels currently experienced within Kenyan cities (Maina et al., 2006; Vliet and Kinney, 2007). From their assessment, they found a gap that hinders cost-effective methods to cut the burden of health effects caused by the air pollutant and ensuing impacts to urban transport and planning policies with respect to air quality. PM2.5 being regarded mostly from combustion of fuel in motor vehicles means an increase in the use of motor vehicle directly translates to higher $PM_{2.5}$ concentration values. Therefore an optimum usage is a delicate balance to achieve.

UNEP, (2011), concludes that 90% of air pollution has been estimated in rapidly growing cities, and most of it is attributed to motor vehicle emissions. Where areas there are multiple sources of contributors of air pollution like burning of refuse and biomass in open air (Gatari, 2006), industrialization processes and the motor vehicle still plays a significant role in contributing to a $PM_{2.5}$ problem. JICA, (2006) posits scenarios in future, and in one scenario of “do-nothing” (or BAU) scenario that Nairobi alone will have an increase of 148% of vehicle trips between 2004 and 2025. And the average trip speed shrink to 11km/hr from 35km/hr which makes it so reasonable to assume the worst in terms of air quality if nothing happens.

In a study conducted by Wandiga, et al. (2007), he sampled selected sites within Nairobi, Kisumu and coastal strip within specified time. He concluded that, the concentration of Sulphur dioxide in Ngong forest in Nairobi and its environments, Kibos area in Kisumu and Kilifi did not exceed 24 hours WHO guidelines of 125 $\mu g/m^3$. These levels of Sulphur dioxide also did not exceed 1-year guideline of 60 $\mu g/m^3$ in all sites except in Vipingo. In his conclusion, he noted that certain sites within Nairobi and coastal strip had exceeded the threshold. The trends exhibited by Nairobi, Kisumu and Mombasa were also worrying as they were towards the roof of outdoor WHO standards. Wandiga et al. (2007)found N_2O concentrations at all sites except in Industrial Area inNairobidid not exceed the WHO guide lines (1-yearguideline of 40 µg/m3and the 8-year guideline of 120 µg/m3). In industrial Area, the levels exceeded the 8 hours WHO guideline of 120 µg/m3 in 2009. Particulate Matter ($PM_{2.5}$) at all sites was significantly high and exceeded the WHO guidelines. He also concluded that sites that were close to the roads recorded comparatively higher pollution levels

Anthropogenic pressures are as a result of population growth as a consequence of urbanization; this increases economic activities within a locality due to the emerging demands for agriculture products, transport, and industrial products. These activities have a very important part in diffusing and distribution of emissions within and without the city (Clarke, 2002; Ryu et al., 2012). Meteorological condition exacerbates the effects of the emissions, particularly within the vulnerable poor areas. These meteorological conditions include the characteristics of the terrain and sources of emission which together play to aid pollution.

2.3 Climate change perspective

In a bigger context, air quality as impact globally in terms of climate change. From the pre-historical times of industrial revolution in 19th century, GHGs have been on an upward trend which contributes to greenhouse effects. From the global climate models, air temperature changes and sea surface temperatures have been observed in terms of trends. Rockstrom et al (2007) posits that the globe is in most destructive mode. The planetary boundaries that work in synergistic manner have exceeded the thresholds. Climate change being the main boundary is way above the threshold with only atmospheric aerosol loading and chemical pollution still to have their threshold determined. This change has been documented extensively in IPCC fifth assessment report, Working group I (IPCC, 2014a). To this effect, green programs have been enhanced to reduce the effect of GHGs. Kenya being a signatory to Kyoto protocol has not been left behind with strategies that are meant to address the cost-effective ways of dealing with GHGs (Jim and Chen, 2009).

Forests in their natural state act as sinks of emissions; they remove pollution by obstructing them and absorbing them through openings in their leaves, and lenticels which are the porous membrane which is found in the roots or in the bark of the plants (Scholes, et al., 2009). The trees within the forest have a long memory of pollutant storage and can help in acting as pollutant reservoirs. In Kenya, the three cities are not well covered by extensive forests to help sink the pollutants. Initially, Nairobi's National park meant it gave a better coition in terms of what forest can offer but with industrialization and population pressure, the forests area is significantly reducing. Other cities that are Kisumu and Mombasa don't have forests near them hence they lack the advantages of that forests can offer.

Different programs funded by donors and the ministry of environment have helped in trying to restore the forest cover. However, the challenges of economics have made this activity at least successful in rural areas than in urban areas (Forest Policy 2014). Because of this, urban centers have been in an economic sense been left out as industrial and commercial zones that only non-agricultural activities take place. The three major cities in Kenya actually are now more of industrial zones which meant more anthropogenic emissions (Ongoma et al., 2013).

2.4Baseline Emissions

Vingarzan (2004) documented the trends of ozone. In his definition of background emissions, he termed background emissions as GHGs and particulate matter that occurs in the absence of human impacts. In his study, he found an increasing trend of background emissions in the northern hemisphere which also threw a spanner in the works where without anthropogenic activities, if the cumulative trends of pollutants can be managed. To understand the reason why background emissions are increasing, probable factors contributing to it are variability in stratospheric flux (Hess and Zbinden, 2013) and changes in transport patterns (Pausata et al., 2012).

Mt. Kenya GAW data in terms of emissions and meteorological variables are chosen to analyze the natural pollution. Mt. Kenya GAW station is found deep within the forest and protected by the governing legislation against human interference hence a good site to compare natural trends of pollution. It should not be forgotten that also within the assumed natural setting, Mt. Kenya experienced a huge fire in 2012 (Downing et al., 2017), which resulted in biomass burning and as consequence increased particulate matter and other pollutants within an otherwise protected region.

2.5 Natural and human induced emissions

The concentration of greenhouse gases is at unprecedented levels. The greenhouse gases concentration has grown in the past few years, for example since 1750, 40% of Carbon dioxide, 150% of methane, and 20% of Nitrous oxide in terms of increments. CO_2 has the fastest growing ten-year change rate of (2.0 ± 0.1 ppm/yr) for 2002– 2011. CH4 had in a decade shown a stable concentration in the 1990s, from there it has shown revamped increases from 2007. The total anthropogenic emissions from 1750 to 2011, is computed to have a warming impact of 2.3 (1.1 to 3.3) W/m^2 and the increase from 1970 has been so rapid than during the prior decades. Among the emitters, CO_2 is the highest contributor to pollution since 1970 (IPCC, 2014b). Human induced pollution estimates for 2011 was substantially greater (43%) more than estimates in the IPCC fourth report (IPCC, 2014a).

2.6 Relationship of Wind and Air Pollution

There are so many atmospheric processes that lead to interactions that cause air pollution concentrations to increase. Some of these interactions come from the patterns within the locality of a place and other global circulation. Winds direction and strength are affected by geography of the place and human induced activities. The propensity of human beings to respond to changes in weather is different, which include the beginning of the season in terms of cold and warm temperatures leading to increased energy need. This occurs generally in so many places, however, there are other places by the virtue of their locations, they are exposed more to air pollution than others hence leading o poor air quality. This can be partly because the climate is conducive to some chemical reactions that causes transformation of emissions, and because of the topography there is a limit in how the pollutants are dispersed (Kossmann and Sturman 2004)

The general annual cycle of pollutants in Kenya can be explained from the behavior of seasonal variation of monsoon flow over equatorial East Africa (Fig 1), which is heavily controlled by the seasonal displacement of the inter-tropical convergence zone (ITCZ) (Asnani, 1993; Slingo et al., 2005). Throughout DJF season, the ITCZ is in the southern hemisphere (10–15◦S) extending from the northern tip of Madagascar towards southern Tanzania and then northward towards Lake Victoria

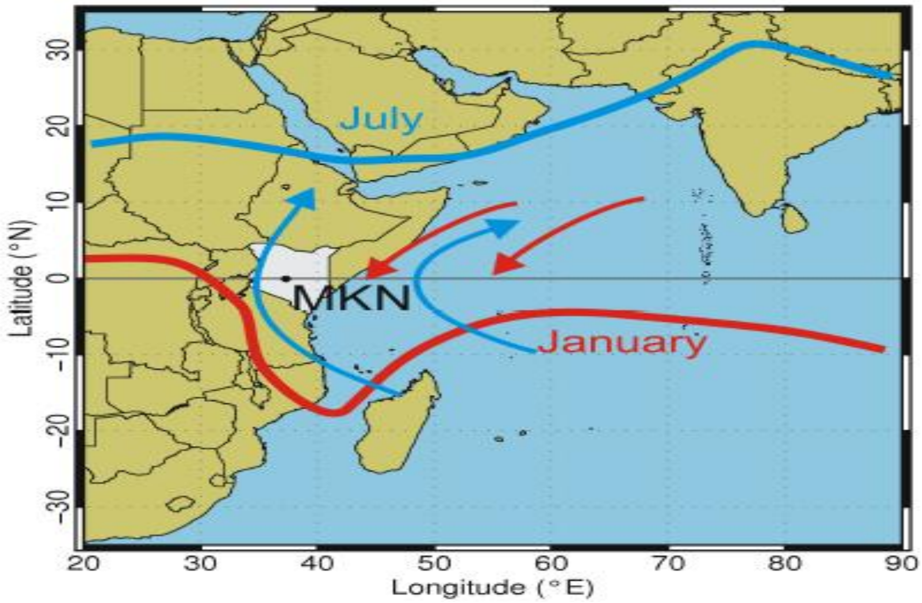


Figure 1 A representation of ITCZ and associated wind flow over the Indian Ocean

(Source: Henne et. al., 2008)

During JJA, the ITCZ is situated far to the northern hemisphere (15–20◦N) and along the southern coast of the Arabian Peninsula (10–15◦N), this caused southerly net flow of winds which turn to southeasterly over the central parts of Kenya. During this time there is also a chance for increased CO_2 due to increased biomass burning emissions (Novelli et al., 1998a, 2003)

Seasonal cycles have a significant influence on pollution as some of them demonstrate. Now with this piece of literature, certain prerequisite for pollution episode conditions have to be met for pollutants to either scatter, disperse or deposit in the atmosphere. Mostly, air pollutants are associated with slow and stationary anti-cyclones or high-pressure systems because these systems often reduce the rate at which the pollutants are transported from the source to a settling destination (Schichtel and Husar 2001). Turbulence and vertical temperature are the main effect to the three-dimensional wind. To cap on the interactions of atmospheric interactions, weather related factors also influence the dynamics and chemistry of the pollutants which help in the formation of other pollutants such as the ozone (Nilsson et al., 2016). With the sides of the anti-cyclones, airflow can transport ozone precursors, creating ozone event conditions. Huge air with bigger scales like anticyclones but not related can interact with the topography of the place, mesoscale systems that include land/sea breezes, and anabatic anabatic winds which lead to increased concentration of pollutants (Cheng et al 2001; Dayan and Levy 2002; Hess et al., 2003). And according to tropical meteorology, global circulations are influenced by pressure cells that are distant far from the point or source of pollutant. However, their interaction may lead to formation of tropical cyclones and low-pressure systems that normally are found within the coastal which have a possibility to high pollution levels within this (Tanner and Law 2002).

Another phenomenon that has a greater contribution to local and regional quality of air can be explained both directly and indirectly. The direct route that this affects air quality is chemically with the changes that the rate of chemical reaction and boundary conditions which has an effect in mixing of pollutants vertically and also changing the large-scale air flow patterns that govern transport of pollutants. The other way that climate change indirectly affects the rate of pollution is via the changes of the anthropogenic activities that affect the levels of biogenic emissions due to the changing weather variables and land use.

Very high temperatures have an increasing effect on isoprene which is a volatile hydrocarbon which happens to be ozone precursor that comes from the plants. However, coming up with the parameters in terms of the scale and directional change of the levels of pollutants is still s huge challenge in research (Swart et al., 2004). Another meteorological variable of interest is temperature. Temperature is very important in aggregating and variability of pollutants. The variability of most pollutants depends on available solar radiation, temperature variability, winds, seasons and altitude, among other factors (IPCC, 2007). In general, temperature and long-term urban warming have a serious impact on urban pollution; this caused higher pollution concentration for instance ozone since from previous studies heat increases the rate of chemical reaction in the atmosphere (Walcek and Yuan, 1999).

With ozone, there is lot of information that has been researched than other pollutants, its effect particularly on ground-level ozone, leaving the effect other pollutants an area of little interest for more researchers. In terms of air quality within the urban centers, air pollution is affected by meteorological conditions that affect both transport and dispersion which normally occur at the planetary boundary layer, (Ekman layer). This layer is about or less 1000 m of the atmospheric thickness. At this level of the atmosphere, the wind variable in terms of direction and speed is influenced by surface characteristics and vertical elevation of flows (Seinfeld and Pandis, 1998).

Hung, 2010 gave a characteristic of how air pollution source is characterized, with a point, line, area and volume source, and dispersion. The dispersion is well explained by different dispersion models that are available in tracking the transport of a parcel. Emission modeling is a mathematical simulation of how emissions are transported in the air. The models are important in describing both physical and chemical processes that are able to compute the pollution levels within a location (Vardoulakis et al., 2007). To estimate the amounts of pollutants in the atmosphere coming from the source, we use these models. The cumulative amounts of emission released now can be tracked back by the knowledge of the process or otherwise doing actual measurements as in the case of this study. There are different types of dispersion models that is not discussed in this study, however, Hung, 2010 expounds on this kind of this general types of models.

2.7 Design of the study

This study followed a Drivers – Pressure – State – Impacts - Response framework (DPSIR). The DPSIR framework is a conception tool that helps in showing the environmental indicators. This model is very powerful in trying to analyze the complex environmental problems and has been used in South Africa to analyze state of the environment. It was first worked on by European agency in 1999 which was basically an interaction between pressure and status otherwise known as Pressure-Status-Response (PSR). This was used to modulate the balances between pressure and the status of the environment (OECD, 2014). DIPSIR has finally been adapted and used in so many researches in handling environmental information systems (Kristensen, 2004; Hanne Bach, 2005). DPSIR has five components. With respect to the assessment of quality of urban air, they are briefly described below:

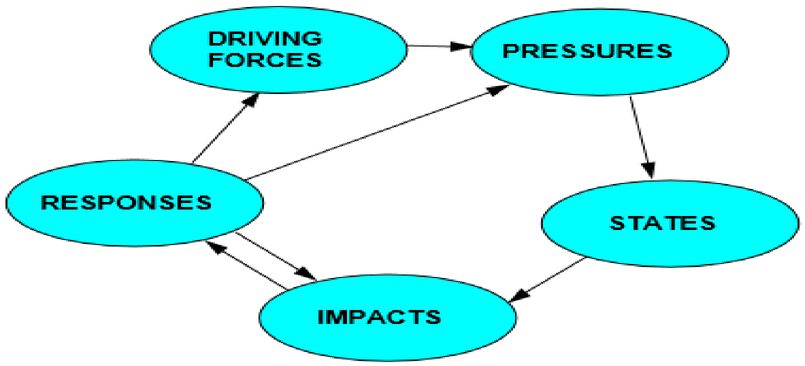


Figure 2:DPSIR framework

1. Driving forces

Anthropogenic causes that cause degradation of Kenyan cities air quality are urbanization, industrialization, and motorization.

2. Pressures

Products of driving force create pressure on the status of the environment, in our case it leads to pressure on the state of the quality of air. The main pollutants are CO_2, SO_2, and $PM_{2.5}$

3. State

This is the characteristic of the pollutants. It can be in the form of concentration, spatial and temporal distribution of the SO_2, CO_2, $PM_{2.5}$ in the atmosphere. This can be done by accessing modeled or measured data.

4. Impacts

This is what the air quality has an effect on the environment. The environment is composed of people and the ecosystem that is leaving the cities and in the neighborhood of the city. The vulnerable people within the city are at a greatest adverse health effect. These vulnerable people have poor living conditions. From literature the vulnerable individuals are the elderly and the children are the most affected and respond sensitively to the effect of changing quality of air. The other secondary parameters that are affected are plants and building materials (Hung, 2010).

5. Responses:

This is the measures the society takes to bring down the fangs of pollution. The strategies to reduce the impacts might be in terms of laws that can help in monitoring or mitigating the effects of urban air quality. In brief, these responses are as a result of both national and county governments' policies that address air quality standards that are accepted that are friendlier to the environment and sustainable in nature a friendlier environment and sustainable development cities.

2.8 Conceptual Framework

This study follows two channels of pollution data analysis and wind data analysis as captured by the specific objectives. The specific objective 1 (SOB1) is to look at the spatial and temporal analysis of the wind variable. The data is analyzed with time series to have a view of trend analysis of the pollutants within the stations. Specific objective 2 (SOB2) brings conceptual ideas for winds, how wind frequency and direction within four stations behave. This is aided by HYSPLIT trajectory analysis for tracing the movement of air parcel. Windrose is used to tabulate the trajectory of the winds in direction and speeds. The two concepts are together analyzed to specific objective 3 (SOB3), where the relationship of the two constructs behaves in different seasons. The final specific objective (SOB4) is when the model analysis come in to determine the contribution of anthropogenic activities to pollution.

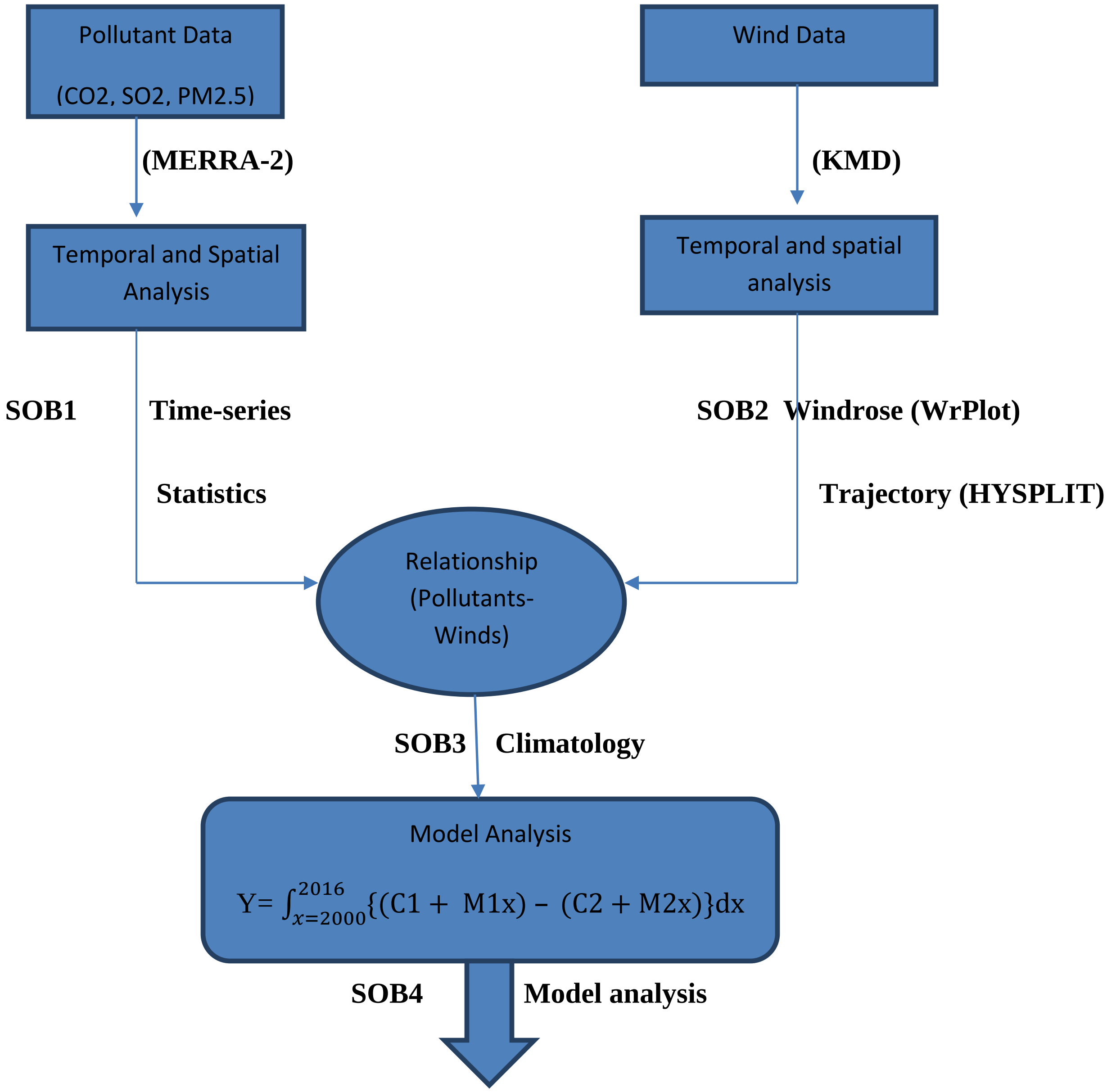


Figure 3: Conceptual framework

CHAPTER THREE: DATA AND METHODOLOGY

3.0 Introduction

This chapter deals with the source of data and methodology. The chapter delves in detail the type of data used and the analysis thereof. This study follows a comparison analysis where two different variables are compared. Pollution and wind data were the type of data used for this study. This chapter is arranged in three parts; the first one describes data and its type, the second part discusses the methods applied and the software that were used in data analysis. The third part of this chapter explains the design of this study. The research design for this project gives procedures and steps that the study follows in getting the objectives and results.

3.1 Data

Pollution data was sourced from archived satellite data, the second Modern-Era Retrospective Analysis for Research and Application (MERRA – 2). The data sourced was for SO_2 from the year 2000 to 2016 which was same for $PM_{2.5}$ for Nairobi, Mombasa, Kisumu and GAW. For CO_2, there was no data for the first two years meaning the data is from 2002 to 2015. MERRA-2 is a NASA atmospheric reanalysis that replaced the original MERRA (Rienecker et al., 2011). It includes the updates of the model and to the Global Statistical Interpolation (GSI) scheme. All the data are provided in the horizontal grid with a corresponding resolution of 0.625^o x 0.5^o. MERRA-2 uses observation-based precipitation data as forcing for parameterization. Along with the enhanced use of the satellite observations in MERRA-2, the secondary motivation is the inclusion of more aspects of Earth system which helps in the assimilation of aerosols information based on "MERAAero" that is integrated using meteorological. Pollution data was selected based on availability and climatology of the place and the impact to the ecosystem based on anthropogenic activities.

3.1.1 Air Pollution Data

Pollution data was obtained from MERRA-2 satellite archived data for SO_2, CO_2 and $PM_{2.5}$. The period of interest was also chosen between 2000 and 2016 to analyze the trends in terms of spatial and temporal analysis. The reason to arrive at the three pollutants was because of the consistency of the available data and relevance of data to climate change. CO_2 represents climate change forcing which is imperative in coming up with how pollutants increase in the changing climate. SO_2 and $PM_{2.5}$ are industrial and landuse gases which correlate to human activities; the increase informs the increase in human activities. SO_2 and $PM_{2.5}$ data were calibrated in micrograms per cubic (µg/m^3) while for CO_2 was parts per million (ppm). SO_2 and $PM_{2.5}$ data was for the period from 2000 to 2016, while CO_2 had missing data for 2000 to 2002.

Background emissions site is basically free from anthropogenic emissions; however there are some episodes of intrusion of human activities that lead to pollution being transported to the forests around GAW. These episodic influences were however reduced by climatic filtering by use of monthly data which removes the local effects like bush fires that are prevalent. Not only was the local effects but also the effects of the influence of variable atmospheric boundary layer (ABL) which cause diurnal variation in atmospheric trace gases, and this is particularly in the high altitude areas (Henne et al., 2008). This problem was mitigated by the use of monthly averages as opposed to daily data which is prone to short term variations.

3.1.2 Wind Data

Wind data used in this study was obtained from Kenya Meteorological Department that is tasked in observation, archiving and managing weather data in Kenya. The four-main station for the study has active wind recording instruments that corresponded with the data that was necessary for this study. Meteorological data that was used for this study was wind direction and speed for Kisumu, Nairobi, Mombasa and Mt. Kenya (GAW). The winds were analyzed from daily means to monthly means for the period between 2000 and 2016. The data was analyzed to come up with average wind direction based on the frequency of occurrence; this was done with the help of WrPlot which was used to come up with frequencies and later the windrose.

3.2 Methodology

3.2.1 Time series analysis

To analyze pollution characteristics, time series analysis was conducted on SO_2, $PM_{2.5}$ and CO_2 to ascertain the time-pollutant distribution. This was done in particular to ascertain the time-pollutant characteristics for each pollutant at a particular station. This method was important to give visual view of the behavior of the pollutants. the cyclic and seasonality was best analyzed by variations with time. Anomaly indices were carried out to predict how the observed data varies from the presumed background pollution levels. The background pollution level was also adjusted to minimum to bring out the anomaly of the pollutants. For pollutants, time series analysis for individual pollutants and pooled series was presented. This in the end was used to compare the different amounts of pollutants within each city, and also within months and seasons. This was done to examine seasonal variation of air quality with time. Cross-sectional analysis sampling was done to ascertain behavior of pollutants at the same time. This was critical in analyzing the spatial characteristics of the pollutants.

3.2.2 Statistical analysis

Correlation statistics was done to give an insight of how pollutants trend is with respect to stations of interest. This was important to analyzing the coefficients of increase within stations with time. This increase however was prudently examined by looking at the trend series of the pollutant. This was done by plotting a trend line equation on the general distribution of pollutants and the data that was given for all the four stations was analyzed. To do this, a trend analysis for the annual distribution of pollutants over all the four stations was done.

T-test statistics was carried out to develop hypotheses of variable interaction. The main Statistical approach was carried out to determine significance of means in terms of difference at 95% confidence interval. This was to check for significance of difference of means from the background emissions.

3.2.3 Hysplit and WrPlot analysis

Wind data was analyzed using the available software to answer the specific objective (ii). To analyze the temporal distribution of the winds, WrPlot was used to come up with wind rose which gave the frequency of the winds in terms of strengths and direction. The spatial distribution of winds will be analyzed from the WrPlot outputs showing the same distribution at the same time within the four seasons of the year. The main method used was wind rose plot where frequency of winds was pooled within all the stations and different seasons to advance the dominant wind directions. The relationship between $PM_{2.5}$, SO_2, CO_2 and their interaction with winds was determined with the use of trajectory analysis. The prevailing wind direction over the area of study was obtained by plotting trajectories using the HYSPLIT software.

The Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT) was developed by the air resource laboratory is one of the tools that have been widely used in trajectory analysis (Stein et al, 2015).Used in Ready online platform contains archived wind data for gridded locations. GDAS data is used because of the ease of use in HYPLIT and also the fact that the data span is slightly large covering from 1980 to current. A rigorous sampling of the years was done to ascertain the behavior of pollutants within seasons. A sample of wet years was selected based on statistics from ICPAC, an organization charged with seasonal forecasting. After sampling, a midpoint of the selected season was chosen to represent the season long. To understand the boundary conditions, trajectory analysis was carried out with HYSPLIT, this was done with different height levels of 10,500 and 1000 AGL, and this was for the purposes of bringing in the concept of planetary conditions. Trajectories were analyzed for the four seasons in all the four stations that were of interest. An initial monthly average was sampled for different years before finally choosing the week three of every mid-season month. This was in the assumption that localized wind regime stabilize within five day period. For this, the third week of March, July, October and January were chosen to represent MAM, JJA, SON and DJF seasons. The reasons why the third week in these months chosen was after sample runs (not shown) to represent 5-day period that present a better description on the season. The levels taken were 10m which is near surface, 50m and 1000m which give the behavior of the boundery conditions.Finally, to examine the concentration of particles, HYSPLIT trajectory concentration was also carried out within dates chosen in consonant with the wind trajectories, to follow path of the wind with the assumptions that the parcel of the aerosol follows the same trajectories.

The last specific objective of the study requires determining the anthropogenic contribution, trend analysis differences was conducted to come up with natural and human induced pollution. This was done by subtracting the GAW pollution levels trends from the current city pollution. GAW is assumed to be an area with less pollution. It is assumed to only have natural pollution whilst the city was assumed to have both natural and human induced pollution. Hence to find the final contribution the model

$$Y = \int_{x=2000}^{2016} \{(C1 + M1x) - (C2 + M2x)\} dx \quad (1)$$

Where Y is the contribution, M_1 and M_2 are the gradients for series 1 and 2.

3.3 Research Design

This study follows a case study design where different stations have been selected and case by case analysis done on them. To do this, different parameters were selected to compare their behavior in different environments. The case study in this study follows a cause – response model that has been likened to Drivers – Pressure – State – Impacts - Response framework (DPSIR). To have an insight about Air quality, then the management of it must be condensed and aggregated information. To understand this, then a considerable attention is directed to the perceived indicators of the environment. There is important information that is given on the environment and the problems the environment is facing. Since they are indicators, they can also help in identifying the main areas of the environment that cause pressure on it and help in coming up with certain policies that are important and in the end help in monitoring the response caused by pressure by the set policies (Hanne Bach, 2005).

In DPSIR framework, both social and economic facets are structured into Driving forces (D), Pressures (P) that is felt by the environment, then the resulting response, State (S) and status of the of the environment. Now the model shows the interacting factors of the environment, showing the changes that eventually have an Impact (I) on environment, this can be either how the human are affected in terms of health and materials. Because of the said Impacts, there is an equal and opposite society Response (R) to the forces or towards the pressure. The other response is towards the state or impacts that are directed towards the environment and this is through preventive, adaptive and curative solutions (Hanne Bach, 2005; Jago-on et al., 2009). With it, DPSIR can help in understanding the complexity of linkages and feedback mechanism between the cause and effect within the environment.

CHAPTER FOUR: RESULT AND DISCUSSION

4.0 Introduction

This chapter gives an account of the results that have been analyzed. The researchable question of anthropogenic contribution in the changing climate was specifically looked into based on spatial and temporal distribution of pollutants and its help in transport by winds, the resultant conclusion is made based on the results that have been discussed in this chapter in great depth.

4.1 Spatial-Temporal characteristics of air pollutants

The four stations, Kisumu recorded the highest PM2.5 value of 20.3μg/m^{3}while Nairobi registered the lowest of 11.5μg/m^3. The clustered mean value of the four stations still showed Kisumu 3.8μg/m^3,Nairobi 3.6 μg/m^{3}and Mombasa 3.4 μg/m^3. This compared with GAW which had 2.9 μg/m^3 showed a significant difference in terms of the means. SO2 which is an industrial product from combustion of sulphur products is very corrosive. Less amounts of sulphur in the atmosphere have significant effects to the ecosystem. Kisumu recorded the highest amount in terms of mean at 0.59 μg/m^{3}while Nairobi recorded lowest value of 0.53 μg/m^3. This however did no corroborate with the standard deviation, as Nairobi had the highest standard deviation and Kisumu had the lowest at 0.07 and 0.045 respectively. The variance will be discussed later in this chapter.

4.1.1 Descriptive analysis of pollutants

The average monthly $PM_{2.5}$ distribution within the three major cities in Kenya that is Kisumu, Nairobi and Mombasa were well below the WHO guidelines of $PM_{2.5}$. The three cities had an average of 3.8μg/m^3 for Kisumu, 3.4 μg/m^3, Mombasa and 3.6μg/m^3 for Nairobi. Compared to the background emission for $PM_{2.5}$, GAW which had 2.9 μg/m^3, which is within the accepted WHO standards. The WHO standard for $PM_{2.5}$ is 10 g/m3 annual mean (WHO, 2005).

The variation in means for $PM_{2.5}$ almost remained steady within the three cities. The monthly variability for $PM_{2.5}$ was high during DJFM season which happen to be dry season and highest pollutant distribution. It was also noted low variability of the pollutants in May in almost all the cities with the exception of GAW and Nairobi having slightly a higher variability in June

Table 1:Data summary of ambient $PM_{2.5}$, SO_2 and CO_2 concentrations

POLLUTANT	DESCRIPTORS	GAW	KISUMU	MOMBASA	NAIROBI
$PM_{2.5}$ concentrations ($\mu g/m^3$)	MEAN	2.9	3.8	3.4	3.6
	STDEV	0.54	0.6	0.66	0.56
	MIN	0.4	0.35	0.08	0.3
	MAX	14.5	20.3	15.4	115
SO_2 concentrations (µg/m3)	MEAN	0.53	0.59	0.57	0.54
	STDEV	0.052	0.045	0.049	0.07
	MIN	0.26	0.1	0.1	0.1
	MAX	1.3	2.6	1.1	0.9
CO_2 concentrations (PPM)	MEAN	381.4719	381.6383	382.435	381.5123
	STDEV	6.66	6.6	6.19	6.72
	MIN	371.6	371.7	373.5	372.1
	MAX	391.12	391.5	392.3	391.8

Surface SO_2 were also measured in the same three cities and compared to Mt. Kenya (GAW) station. The concentration of the SO_2 was measured to ascertain the contribution of human activities towards increase in pollutants. The average monthly SO_2 distribution within Kisumu, Nairobi and Mombasa were well below the WHO guidelines of $SO_2$of 5 – 10 $\mu g/m^3$ long term exposure. The three cities had an average of 0.53$\mu g/m^3$ for Kisumu, 0.59$\mu g/m^3$ Mombasa and 0.55$\mu g/m^3$ for Nairobi. It is worth noting the corrosive and harmful nature of SO_2 means its abundance in the atmosphere close to the surface has catastrophic effects. SO_2 basically is measured within 10-minute and 24-hour cycle with WHO standards requirements. When compared with the background emissions that's is GAW at a mean SO_2 which has less anthropogenic effects at 0.53$\mu g/m^3$ which is still less that WHO mean long-term exposure.

Carbon Dioxide unlike the $PM_{2.5}$ and SO_2 has a global footprint and is heavily transported globally leading to it being the greatest source of global warming at least from available literature. $CO_2$is mainly caused as a result of fossil fuel and biomass burning in the presence of sufficient oxygen. In the presence of insufficient oxygen, the product includes the presence of CO_2 as one of the product. CO_2 forms the basis of the changing climate because of its global warming attributes.

The concentration of CO_2 was monitored to analyze the increase of it based on the background emissions. The average monthly CO_2 distribution within Kisumu, Nairobi, and Mombasa cannot be a good indicator of CO_2 performance. CO_2 increase with time in all the stations showed a significant trend irrespective of season and time. The average value since 2002 to 2013 can be used to compare the moving mean values in the past and in the future to come up with the durational change in means. It is also worth noting that being a comparative study, the difference in means is an indicator of which station is recording high pollutants. However, for this study, it was imperative to use statistical durational mean to compare station-wise and come up with factor contributing to this increase. The average concentration of CO_2 in indoor and outdoor surface emission is in the figure between 250ppm to 350ppm having Normal background concentration in outdoor ambient air, and 350 to 1000ppm having Concentrations typical of occupied indoor spaces with good air exchange. With our research based in occupied indoor space with good air exchange, the standardized CO2 levels are between 350 – 1000ppm. Above this values complaint of un-comforting state will start setting in (WHO, 2012)

Based on this simple analysis, all the four stations had the mean of between 381ppm to 383ppm which occupies the base of the lower band well below the WHO guidelines of CO_2 severe levels. It is worth noting the effects of CO_2 on climate change, its warming effects hence its increase is subject of interest amongst climate change researchers. CO_2 also acts as a response indicator for biomass burning and so its increase can be used as a proxy for biomass burning which indicate human activities within a region, notwithstanding the global transport effects.

The Two-tailed test for significance of means also showed a significant difference in means $PM_{2.5}$ concentrations between Mt. Kenya and Kisumu for the period of study ($P < 0.05$). The concentration of $PM_{2.5}$ in Kisumu was significantly more compared to Mt. Kenya. T-test significance for $PM_{2.5}$ as shown in the table ---, shows all the stations having significant difference with GAW.

The Two-tailed test for significance of means showed significant difference in means of SO_2 concentration between Mt. Kenya (GAW) and other three stations at 95% confidence level. To start with Kisumu for the period of study, the critical value ($P < 0.05$) according to (Table ….) shows the concentration of SO_2 was significantly more compared to Mt. Kenya. SO_2 for GAW concentration ranged between 0.26µg/m^3 to 1.35µg/m^3 while the concentration of SO_2 in Kisumu ranged between 0.1µg/m^3 to 2.6µg/m^3 but with less variability. Mombasa also recorded a significant difference in means getting high amounts of SO_2 in the period of study ($P < 0.05$). The concentration of SO_2 was between 0.1µg/m^3 to 1.1µg/m^3. The same can be said for Nairobi which also showed a significant mean difference with ($P < 0.05$) with mean values for the SO2 between 0.1µg/m^3 to 0.8µg/m^3.

The Two-tailed test for significance of means for CO_2, showed no significant difference in the means for all the three stations as compared with GAW, which in simple terms shows less departure from the background emissions.

Table 2: Two-tailed t-Test analysis with unequal variances of $PM_{2.5}$, SO_2 and CO_2 concentrations

Pollutants		**Degrees of Freedom**	**T-Value**	**P- Value / α = 0.05**	
				P	**α**
$PM_{2.5}$	GAW & Kisumu	32	-4.29	P < 0.05	2.037
	GAW & Mombasa	32	-2.21		2.037
	GAW & Nairobi	32	-3.73		2.037
SO_2	GAW & Kisumu	31	-3.0612	P < 0.05	2.04
	GAW & Mombasa	31	-2.2472		2.04
	GAW & Nairobi	31	-0.8594		2.04
CO_2	GAW & Kisumu	20	-0.341	P < 0.05	2.086
	GAW & Mombasa	20	-0.4701		2.086
	GAW & Nairobi	20	-0.0175		2.086

4.1.2 Time series analysis

SO_2 showed two peaks in the general distribution annually with Kisumu having the highest pollutant distribution, followed by Nairobi then Mombasa. The values represented also shows a significant difference in terms of the means as the two cities that are Kisumu and Mombasa cities with T-statistic values of -3.0612 and -2.2472 respectively, which showed a significant difference in terms of the means. Nairobi, on the other hand, did not show significant difference in means. The two-tailed T-statistics with $P < 0.05$ showed the two cities values outside the values around the mean while for Nairobi it was within the means.

A general time series of $PM_{2.5}$ exhibits a near cyclic trend with two sharp peaks being visible in the distribution. The two peaks are at the beginning of the year and the end of the year, based on these and extensive discussion will be given based on the result

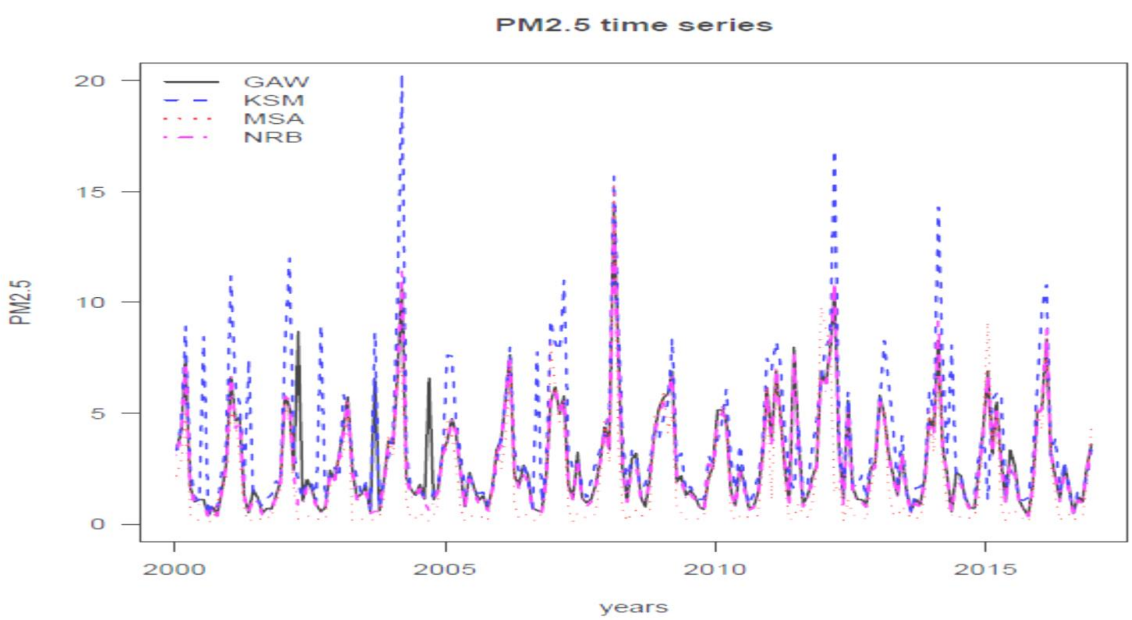


Figure 4: Time series of $PM_{2.5}$over GAW, Kisumu, Nairobi and Mombasa stations

The distribution of the $PM_{2.5}$and variability also showed temporal differences. The other cities also are represented with their maximum and minimum values also recorded. A keener look of the time series shows two peaks within a year. This distribution takes a near repetitive cycle in almost all the stations. Kisumu shows a significant high peak than the other stations while

Nairobi showed slightly lower peak. This however was within the same cyclic trend that was observed in all the stations. Based on this finding, it is without no doubt that Kisumu and Nairobi bring in interesting information in terms of $PM_{2.5}$ tendencies. There is a major player that leads to increased levels of this pollutant in Kisumu than in Nairobi. Land use and location of these stations to pollution is one reason this level was varying in this station. The season also played a crucial role in bringing this variation. However, the two stations enjoy near homogeneous climatology and such variation can be explained by factors that are more exterior to the contribution of climate. Land use comes in as one factor that can lead to increased $PM_{2.5}$. Kisumu is fairly agricultural by the fact that vast of the lands in the immediate south border the Kano plains. The east of Kisumu also is on the lee ward side of the Bunyore hills that practices farming. These reasons also are important in transporting this pollutant to the city. The issue of winds will be looked further in this chapter.

The general behavior of SO_2 showed tendency of high pollutant values within dry season. These dry seasons are DJFM and JJA seasons. Kisumu showed less variation with a near flat behavior and also less annual values. The behavior of SO_2 in all the four stations did not depart from each other with all the stations having a major peak during the DJFM season which is regarded a dry one. There was also an agreement in terms of less SO_2 advection during the wet season. In deeper discussion this behavior is due to the wash effect that is occasioned by rain deposition of the pollutants. SO2 is highly soluble in water and you will expect it to be washed by rain if it is in the atmosphere and this is the reason why during wet season the amounts of SO_2 were at minimum.

Finally as expected the annual variations of CO_2 remained near flat as most of the CO_2 is as a result of global transport as will be discussed further in this section. But of interest were the annual variations in Mombasa where the distribution showed high values from November to March. CO_2 is as a result of combustion of fossil fuels and global transport. The near flat variability of distribution is partly aided by two by the spatial distribution of combustion activities. With global wind transport, CO_2 is able to be transported far and be mixed within environments that were initially devoid of pollution. Mombasa is affected by East African Low Level Jet that steams near the coast joining Indian monsoons. These winds are partially the cause of variable tendencies of CO_2 distribution around Mombasa.

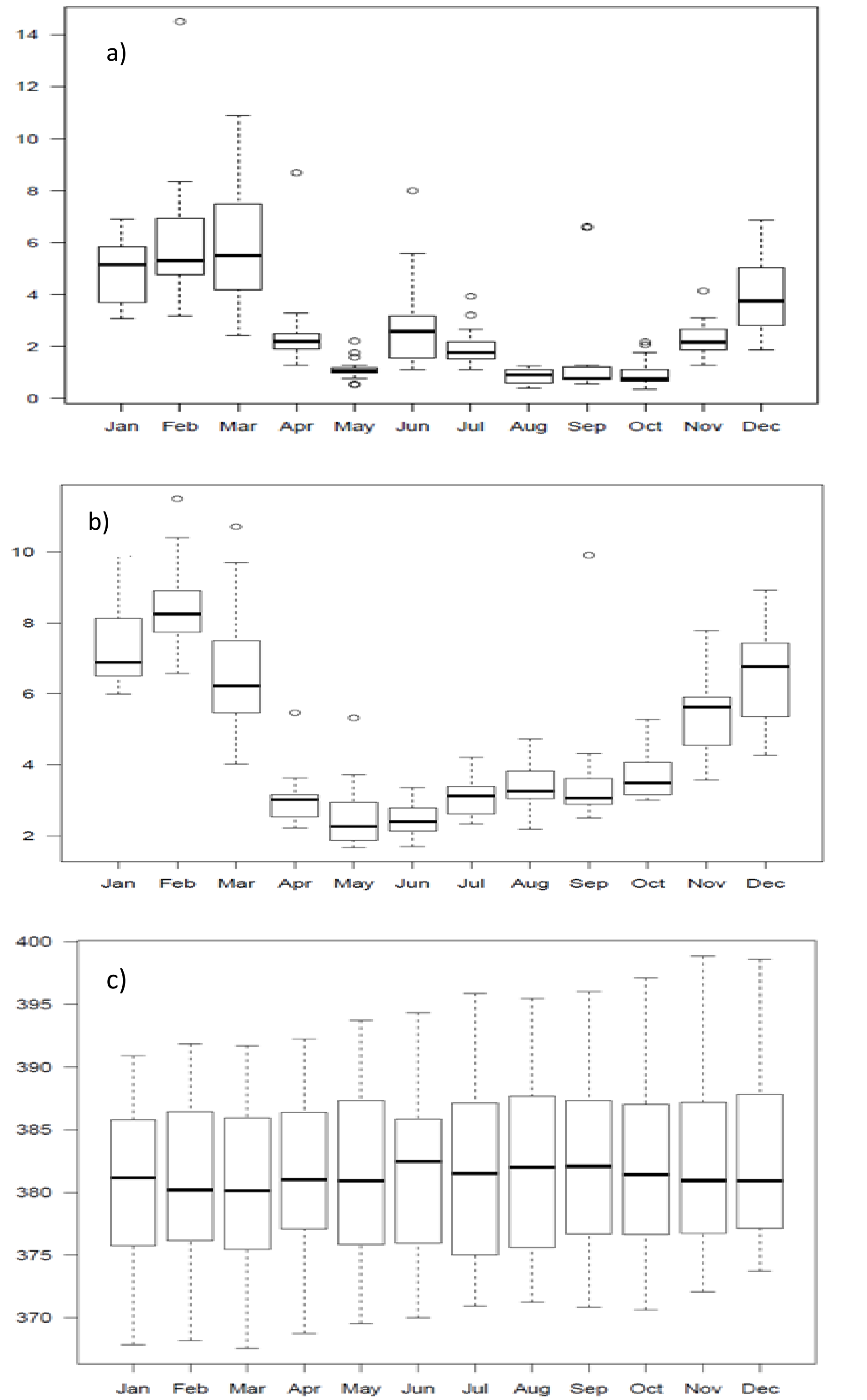


Figure 5: Mean Monthly Variability of a)$PM_{2.5}$ Concentration (µg/m^3) b) SO_2 Concentration (µg/m^3) and c). CO_2 Concentration (PPM)

4.1.3 Temporal interactions with pollutants

The general annual cycle of pollutants in Kenya can be explained from the behavior of seasonal variation of monsoon over equatorial East Africa which is heavily controlled by the seasonal displacement of the inter-tropical convergence zone (ITCZ) (Asnani, 1993; Slingo et al., 2005). Throughout DJF season, the ITCZ is in the southern hemisphere (10–15◦S) extending from the northern tip of Madagascar towards southern Tanzania and then northward towards Lake Victoria. With this kind of synoptic behavior, East Africa is generally dominated by north-easterly monsoon, transporting air from the northern hemisphere carrying northern hemispheric air towards Kenya that is enriched in pollutants (Novelli et al., 1998, 2003).

During the movement of ITCZ travelling to the north, it brings with it Long-rains in most parts of the country and this happens from mid-March to equatorial East Africa and with it clean air from the Indian ocean, causing less amounts of pollutants within the region. This is the explanation as to the behavior of having most pollutants having high values during this boreal winter period. CO_2 on the other hand has a global foot print which means there is a tendency of its variability to be very minimal in almost all the stations. Mombasa on the other hand has a boundary characteristics since it boarders a water body. Because of these characteristics, there is a distinct contribution based on where the winds are coming from. CO_2 in Mombasa comes from both maritime and continental source, and the assumption is the maritime component is perceived to be cleaner than the continental source, and this has been captured by the strong drop of CO_2 amounts during maritime source period, i.e. April to October.

Anomaly indices were done to compare departure of the pollutants from GAW, which in this study is assumed background. This was done by reducing GAW values to the minimum and comparing with other stations. This helped to give an insight of how stations compared to GAW with respect to the four seasons.

Anomaly distribution of $PM_{2.5}$ generally had MAM and JJA season with positive anomaly, whilst SON and DJF showing a negative anomaly. This was with the exception of Mombasa and Kisumu which still had negative anomaly during MAM and JJA seasons respectively. This can be attributed to the seasonality of the general flow and the boundary characteristics of land and water in Kisumu and Mombasa. During JJA and MAM, the general flow is South easterly towards GAW which brings with it emissions due to biomass burning particularly in JJA. While in MAM most of the places experience long rain season with maritime southerly winds meant to a scenario where most of the stations mentioned, i.e. Mombasa to have less $PM_{2.5}$ with respect to GAW. Kisumu on the other hand had less $PM_{2.5}$ due to less mixing occasioned by rainy season (MAM) and variable winds in JJA. In terms of monthly variability, December to March showed high variation with high values of the pollutants as compared to the rest of the months.

SO_2 showed positive anomaly for all the station with respect to GAW and this is because the city stations exhibited higher values of pollutants than GAW. DJF however had the lowest anomaly for both Nairobi and Kisumu and this because the two stations had near equatorial tendencies, and benefited from the synoptic strong winds during this time. The other three seasons however, the two stations registered higher anomalies. Mombasa had the lowest anomaly during the JJA season and this is because of the prevalence of onshore winds during this particular time of the year. The contribution of EALLJ can also not be assumed to have no effect during this season.

CO_2 also showed positive anomaly for all the stations and seasons as expected because of the global rising amounts. Nairobi showed slightly lower anomaly as compared with the rest of the stations with Mombasa registering the highest anomalies. The reason why Nairobi anomaly was lower is due to the fact that GAW and Nairobi share partially in terms of climatology. This gives picture of same behavior in terms of rain wash of the pollutants within a season. Again CO_2 has slightly longer resident time, which gives it a spatial mean that spreads greater distances compared to other pollutants that have less resident time. With this it is not easy to apportion point source for CO_2 as can be done with other pollutants; hence its presence in the atmosphere has less spatial variability. This said, the characteristics at GAW will have a near resemblance to Nairobi at least for CO_2, hence having less anomaly.

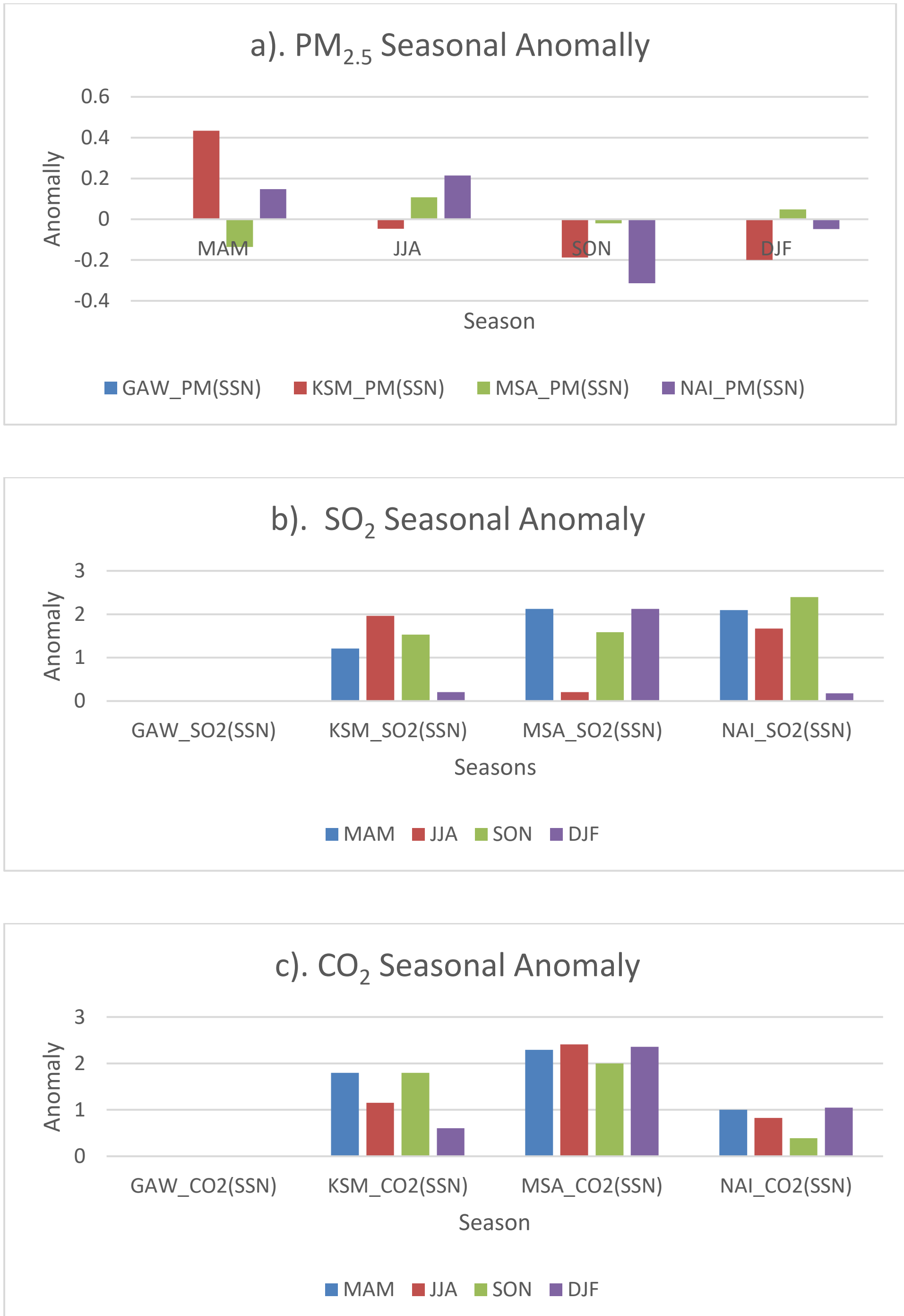


Figure 6: Seasonal anomaly of a) $PM_{2.5}$, b) SO_2 and c) CO_2

Correlation coefficient of GAW to the three stations was positive. Of note was Nairobi that showed very strong correlation for all the pollutants. This was attributed to the fact that Nairobi though more industrialized than GAW, still showed near same tendency of increase in pollutants with time. By having a strong correlation in this study, it shows that pollutant increase in the station is close to the same increase at GAW. Lower coefficient shows more increase to the station than GAW. The correlation coefficients show Mombasa and Kisumu with low values particularly for $PM_{2.5}$ and SO_2. This leads to a conclusion that the increase of pollutants in Kisumu and Mombasa is more significant as compared to Nairobi. CO_2 on the other hand showed very strong coefficients for all the stations with values ranging of 0.90 to 0.94. With this in mind it is hard to differentiate which station is recording maximum increase than the other. An interesting finding was none of the stations showed more than 1 in terms of correlation coefficient, which would have given a conclusion of having an increase in pollution that is less compared to GAW. Even with these high coefficients, it is easy to notice the increase in CO_2 within the three stations is higher than the increase at GAW. Correlation coefficients values are tabulated in the (Table 3) below.

Table 3: Pollutant correlation coefficients between GAW and other Stations

Pollutant	**Correlation Stations**	**Correlation coefficients**
$PM_{2.5}$	GAW/Mombasa	0.73
	GAW/Kisumu	0.76
	GAW/Nairobi	0.94
SO_2	GAW/Mombasa	0.67
	GAW/Kisumu	0.65
	GAW/Nairobi	0.83
CO_2	GAW/Mombasa	0.94
	GAW/Kisumu	0.90
	GAW/Nairobi	0.93

4.2 Spatial and temporal Characteristics of Winds

Wind fields that were observed in Mombasa, Kisumu, Nairobi, and GAW showed a dominance of certain characteristics in terms of speed and directions. The winds were averagely analyzed from the hourly wind data to daily then monthly average to ascertain the dominant direction and speeds of wind. The same was used to come up with seasonal dominant average winds to determine the partial contribution of emissions. Within the four stations, Mombasa recorded stronger winds of up to 40kts, followed by GAW then Nairobi.

Mombasa had two seasons with clear distinct dominant wind regimes. DJF and JJA had well organized wind directions compared to MAM and SON. DJF and JJA are dry seasons in Kenya to go by climatology of the area while MAM and SON are wet seasons in Kenya and by extension Mombasa. With this in mind the average winds speeds in DJF ranged between 11-17 Kts and had a Northwesterly dominant direction. During this time of the year, the North east traverse slightly a bigger area that is occupies by dust and other pollutants in the expansive Tsavo. The orientation of the coastline in Kenya tends to be parallel with the flow of winds, bringing in pollutants that come from the developed coastline. During JJA, the winds are southwesterly and very strong with speeds in the excess of 20 kts. With this strength, the winds traverse larger distances within the residence period of the pollutant. And though the southwestern of Mombasa is also developed, the distances travelled by the winds do not warrant more pollutants.

SON and MAM in Mombasa are wet seasons and you will expect the same outcome of lower pollutants. The winds during these two seasons are slightly North to south and the speeds are not with specific dominance. It is expected with variable wind direction to have more fetch in terms of pollutants but this is not the case as the wash effect takes precedence in wet.

Kisumu had relatively calm winds in three seasons; that is DJF, JJA and MAM of 7-11kts, SON had less than 7kt. Most of the winds in Kisumu had westerly component varying from 240-310 degrees. The main source of pollutants within Kisumu is within its immediate neighborhood. This is due to land use and industries around Kisumu. DJF still had the highest pollutants within this region and during this in Kisumu is a dry period. Climatology also played a big role in affecting the amount of pollutants during MAM and SON as washing effect also contributed to reduced pollutants during this time.

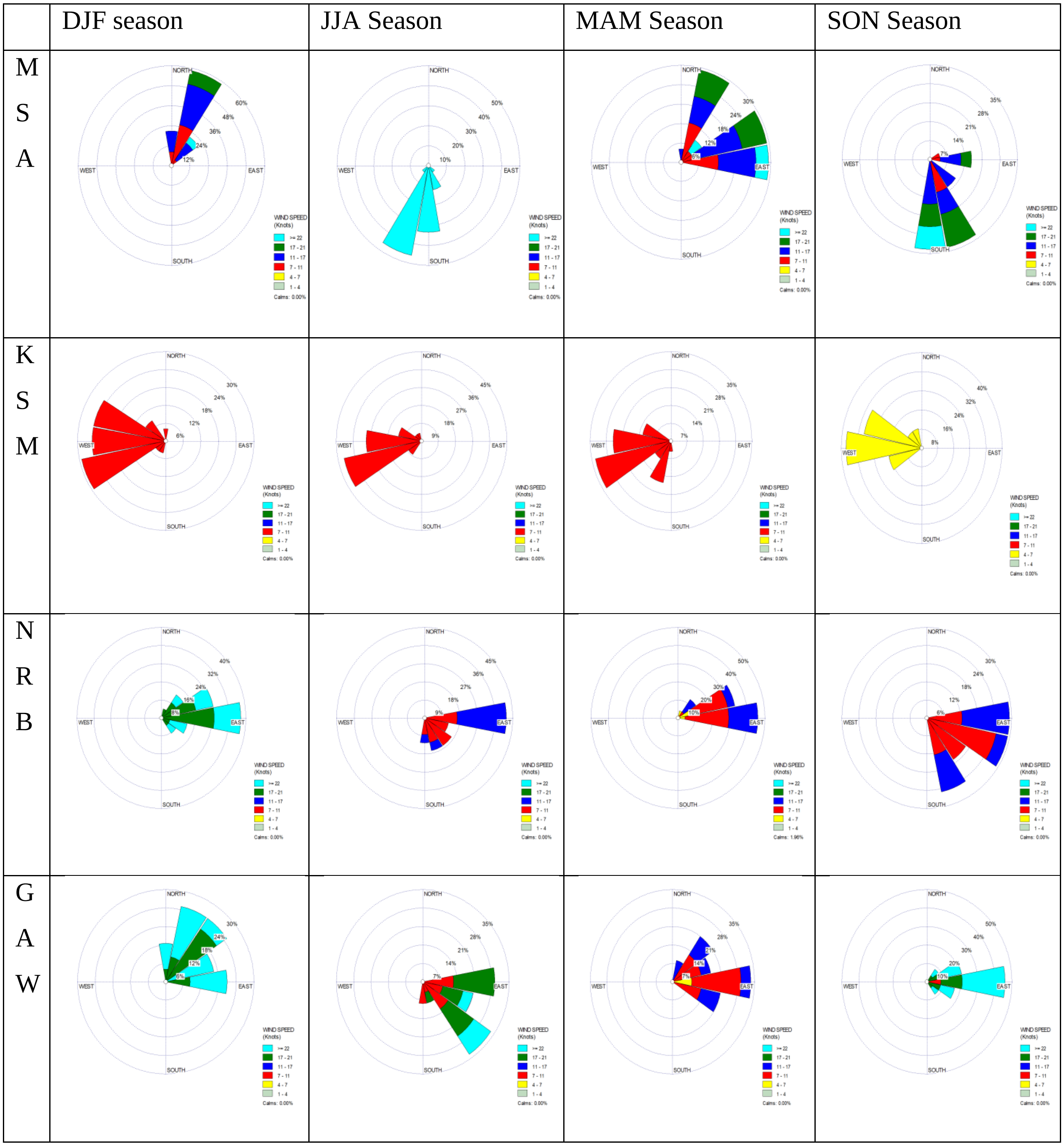


Figure 7: Seasonal wind speed and direction frequency

The westerly winds in Kisumu are assumed to come from the lakeside which will lead to a conclusion of Kisumu being a less polluted city. But this is not the case as the result shows the rate of increase in pollution in Kisumu is very high. The calm winds are the major player of transporting pollutants within and around the city. This can be seen with SO_2 that has two high peaks in Kisumu. SO_2 has less residence time which leads to its presence in the atmosphere to be within or near the source

Nairobi and GAW have near same wind characteristics, easterly. The winds in Nairobi pass through the Eastland’s before blowing over the city. This, with extensive landuse activities over the Eastland tends to bring in pollutants. DJF is the driest season in Nairobi and expected to have more pollutants as a result of polluting activities. This does not hold to be true, at least considering the level of pollutants compared with other stations. During DJF, the wind speeds are strong, and they either cause mixing of the pollutants of transport them further past the city. However a good indicator is the high values of SO_2 in both the dry seasons. SO_2 owing to its mass has shorter residency period in the atmosphere. The presence of this pollutant in the air is an indicator that it is within or around the station. Nairobi post JJA with also high amounts of this pollutant, and it leads to a conclusion that most of the pollutants are transported also by wind. Another point of concern in this study for Nairobi is where the data was collected with respect to highly industrialized zone.

The winds in Nairobi that would be laden with more pollutants are the southerly winds. This is because of the density of industries south of Nairobi city. This was not the case for this as the station selected for this research is in the north of the industrialized zone. SON season had southerly winds however, during this time in Nairobi is a period of short rains and this led to wash of the pollutants. This short rain season however ends early in November and it has been evident with most pollutants picking up from November to early march particularly for Nairobi.

Mt. Kenya (GAW) being used as a background station also recorded some concentration depending on which season is of interest. DJF still posted the highest concentration of the PM2.5. Relatively the concentration was slightly lower than the concentration in other cities of interest. During this season the dominant winds here are the NE mostly coming down from the Isiolo region and the arid area in the NE.

Finally, winds are highly dependent on Synoptic, Meso-scale and micro-scale systems. Kenya lying at the tropical equatorial region is not spared of the effects. The synoptic system in this case includes the Inter Tropical convergence Zone (ITCZ) and The East Africa Low Level Jet (EALLJ). Local features that have short life span like the land/sea breezes also have a greater effect on the behavior of the winds. ITCZ was extensively discussed in the aforementioned section, and is one of the main drivers of wind attributes within Kenya. The winds in Kenya follow systems that are occasioned by low and high pressure systems. The low system in Kenya is dependent on ITCZ and its displacement, occasioning different seasons of the year and different dominant winds.

All the four stations gave in varying strengths in terms of wind speeds, and the frequency of occurrence was dependent on seasonal phases. GAW and Nairobi are not so far from each other sharing the same climatological wind regime. The two stations had near easterly wind ranging between 10 to 20 knots. The frequency of occurrence was also dependent on which season of the year that affected both the direction and speed. The variance in terms of wind speed again was not so significant within a season and from season to season.

Mombasa, on the other hand, had a significant change of wind speed and direction. The wind speeds varied from 10-40 knots, with directions changing from SE to NE based on which season you are looking at. Kisumu because of orographic influences had near calm winds averagely, with strong winds going up to 15kts. This region had winds that were westerly in orientation meaning they were mostly onshore winds with fewer aerosols in them.

Mt. Kenya GAW station is located in eastern equatorial Africa it is largely unaffected by direct African biomass burning emissions that are most prominent in the western parts of the continent but insignificant in Kenya. This station was used to differentiate natural emissions from non-natural sources. The immediate surroundings to GAW is generally free from anthropogenic emission and makes atmospheric baseline measurements possible. The DJF season maximum was caused by advection of northern hemispheric air that is enriched in pollutants during the boreal winter. In contrast, JJA maximum was observed during advection of southern hemispheric air loaded with emissions from biomass burning in southern part of the region; however, these emissions were slightly low. Inter-annual variability in summer time pollutants could mostly be explained by a combination of changes in transport patterns and biomass burning intensity

4.3 Relationship between wind and pollutants

4.3.1 Wind rose analysis

$PM_{2.5}$ can be regarded as dust particles in simple terms which mean it is heavily affected by winds, looking at the concentration of $PM_{2.5}$ within the cities and within seasons, there is a simple analysis which places a higher concentration of dust close to arid areas with close proximity with the direction of winds. There was a prevalence of dust particles in Mombasa and Kisumu during the DJF season. From the section above, it is evident that $PM_{2.5}$ thrives well when the atmosphere is deprived of moisture and that is the reason why DJF has the highest proportions in terms of concentration. In Kisumu, the atmosphere is dry hence much of the year we expect to have$PM_{2.5}$ in the atmosphere and this is the reason why Kisumu had the highest levels. It's important to note that the concentration of PM2.5 increases with land use activities with basically attributes its occurrence to human activities. GAW is not spared either with the winds predominantly being easterly around Mt. Kenya hence bringing in the dust particles from the Eastern region which is perceived to be dry.

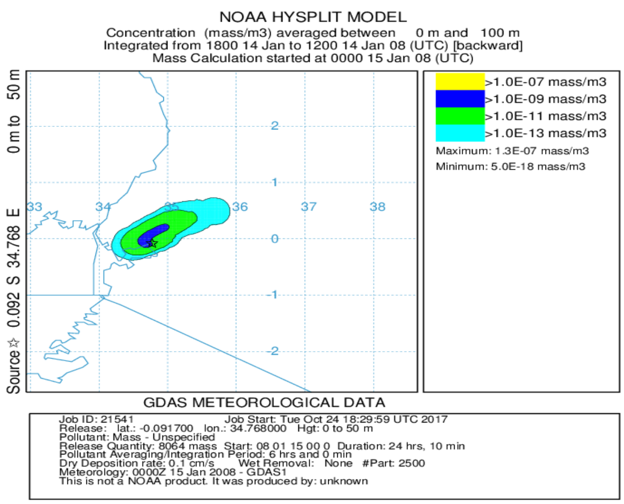
In matters to do with SO_2, the concentration mostly is affected by the source of this then aided with the winds. Industries contribute this pollutant and it being slightly heavier, there is a probability of this pollutant being deposited close to the source. Looking at wind data from GAW, which is perceived a background source, an Easterly component of winds still dominate and basically, the contribution may be as a result of industries upwind. The upwind of Mt. Kenya is not fairly developed hence the contribution here can be attributed to global circulation and also localized pollution. Wet seasons, SON and MAM have slightly less concentration as opposed to dry seasons of DJF and JJA from the distribution. During these seasons, MAM happened to have the lowest concentration of the SO_2 and this is also represented with weak winds during this season. SO_2 has a high affinity to dissolve in water hence any increase in moisture in the atmosphere leads to its deposition.

Nairobi and Mombasa, on the other hand, have more industries than the other two stations. For Nairobi, there was more concentration of SO_2 during the JJA season. JJA season is fairly cold in

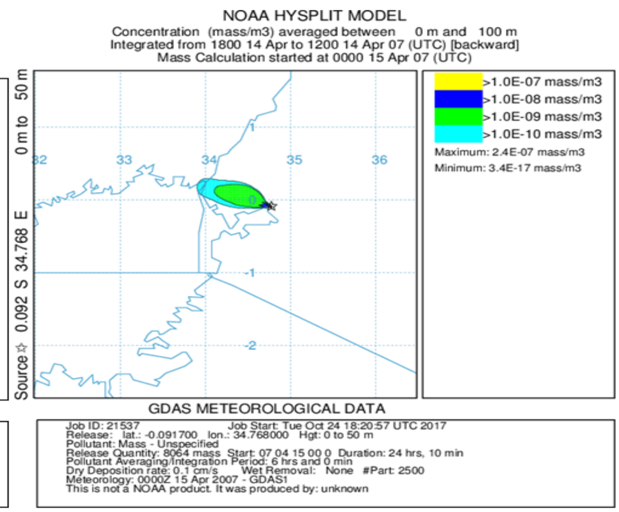
Nairobi with weak to moderate easterly winds. This supposes that much of the aerosols in this region is basically local, coming from industries within the vicinity of Nairobi, which in this case are the factories around Mombasa road and Athi- River. Same cannot be further from the truth for Mombasa, as during the DJF season had predominantly NE winds which mean the SO_2 present in this region was as a result of the industries within this region. Mombasa has industries towards the north and NE of the city that produces more aerosols.

This coupled with the geographical distribution of these industries means more of the SO_2 is blown far past Mombasa to the ocean and the remaining bit is the one captured in this study. It is also important to note that street emissions have a better distribution than the satellite SO_2 distribution. Finally, Kisumu has weak to moderate easterly to variable winds and largely not covered with a good network of industries around this region. This means much of the aerosols are as a result of vehicle emissions as opposed to industrial emissions. In Kisumu, weak to moderate SW component of winds during JJA being the main contribution of the highest concentration which basically means the emissions were as a result of localized activities.

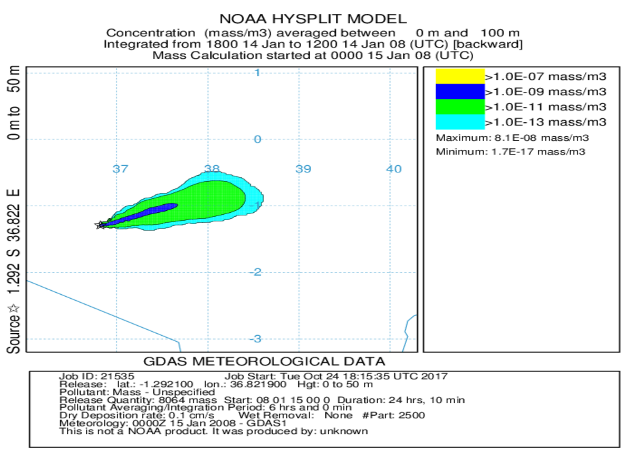
Finally, matters to do with CO_2, all the station showed an increasing trend. However, within seasons all the stations showed high values during the dry seasons as opposed to wet seasons. CO_2 in MSA was high when the winds were moderate NE and low when the winds were strong southerlies. This as earlier explained is a response to prevalence and distribution of industries within the northern parts of Mombasa. In Nairobi, these two wet seasons have a slight difference in terms of wind contribution as Nairobi is dominated by an easterly component of winds. Easterly winds within Nairobi contributed more as compared to the SW component of winds. In Kisumu, weak winds contributed to slightly more concentration than moderate winds which also agree to the fact that most of the CO_2 and other aerosols within this city is caused by vehicles as opposed to industries. Finally, in Mt. Kenya (GAW) the strong winds contributed to high levels of CO_2 as opposed to moderate winds. GAW is dominated by southeasterly and mainly being blown from the NE and SE, with most concentration coming from the SE due to the strong winds from the coastal region.



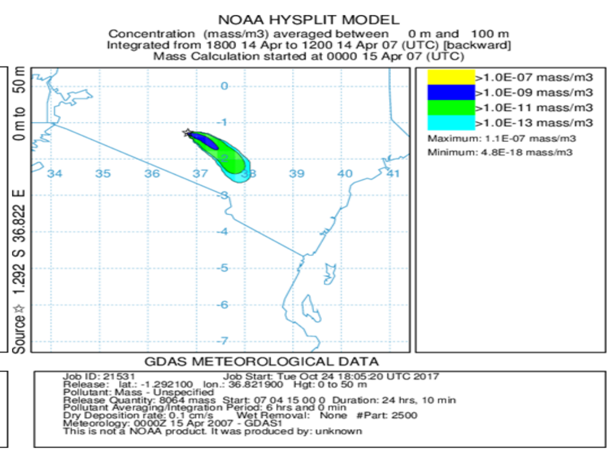
a). DJF Season (KSM)



b). MAM Season (KSM)



c) DJF Season (NRB)



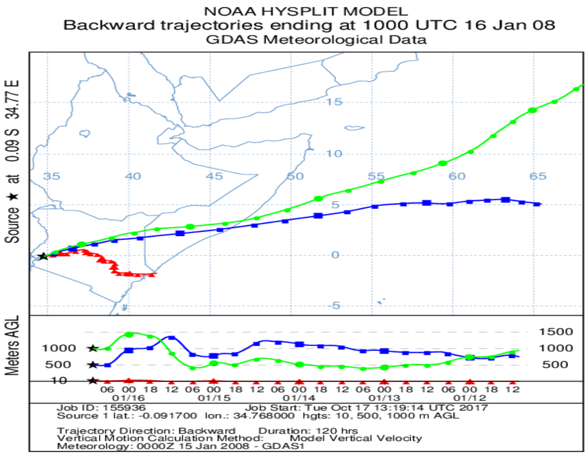
d). MAM Season (NRB)

Figure 8:(a-d): Concentration trajectories

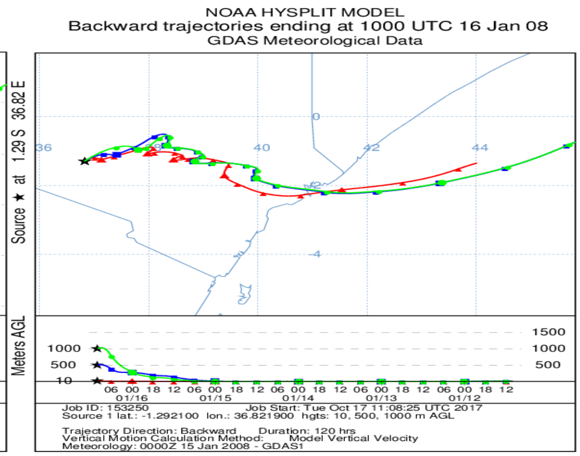
The concentration distribution as shown by the (Fig 5), there is a general distribution that follows the trends that was initially discussed for the winds. The concentration was done for different levels that are 10m, 500m and 1000m above sea level. In Kisumu, winds were not specific with variable flow particularly during JJA season. The other three seasons showed Northeasterly, Easterly and near westerly contribution. The important point of distribution shows that most of the concentration around Kisumu came from near sources, the distance travelled were not so extensive.

4.3.2 Trajectory Analysis

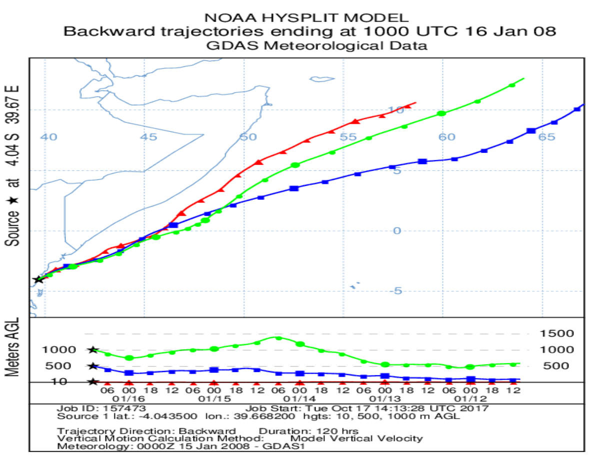
Trajectories were analyzed for the four seasons in all the four stations that were of interest. The procedures to identify the selected days of interest were as the ones followed for winds. The levels were taken were 10m which is near surface, 50m and 1000m which give the behavior of the boundery conditions.



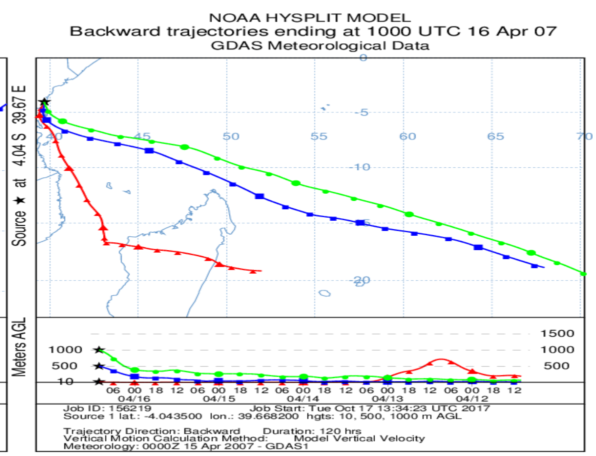
a). DJF season (KSM)



b).DJF Season (NRB)



c). DJF Season (MSA)



d). MAM season (MSA)

Figure 9: (a-d): Wind trajectories

Wind Trajectory for all the staions during DJF had an esterly component. This was particulary due to Noerth east monsoon that is occassioned by intensification of the arabian Ridge. The trajectory for Kisumu gives an easterly direction which also adds to the fact that the pollutants are transported from the continent. The same can be said of of Mombasa which had highest pollutant with northeast winds; this is in agreement with the trajectories. MAM was selected for Mombasa to sgow the shift of winds particularly with the displacement of the ITCZ towards the north.

Wind trajectory were most blowing from the east around Kisumu and Mombasa showing westerlies, though with generally weak speeds. During the rainy seasons MAM and SON, the air mass origin was easterly, indicating the presence of the ITCZ over Kenya. From the the trajectory distribution, there is a general easterly component in most of the station studied. Starting from GAW, the trajectories oscillate generally from easterly to southeasterly component, this follows the position of the ITCZ in which during DJF, there is a general northeasterly wind towards GAW, Nairobi and Mombasa. Within this oscillation, there is a great contribution of pollution when the trajectorries are Easterlies and Southerlies and mostly during DJFand JJA seasons. DJF is dry season having less rainfall wash effect during which most of the pollutants this time are highest. The other two seasons are slightly wet and with the concentrations of $CO_{2,}$ $PM_{2.5}$ and SO_2 also recording slighly low values, which leaves a general conclusion of localised and global transport bringing in these pollutants. GAW boarders the expansive Northeastern arid areas which provides a source of most of this pollutants during southerly component of the winds.

Dry seasons contributed more pollutants than the other two slightly wet seasons that is MAM and SON seasons in Kisumu. From the pollutants distribution CO_2, SO_2 and $PM_{2.5}$ have high values within DJF anfd JJA seasons. Within these two seasons, the winds have an easterly component which means most of the pollutants came from the city itself as opposed to the winds that may emanate from the neighbouring contries and passing through the lake, this will be expounded further in the concentration discusson below.

Mombasa on the other hand has shown prevalence of onshow winds or near onshow winds. But of interest was the high concentrations of pollutants recorded when the winds were either northesterlies and Southwesterlies. These two kind of trajectory distribution means that the winds were either blowing parallel to the shoreline or most of them were off shore. The two seasons that this winds were behaving this way was during the dry seasons which are DJF and JJA, with JJA having less contribution than DJF.

Finally, Nairobi recorded highest pollutants with Northeasterly and southerly trajectories and the two occurred during dry seasons climatologically within Nairobi. SO_2 was more pronounced during the JJA season as opposed to DJF season because of the strong winds at this particular time of the year. It is expected that during DJF the winds are slightly faster and stronger than JJA, which means SO_2which is assumed heavier then deposits more during this time.

Mombasa which had predominant on show winds particularly during DJF and SON seasons with SE during the remaining seasons showed a greater distance of pollutants. The distances that were covered by the pollutants travelled greater distances before being deposited. However, with this information there was low contribution of low level concentration which meant that most of the contributions were closer to the source. Nairobi on the other hand had Easterly and Southeasterly concentration. Depending with the season, there was more deposition from far and closer to the source.

Dominant wind speed over the Nairobi is generally easterly; with the direction ranging from north easterly in DJF to south easterly in JJA (Fig. 5). The results found in this study are agreeing with other studies on wind patterns (e.g. Opijah et al., 2007; Ongoma et al., 2013) which showed that easterlies are the dominant winds in January and November over Nairobi city. From these results, most of the pollutants appear to be transported beyond 100 m throughout the year. To put into perspective the trajectories during the cold season (Fig.5d), the dispersal of pollutants is observed to be in the north eastern direction.

The dispersal is observed to be furthest during the DJF and JJA seasons and least during the MAM and SON seasons. The reason as why most pollutants are dispersed furthest during dry seasons can be due to the fact that during this time, strong monsoons blow over the country during DJF and JJA (Omeny et al., 2008; Kalapureddy, 2007; Okoola, 1999). This implies that the concentration of pollutants in the atmosphere during the two rainy seasons is likely to be higher than what is observed in dry and cold seasons. However, wet deposition due to the precipitation occurring during rain seasons is likely to reduce atmospheric pollutants from atmosphere in the locality (Kaskaoutis et al., 2010).

4.4 Anthropogenic contribution

The monthly and seasonal distribution of PM2.5 within the cities compared to the background emission (Mt. Kenya, GAW) also showed a tendency of having more emissions towards December, January, and February, with fewer emissions within other months (Figure 6). This also corroborated with the seasonal distribution of the $PM_{2.5}$ with JJA and SON posting less distribution.

Based on model equations (Table 5), Mombasa and Nairobi have a slightly higher increase per year at 0.05μg/m^3 which gives a difference 0.04μg/m^3 per year. This is arrived at by having the difference on the gradient of the two stations with that of GAW. This anthropogenic contribution may not sound so much but if the trend takes a straight line as opposed to a more random and realistic trend, where these trends are mostly controlled by industrialization, urbanization, population growth and other economic activities.

Table 4:$PM_{2.5}$ Model gradients for the selected station

Pollutants	STATION	MODEL EQNS
$PM_{2.5}$	GAW	Y=0.01X+3
	KISUMU	Y=0.02X+4
	MOMBASA	Y=0.05X+1
	NAIROBI	Y=0.05X+2
SO_2	GAW	Y=0.005X+0.5
	KISUMU	Y=0.005X+0.5
	MOMBASA	Y=0.006X+0.4
	NAIROBI	Y=0.007X+0.5
CO_2	GAW	Y=1.9667X+396.58
	KISUMU	Y=2.0303X+370.57
	MOMBASA	Y=2.0321X+371.32
	NAIROBI	Y=2.2024X+369.37

Mt. Kenya (GAW) showed a yearly increase of the SO_2 of 0.005µg/m^3. This forms the base or the background level in terms of the rate of increase without the influence of human activities. Kisumu had the same increase per year of 0.005µg/m^3 which means the contribution of human activities in Kisumu is well within the bounds of natural contribution. Generally, there is less proliferation of Sulphur based companies in Kisumu; hence the increase of this pollutant with time is not abnormal. Based on this it's highly likely that the increase may not necessarily follow a straight line but with this factual result shows an increase of 0.05µg/m^3 in the coming ten years. This is still low but considering the corrosive and health effect of this; it's worth monitoring its growth.

Mombasa and Nairobi had slightly higher increase per year at 0.006µg/m^3 and 0.007µg/m^3 respectively. Again, since SO_2 is basically an industrial gas its increase in highly correlated to increase in industries, and with this age of industrialization the projection will be at least best to say that it won't be a straight-line model but exponential or random but with the upward tendency.

CO_2 trend analysis for all the four stations showed increases with time with different gradients. Mt. Kenya (GAW) showed a yearly increase of 1.9667ppm. This forms the base or the background level in terms of the rate of increase without the influence of human activities. Kisumu had the increase per year of 2.0303ppm which means the contribution of human activities in Kisumu to be in the region of 0.0636ppm per year. Mombasa had an increase of 0.0654 ppm per year while Nairobi, had 0.2357ppm. The reason why Nairobi values are higher is due to motor vehicle traffic and presence of industries.

To summarize on the anthropogenic contribution of $PM_{2.5}$ within the three major cities in Kenya, the result shows a 0.01, 0.04 and 0.04 inµg/m^3 per year surface increase of the particles for Kisumu, Mombasa and Nairobi respectively. The levels are still low and within WHO standards but if nothing is done the levels are bound to increase to level that are harmful to humans and the ecosystem. SO_2on the other hand showed 0.0001, 0.001 and 0.002 in µg/m^3 per year surface increases of the emissions for Kisumu, Mombasa and Nairobi respectively.CO_2 showed 0.0636, 0.0654, and 0.2357 in ppm per year surface increase of the emissions for Kisumu, Mombasa and Nairobi. To just be factual from the annual increase, the average annual increase of CO_2 is almost 2ppm which translates to 200ppm in the next 100 years assuming that nothing changes in terms of new addition of vehicles, population, urbanization, and industries.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.0 Introduction

This chapter includes the conclusion and recommendations that this study findings lead to. The main focus of the study was to assess anthropogenic contribution to ambient air quality with background emissions in Nairobi, Mombasa and Kisumu. The study further aimed to compare the concentrations of some air pollutants recorded at the three cities types with background concentrations obtained from Mt Kenya (GAW) station.

The quality of air is highly affected by prevailing meteorological variables. In general, pollutants tend to increase with calm winds and stable atmospheric conditions while strong winds with unstable atmospheric conditions tend to reduce the concentration of pollutants within the region.

5.1 Conclusions

All the air pollutants were within the WHO standards, there was no pollutant that was more than the WHO standards. The average monthly PM2.5 distribution within Kisumu, Nairobi and Mombasa were 3.8μg/m^3, 3.4 μg/m^3 and 3.6μg/m^3 respectively. The monthly and seasonal distribution of PM2.5 showed a tendency of having higher emissions towards December, January, and February, which collaborates with dry period in the respective areas and periods of northeast monsoons that bring in northern-hemispheric air that is laden with pollutants. Biomass burning is also a significant contributor to particulate matter emissions during the dry months that have been listed, as a result of increased charcoal burning. However, according to (Kornelius et al., 2012; Naidoo et al., 2014), posits that during colder months domestic biomass burning is more than warmer months due to domestic heating.

The prevailing winds in Nairobi, Kisumu and Mombasa vary according to the season. Case for Nairobi, winds is mainly easterlies implying that the pollutants will mainly be transported to the southwest and northwest of the town. Mombasa has more pollutants during DJF where the winds take a northwesterly. The pollutants are transported mainly from the industries and land fields that are over the northeastern of Mombasa. Backward trajectories from Mombasa show Northwesterly flow of the pollutants particularly during DJF

Trajectories in Nairobi generally show an easterly flow of pollutants most periods in the year emitted within the city. The pollutants are dispersed beyond 50 km within short periods with the least dispersion occurring during the long rain season. However, the spatial and temporal interactions with different scales bring in a different flow characteristics of wind. This differential scale differences is seen in most stations that have built canopy particularly in urban centers. Another issue than complicates the nature of flow is the densely populated built structures that alter the flow of pollutants. This leads to a scenario called surface inhomogeneity. This inhomogeneity causes spatial and temporal differences that are intense which makes handling the forecast and monitoring of the pollution a challenge. This calls for specific space and time monitoring of flow of pollutant concentration.

The assumption of having natural emissions at GAW means that the values by and large for this station form the base level of pollution. Put this in consideration, the difference can be attributed to non-natural activities in the general conclusion. Based on this finding, anthropogenic contribution in Kisumu is in the range is gradually increasing. The contribution may not be as significant as such but if only the trend takes a straight line as opposed to a more random and realistic trend where these trends are mostly controlled by industrialization, urbanization, population growth and other economic activities.

The findings of this study suggest that human activities are contributing to the burden of pollutants in the near surface atmosphere. Wind and other natural factors also come into play but the main player is human activities that have contributed much. This can be deduced to the fact that the background emission is increasing. The case of GAW having increasing trends of all the pollutants plays a bigger role to explain the fact that natural pollutants also have a huge proportion in terms of altering the ambient air quality.

The reality is in the fact that the gradient of the pollutants was increasing more than the background emissions. This shows the growing influence that human beings have placed on otherwise naturally growing pollutants. It is again simple to correlate the fact that pollutants have a correlation towards industrial emissions hence economic growth, which is also a factor of population growth. In a nutshell, with population growth, there is an inevitable reality of pollution growth. Now this economic and population growth are not on a straight-line curve, but more likely to be on an exponential and random curve that points upwards. This brings a sense of slightly more growth in terms of pollutants in the near future as opposed to the postulated straight-line increases.

Finally, the meteorological parameters only come in to aid in pollutant transport as opposed to increasing its presence. Some places it also depends on the strength of the winds as calm winds near the source help transport it from the source and help in spreading it near the source but strong winds near the source blows the pollutants away from the place to distant places. Another factor that also affects the suspension of the particles is its mass. This was not the objective of this study but cannot be assumed and wished away as mass is a function of density that enables a particle to be suspended in the atmosphere.

5.2 Recommendations

The study thus recommends for a consultative planning process of the management of urban centers that accounts for the observed wind characteristics over. For instance, most industrial activities should be located to the extreme western side of Nairobi, Kisumu and Mombasa to minimize concentration of pollutants over urban settlements. The study further recommends that more research especially for a longer period of time be carried out to ascertain the pollutant concentration and quality of rain water during the long rain season. This calls for accurate observation and monitoring of pollution levels over the city and other cities in the country

This study was set to advance the contribution human activities in aggravating pollution within the major cities in Kenya. Within its framework, the main aim was to analyze the trends both temporal and spatial characteristics of pollutants. There were limitations that were found in the study that was mostly financial in nature which in general deprived the gist of the striking result. Transect analysis is key to better get the distribution of pollutants in the cities. To achieve a better understanding of air quality within the city the study recommends further studies to determine cross sectional characteristics of pollutants and finally analyze the effect of pollutants to the ecosystem

References

Abushammala, M.F.M., Basri, N.E.A. and Kadhum, A.A.H. (2009). Review on Landfill Gas Emission to the Atmosphere. European Journal of Scientific Research 30(3):427-436

Albalak, R. (1997). Cultural practices and exposure to particulate pollution from indoor biomass cooking: effects on respiratory health and nutritional status among the Aymara Indians of the Bolivian Highlands. Unpublished Doctoral dissertation, University of Michigan.

Asnani, G. C. (1993). Tropical Meteorology Vol-1.

Beukes, J.P., Vakkari, V., van Zyl, P.G., Venter, A.D., Josipovic, M., Jaars, K., Tiitta, P., Kulmala, M., Worsnop, D., Pienaar, J.J., Virkkula, A. and Laakso, L., 2013: Source region plume characterization of the interior of South Africa as observed at Welgegund, National Association for Clean Air, The Clean Air Journal, 23(1), 7-10.

Brauer, M., Donkelaar, A., Randall, V., Hsu, C., Ralph, K., Robert, C., Lyapustin, A., Sayer, M., and Winker, W.,(2016): Global Estimates of Fine Particulate Matter using a Combined Geophysical-Statistical Method with Information from Satellites, Models, and Monitors;Department of Physics and Atmospheric Science, Dalhousie University, Halifax, N.S. Canada

Cheng, WL.,Pai, JL., Tsuang, BJ. et al.,MeteorolAtmosPhys (2001) 78: 11. https://doi.org/10.1007/s007030170002

Clarke, J., 2002: Coming back to earth-South Africa's changing environment, Jacana Ltd, Houghton;1919777938/9781919777931.

Cohen, A.; Anderson, H.; Ostra, B.; Pandey, D.; Krzyzanowski, M.; Künzli, N.; Gutschmidt, K.; Pope, CA., III; Romieu, I.; Samet, J.; Smith, K. Chapter 17: Urban air pollution. In: Ezzati, Majid; Lopez, Alan D.; Rodgers, Anthony; Murray, Christopher, JL., (2004). Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors, Volume 1. Geneva, Switzerland: World Health Organization; p. 1353-1434.

Crutzen, P. J., and Andreae, M. O.(1990): Biomass Burning in the Tropics – Impact on Atmospheric Chemistry and Biogeochemical Cycles, Science, 250, 1669–1678,.

Dayan and Levy (2002: Relationship between synoptic-scale atmospheric circulation and ozone concentrations over Israel; Journal of Geophysical Research, Vol. 107, No. D24, 4813, Doi: 10.1029/2002jd002147.

Downing, R., Melissa, M., Pouyan, N., Harrigan, T., Woznicki, A., (2017): Climate change and livestock: Impacts, adaptation, and mitigation;Department of Biosystems and Agricultural Engineering, Michigan State University, 524 S. Shaw Lane, Room 225, East Lansing, MI 48824, USA.

Gatari MJ, Wagner A, Boman J. (2005): Elemental composition of tropospheric aerosols in Hanoi, Vietnam and Nairobi, Kenya. The Science of the Total Environment.2005; 341:241–249.PubMed: 15833255

Gatari, MJ, Thadeus E., KanyivaM.,Catherine K (2016):Measuring exposure levels of inhalable airborne particles ($PM_{2.5}$) in two socially deprived areas of Nairobi, Kenya

Hanne Bach (2005): Methodology and process for indicator development. DEA - Vietnam.

Henne, S., Klausen, J., Junkermann, W., Kariuki, J. M., Aseyo, J. O., and Buchmann, B.(2008): Representativeness and climatology of carbon monoxide and ozone at the global GAW station Mt. Kenya in equatorial Africa, Atmos. Chem. Phys., 8, 3119-3139, https://doi.org/10.5194/acp-8-3119-2008,.

Hess, P. G. and Zbinden, R.: Stratospheric impact on tropospheric ozone variability and trends: 1990–2009, Atmos. Chem. Phys., 13, 649-674, https://doi.org/10.5194/acp-13-649-2013, 2013.

Hung N.,(2010): Urban Air Quality Modelling, and Management in Hanoi, Vietnam; Graduate School of Environmental Stress Studies (GESS); National Environmental Research Institute, 2010

Hunter, C., Sung, P., Schejter, E.D., Wieschaus, E. (2002). Conserved domains of the null protein required for cell-surface localization and formation of adherens junctions. Mol. Biol. Cell **13(1)**: 146-57.

IPCC, 2007: Climate Change 2007: The Physical Science Basis. The contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.[Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller (Eds.)].Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

IPCC, 2014a: Annex II: Glossary [Agard, J., E. L. F. Schipper, J. Birkmann, M. Campos, C. Dubeux, Y. Nojiri, L. Olsson, B. Osman-Elasha, M. Pelling, M. J. Prather, M. G. Rivera-Ferre, O. C. Ruppel, A. Sallenger, K. R. Smith, A. L. St. Clair, K. J. Mach, M. D. Mastrandrea and T. E. Bilir (eds.)]. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability.

IPCC, 2014b: Regional Aspects. The contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V. R., C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea and L. L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1757–1776.

Jago-on, K. A. B., Kaneko, S., Fujikura, R., Fujiwara, A., Imai, T., Matsumoto, T., Zhang, J., Tanikawa, H., Tanaka, K., Lee, B. and Taniguchi, M. (2009): Urbanization and sub surface environmental issues: An attempt at DPSIR model application in Asian cities. The science of The Total Environment 407, 3089-3104.

Japanese International Cooperation Agency (JICA). Final Report. Tokyo: JICA; 2006. The Study on a Master Plan for Urban Transport in the Nairobi Metropolitan Area in the Republic of Kenya.

Jim, C.Y., and Chen, W.Y., 2009: Ecosystem services and valuation of urban forests in China, Cities, 26, 187194

Kalapureddy M.C.R., D.N. Rao, A.R. Jain and Y. Ohno. 2007. Wind profiler observations of a monsoon low-level jet over a tropical Indian station. Ann. Geophys. 25: 2125- 2137. www.ann-geophys.net/25/2125/2007/

Klimont, Z., Smith, J., Cofala, J., (2013): The last decade of global anthropogenic sulfur dioxide: 2000–2011 emissions; Environmental Research Letters, Volume 8, Number 1;https://doi.org/10.1088/1748-9326/8/1/014003

KNBS (Kenya National Bureau of Statistics) 2010 The 2009 Kenya Population and Housing Census. Volume II.Population and household distribution by socio-economic characteristics.

Kossmann, M. and Sturman, A. 2004 The surface wind field during winter smog nights in Christchurch and coastal Canterbury, New Zealand. International Journal of Climatology 24, 93-108.

Kossmann, M., and Sturman, A., (2004):The surface wind field during winter smog nights in Christchurch and coastal Canterbury, New Zealand. International Journal of Climatology: https://doi.org/10.1002/joc.981.

Kristensen, P. (2004): The DPSIR Framework. National Environmental Research Institute.

Maina, DM.; Gatari, MJ.; Bundi, P.; Muturi, H. Impact of road transport on air quality in Kenya; Roadside survey in the cities of Mombasa and Nairobi; Proceedings of International Aerosol Conference (IAC2006); St Paul Minnesota, USA. 10-15 September 2006; 2006.ozone concentrations in West-Central Taiwan, Meteorol. Atmos. Phys., 78:11-21.

Muindi, K. (2017): Air pollution in Nairobi slums : sources, levels and lay perceptions (PhD dissertation). Umeå University, Umeå. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:umu:diva-138293 div

Muthama, N.J., Mathu, E. and Kamau, G.N. (2012).'An investigation of the transport and dispersion of atmospheric pollutants over east Africa during the Oldoinyolengai volcanic eruption in July 2007 and march 2008'.International Journal of BioChemi Physics20 http://erepository.uonbi.ac.ke:8080/xmlui/handle/123456789/36396Muthama, N.J., Kaume, C.M., Mutai, B.K. and Ng'ang'a, J.K. (2015).'Simulation of potential impact of air pollution from the proposed coal mining sites in Mui Basin, Kitui County'. Africa Journal of Physical 188 189 Sciences ISSN: 2313-3317 2(1) http://www.uonbi.ac.ke/journals/index. php/ajps/article/download/1370/1142

Nilsson, D.,Buzorius, G., Rannik, U.,&Kulmala, M,. (2016): Vertical fluxes and micrometeorology during aerosol particle formation events, Tellus B: Chemical and Physical Meteorology, 53:4, 394-405, DOI: 10.3402/tellusb.v53i4.16612.

Noubiap, J.J., Essouma, M. and Bigna, J.J. (2015).'Targeting household air pollution for curbing the cardiovascular disease burden: a health priority in Sub-Saharan Africa'. Journal of ClinicalHypertension17(10),4.doi:10.1111/jch.12610 http://onlinelibrary.wiley.com/doi/10.1111/ jch.12610/pd

Novelli, P., Masarie, K., Lang., (1998a) Distributions and recent changes of carbon monoxide in the lower troposphere; Papers on Atmospheric Chemisty; 1998; https://doi.org/10.1029/98JD01366

Novelli, P., Masarie, K., Lang., Hall, D., Myers, R., Elkins, J., (2003): Reanalysis of tropospheric CO trends: Effects of the 1997–1998 wildfires: journal: https://doi.org/10.1029/2002JD003031

OECD and IEA (2014). Africa energy outlook: a focus on energy prospects in Sub-Saharan Africa. International Energy Agency (IEA); Organisation for Economic Co-operation and Development(OECD),Parishttps://www.iea.org/publications/freepublications/publication/ WEO2014_ AfricaEnergyOutlook.pdf

Okoola R.E. 1999. A diagnostic study of the Eastern Africa monsoon circulation during the northern hemisphere spring season. Int. J. Climatol. 19: 143-168. DOI: 10.1002/(SICI)1097-0088(199902)19:23.0.CO;2-U

Omanga, E., Lisa, U., Zekarias, B., Gatari, M., (2014): Industrial air pollution in rural Kenya: community awareness, risk perception and associations between risk variables; BMC Public Health 2014**14**:377;https://doi.org/10.1186/1471-2458-14-377

Omeny A.P, L.A. Ogallo, R.E. Okoola, H. Hendon and M. Wheeler. 2008. East African rainfall variability associated with the Madden-Julian oscillation. J. Kenya Meteorol. Soc. 2:105-114. http://kms.or.ke/index.php?option=com_phocadownload& view=category&id=2&Itemid=78

Ongoma,V., Muthama, J., Gitau, W.,(2013):Evaluation of Urbanization Influences on Urban Winds of Kenyan Cities

Opija, F., Ininda, J., Muhati, D., (2007): Relationship between enso parameters and trends and periodic fluctuations in East Africa rainfall; Journal of the Kenya Meteorological Society (ISSN 1995-9834).

Pausata, F. S. R., Pozzoli, L., Vignati, E., and Dentener, F. J.: North Atlantic Oscillation and tropospheric ozone variability in Europe: model analysis and measurements intercomparison, Atmos. Chem. Phys., 12, 6357-6376, https://doi.org/10.5194/acp-12-6357-2012, 2012.

Reisman, M., (1997): Designing and Managing the Future of the State; 8 Eur. J. Int'l L. 409 (1997)

Rockstrom, J., et, al., (2009): Planetary Boundaries: Exploring the Safe Operating Space for Humanity; Ecology and Society , Vol. 14, No. 2, Dec 2009 :Planetary Boundaries.

Ryu, Y.H., Baik, J.J., Kwak, K.H., Kim, S., and Moon, N., 2012: Impacts of urban land-surface forcing on air quality in Seoul metropolitan area, Atmospheric chemistry and physics discussions, 12, 25791-25832

Schichtel , A., Husar, R., (2001): Eastern North American transport climatology during high- and low-ozone days; Atmospheric Environment,Volume 35, Issue 6, 2001, Pages 1029-1038: https://doi.org/10.1016/S1352-2310(00)00370-8

Scholes, RJ; Archibald, SA; Kirton, A; Van der Merwe, Martina R; Williams, CA; Hanan, N.,(2009) Drivers of inter-annual variability in Net Ecosystem Exchange in a semi-arid savanna ecosystem, South Africa.

Slingo, J., Challinor, J., Hoskins, J., Wheeler, R., (2005): Introduction: food crops in a changing climate; 2005.DOI: 10.1098/rstb.2005.1755

Swart, J., Raskin, P., Robbinson, J., (2004):The problem of the future: sustainability science and scenario analysis:Global Environmental Change, Volume 14, Issue 2, July 2004, Pages 137-146; https://doi.org/10.1016/j.gloenvcha.2003.10.002

Tanner, P.A. & Law, PT. Water, Air, &Soil Pollution (2002) 136: 105.https://doi.org/10.1023/A:1015275404592

UNEP (2016).GEO-6 Regional Assessment for Africa.United Nations Environment Programme, Nairobi, Kenya.

Vardoulakis, S.; Valiantis, M.; Milner, J.; Simon, H. (2007) Operational air pollution modeling in the UK--Street canyon applications and challenges. Atmospheric Environment 2007, 41 (22), 4622-4637.

Vliet, V., and Kinney,P., (2007): Impacts of roadway emissions on urban particulate matter concentrations in sub-Saharan Africa: new evidence from Nairobi, Kenya; Environmental Research Letters, Volume 2, Number 4 ;Focus on Global Impacts of Particulate Matter Air Pollution.

Walcek C J and Yuan H H 1999 Calculated influence of temperature-related factors on ozone formation rates in the lower troposphere; J. Appl. Meteorol. 34 1056–1069

Wandiga, S., Barasa, M., and Lalahb, J., (2007): Seasonal variability of persistent organochlorine pesticide residues in marine fish along the Indian Ocean coast of Kenya; Faculty of Science and Engineering, Department of Chemistry, Western University College of Science and Technology

WHO (2012).Exposure to particulate matter with an aerodynamic diameter to 10 um or less (PM10) in 1100 urban areas, 2003-2010. World Health Organization (WHO) http://gamapserver.who.int/mapLibrary/Files/ Maps/Global_pm10_cities_2003_2010.png

WHO (2015). ‘from MDGs to SDGs:General introduction. ‘. In Health in 2015: from MDGs, Millennium Development Goals to SDGs, Sustainable Development Goals. World Health Organization (WHO), Geneva, chapter 1 http://www.who.int/gho/publications/mdgs-sdgs/MDGsSDGs2015_chapter1.pdf

World Bank (2008). Africa’s population set to double by 2036. World Bank http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/AFRICAEXT/0,,contentMDK:21709116~menuPK:258659~pagePK:2865106~piPK:2865128~theSitePK:258644,00.html

World Health Organization, (2012): World Health Organization Statistical Information System (WHOSIS), Detailed Data Files of the WHO Mortality Databasehttp://www.who.int/healthinfo/statistics/mortality_rawdata/en/ (WHO, Geneva, 2012)