Anthropogenic Contribution to Air Pollution with Background Emissions; Case of Nairobi, Mombasa and Kisumu

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DOI: 10.29322/IJSRP.8.8.2018.p8047
http://dx.doi.org/10.29322/IJSRP.8.8.2018.p8047

Abstract

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 behaviour of pollutants. Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) and Wind Rose plotting (Wrplot) were used to determine wind trajectory and wind frequency

MAM and SON 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 centres. Moreover, the densely populated built structures that alter the flow of pollutants complicate the nature of flow. 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.

Key words: *Anthropogenic Contribution, Pollutants, Background Emission*

1.0 INTRODUCTION

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 (NO_2), 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 favours 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 Sulphur 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 centres. 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).

1.1 Background 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 Context

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, Gatari et 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 centres. 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.

2 MATERIALS AND METHODS

2.1 Area of study

Kenya lies on the eastern side of African continent within coordinates 4º N and 4º S, and 34º and 41º 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 centre 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.

2.2 Data types and sources

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.

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 land use 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 ($\mu g/m^3$) 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.

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 wind rose.

2.3 Methodology

2.2.1 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 behaviour 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 behaviour of pollutants at the same time. This was critical in analyzing the spatial characteristics of the pollutants.

2.2.2 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.

2.2.3 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 behaviour 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

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

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

3. RESULTS AND DISCUSSION

3.1 Spatial-Temporal characteristics of air pollutants

The four stations, Kisumu recorded the highest PM2.5 value of 20.3μg/m^3while 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^3while 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.

3.1.1 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 (µg/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 µg/m^3 long term exposure. The three cities had an average of 0.53µg/m^3 for Kisumu, 0.59µg/m^3 Mombasa and 0.55µg/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 0.53µg/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 1) 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

3.1.2 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.

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 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 general behaviour 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 behaviour and also less annual values. The behaviour 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 behaviour 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.

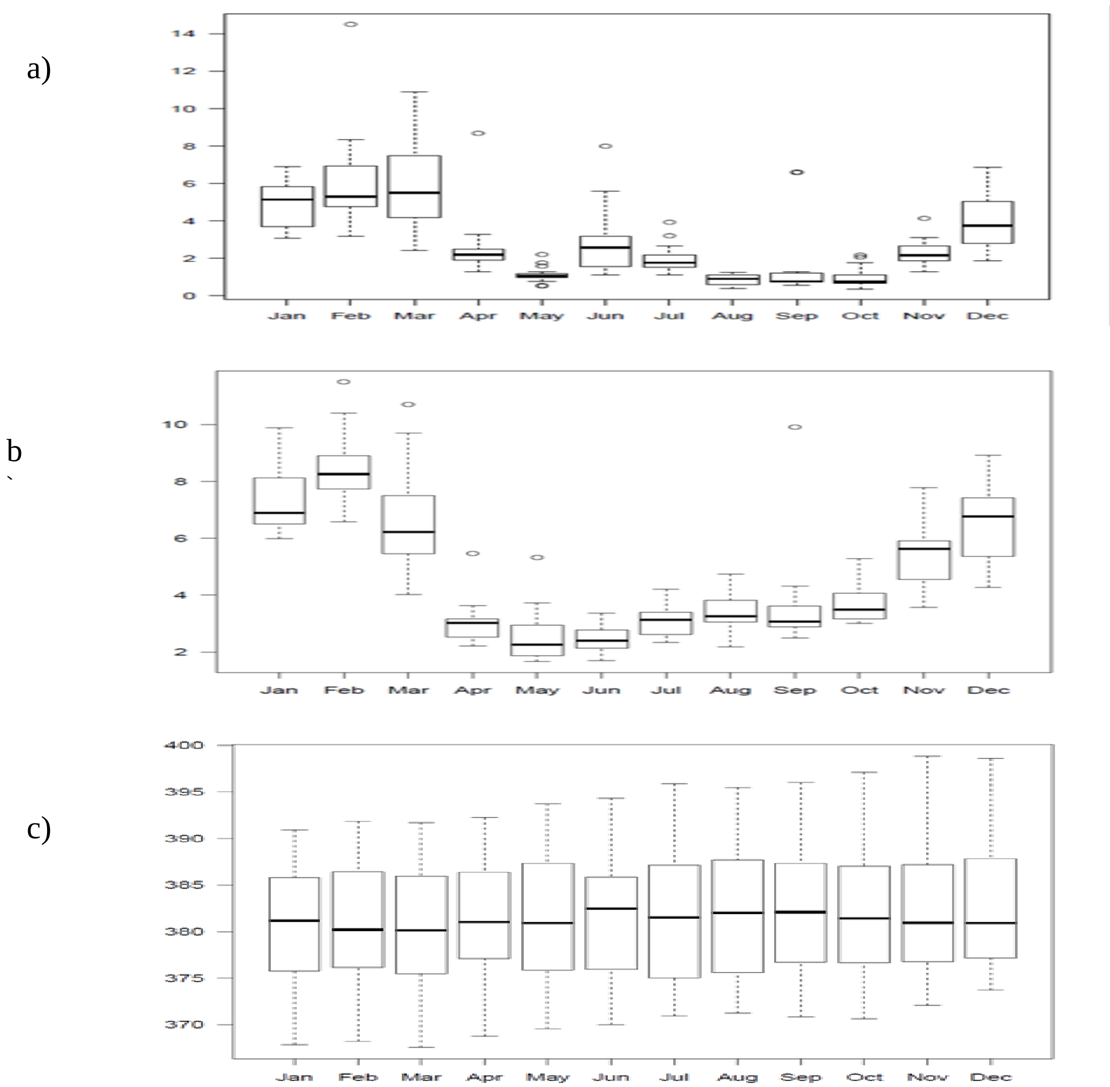


Figure 4: Mean Monthly Variability of a)$PM_{2.5}$ Concentration (µg/m^3) b) SO_2 Concentration (µg/m^3) and c). CO_2 Concentration (PPM)

3.1.3 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 behaviour, 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 behaviour 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.

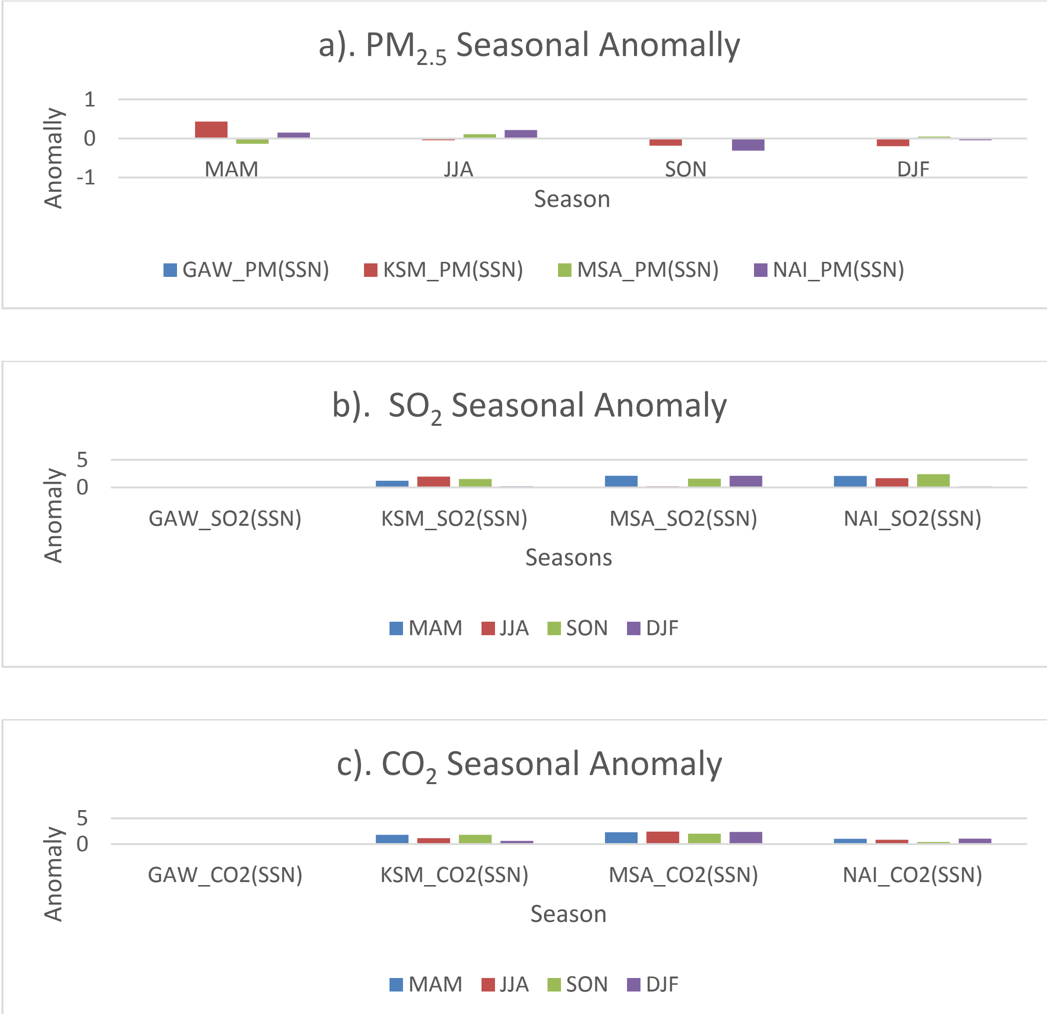


Figure 5: Seasonal anomaly of a) $PM_{2.5,}$ b) $SO_2$and c) CO_2

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

3.2 Relationship between wind and pollutants

3.2.1 Wind rose analysis

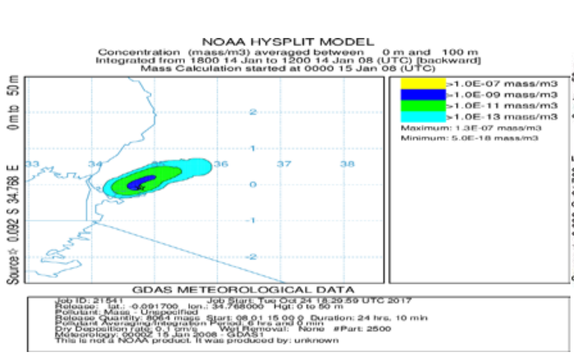
$PM_{2.5}$ can be regarded as dust particles in simple terms which mean it is heavily affected by winds, looking at the concentration of $PM_{2.5}$ within the cities and within seasons, there is a simple analysis which places a higher concentration of dust close to arid areas with close proximity with 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.

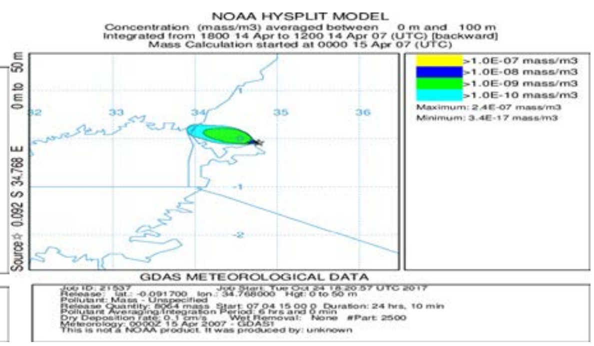
Nairobi and Mombasa, on the other hand, have more industries than the other two stations. For Nairobi, there was more concentration of SO_2 during the JJA season. JJA season is fairly cold in Nairobi with weak to moderate easterly winds. This supposes that much of the aerosols in this region is basically 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.

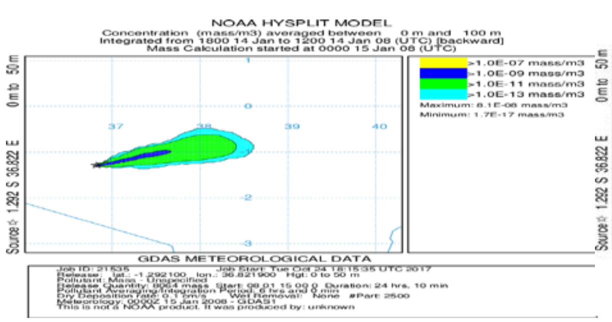
Finally, matters to do with CO_2, all the station showed an increasing trend. However, within seasons all the stations showed high values during the dry seasons as opposed to wet seasons. CO_2 in MSA was high when the winds were moderate NE and low when the winds were strong southerlies. This as earlier 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.



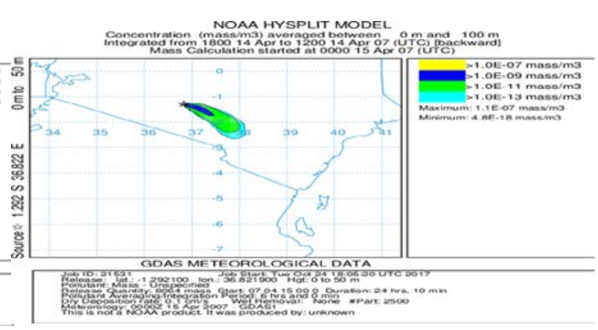
a). DJF Season (KSM)



b). MAM Season (KSM)



c) DJF Season (NRB)



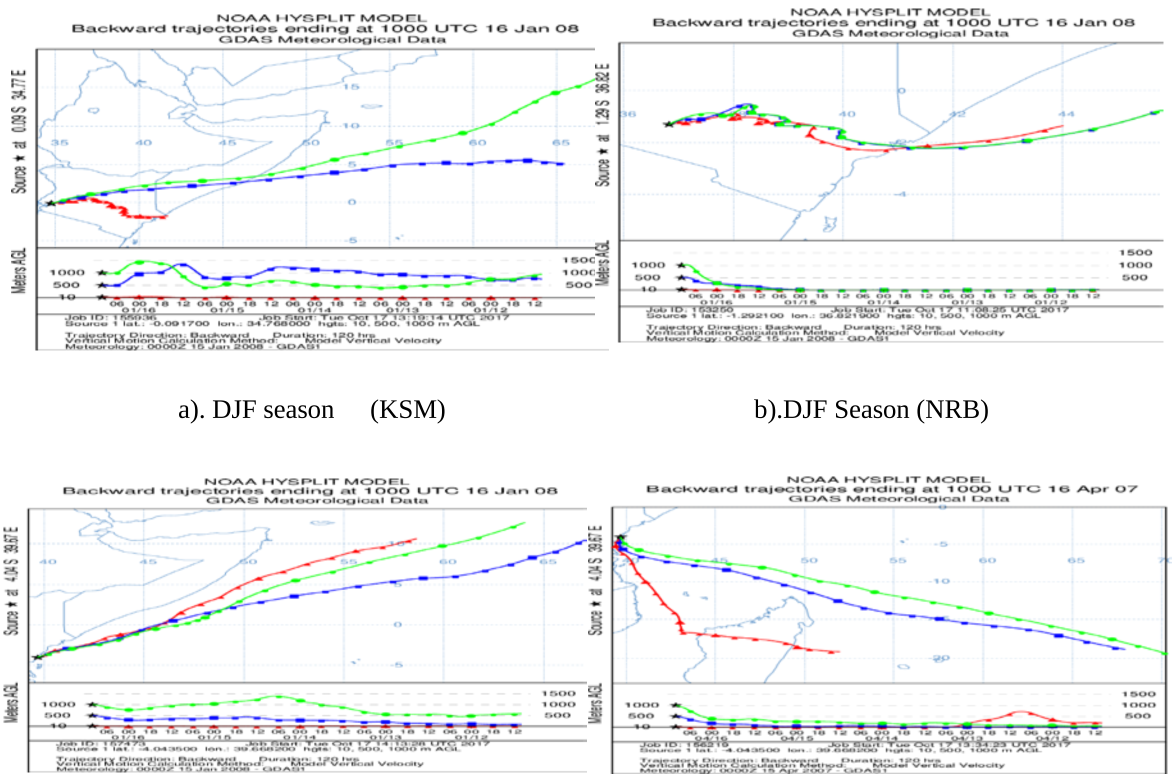
d). MAM Season (NRB)

Figure 6:(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.

3.2.2 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 1: (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).

3.3 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.

4. 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.

ACKNOWLEDGEMENT

I am sincerely grateful to the System of Land-based Emission Estimation of Kenya (SLEEK), an initiative of the Kenyan and Australian Government, for graciously providing the financial, professional and scientific support that made the study a success.

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