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Roadside Air Pollutants along Elected Roads in Nairobi City, Kenya

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Abstract

This paper presents a statistical analysis of air quality monitoring in Nairobi city, at three major roads and Industrial Area, a site closer to the main industrial activities. The study was carried out using different gas analyzers and samplers. From the statistical analysis it was found that, there were extremely high values of black carbon which went beyond the upper limit of the instruments (50,000 ηg/m^3) during the day on Ladhis road. Nakumatt Junction site recorded extreme values of Black carbon (14,008 ηg/m^3) in the evening hours, while at Pangani Roundabout site, the diurnal mean value was extreme (14,446.5 ηg/m^3) for the period. None of the four sites exceeded the WHO 24 h limit for both PM_{10} (50 μg/m^3) and $PM_{2.5}$ (25 μg/m^3). The 24 h mean values of PM_{10} in the three sites also did not exceed the ambient air quality tolerance Kenyan limit of 100 μg/Nm^3 and 150 μg/Nm^3 in industrial area.

The diurnal mean of SO_2 over the four sites was generally low with the highest amount of 1.08 ppb recorded at Pangani Roundabout. This amount is far much below the diurnal WHO and Kenyan limit of 10 ppb and 48 ppb respectively. The global background concentration of carbon monoxide ranges between 0.05-0.12 ppm. The mean 24 h amount of CO in all the sites was above the background concentration, with Pangani Roundabout recording the highest amount of 1.73 ppm. The eight h means for ozone in all the sites were below WHO limit of 51 ppb with the highest amount of 20.2 ppb recorded in industrial area.

Keywords: Ambient air quality; Air pollutants; Ecosystem; Amelioration

Introduction

With the rapid accumulation of vehicular flow on Nairobi roads and the City's economic development, the City's environment is placed under increasing pressure due to air pollutants [1-3]. Public and private transportation sector is important from an environmental and ecosystem point of view; it uses energy, particularly fossils fuels which are a source of air pollutants when ingested and processed. The sector has long been among the main topics of environmental attention in the industrialized countries and in the recent past the issue of air pollution has taken priority in developing countries such as China, Indonesia, and parts of West Africa [2-5]. Knippertz et al. [4] describes the work undertaken by the Dynamics-aerosol-chemistry-cloud interactions in the West Africa project (www.dacciwa.eu) that is set to investigate the influence of anthropogenic and natural emissions on the atmospheric composition over South West Africa and to assess their impact on human and ecosystem health and agricultural productivity.

Road transport emissions load ambient air with attendant pollutants. Air pollution also comes from production of goods and services, heating of houses, and rising particulates from dusty roads and pavements. Time spend on travelling on the roads are long due to traffics build up and jams. For instance, according to Boman and Thynell [2] the average travel time to work in Nairobi is estimated at about an h in traffic, but could have since gone up. Ambient air pollution is closely related to the health of people [6,7]. Air pollution too, has impacts on other aspects of the economy such as agriculture, and contributes to greenhouse gas emissions. Typical values for the vehicle share in total air pollution range from about 40% to 90% for carbon monoxide, hydrocarbons and nitrogen oxides and are somewhat lower for fine particulate matter. Nairobi City is an important part of Kenya's economy and a regional hub on many fronts and has been developing rapidly in all aspects including population density that stands at about 4 million persons [8]. This means that the city holds about 10% of the total population of Kenya. With a population density of about 4000 persons per square kilometer, the city's air pollution levels, atmospheric and environmental issues affect many persons.

Vehicular traffic is an important source of particulate pollution in cities of the developing world, where vehicle population grows fast [3], coupled with a lack of an effective public transport policy, land use planning, resulting in harmful levels of pollutants in the air near major roads. Other factors that aggravate air pollution levels in the city include; uncontrolled or lack a proper urban integrated development plan, allowing into city of transit vehicles that would otherwise not need enter the city, exponential rise in the number of private cars and lack of a credible alternative rail transport system.

Technical support for air pollution control and air quality amelioration must be provided. The dynamic changes in air quality, especially due to vehicular flow, must be systematically monitored and analyzed, especially due increasing urban population, less regulated traffic activities, mechanical state of vehicles on the roads. This study specially examines and assesses the state of emissions on the road corridor under consideration; Ngong Road, Landhis Road, Pangani intersection and the area around industries in industrial area. In recent years, research on atmospheric environmental change focused on compounds of Nitrogen (NO_2, NO, NOx, and NH_4), compounds

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of sulphur (SO_2, H_2S), carbon dioxide, carbon monoxide and total suspended particulate matters. Although flux and concentration measurements, modelling and assessment techniques have been developed to estimate the emissions there is still a need to continuously monitor emissions from specific sources such as road networks. Several organizations have established pollutants limits for atmospheric pollutants concentrations considered as harmful for air quality; these include WHO the European Union and the national agencies such as the US Environmental Protection Agency.

The WHO, 2012 guidelines set atmospheric concentration limits for particulate matter (PM), Ozone (O_3), NO_2, and SO_2. In an assessment of 26 cities, 24 had an annual average of PM_{10} over the level set. The European Commission's Air Quality Standards cover these four pollutants and set standards of atmospheric concentrations for lead (Pb) and carbon monoxide (CO). These represent most atmospheric pollutants in the urban environment.

According to WHO [9] an estimated 4.3 million people a year die prematurely from illness attributable to air pollution caused by the inefficient use of solid fuels. Among these deaths, 12% are due to pneumonia, 34% from stroke, 26% from ischemic heart disease, 22% from COPD, and 6% from lung cancer [10]. Previous findings regarding the association between air pollution and preeclampsia/eclampsia, mostly conducted in developed countries, are limited and have been inconsistent [11-13]. Several recent studies have reported positive associations between preeclampsia and air pollutants including nitrogen oxides (NOx), NO, NO_2, CO, O_3, PM <2.5 μm in aerodynamic diameter ($PM_{2.5}$), and particulate matter <10 μm in aerodynamic diameter (PM_{10}) [11] but others have reported no association with $PM_{2.5}$ or CO [13] or inconclusive findings for PM_{10} and NO_2. Two studies have reported positive associations between gestational hypertension (a risk factor and early symptom of preeclampsia) and air pollutants (PM_{10} and $PM_{2.5}$ [14] and NO_2 and PM_{10}). A study in Spain also observed an increased risk of preeclampsia associated with exposure to fine particulate air pollution [15].

Data and Methodology

Nairobi area

This study was carried out in Nairobi city (Figure 1) and the air samples were collected from the selected sites. The sites were designed to be at busy intersections or roundabouts (Ngong road, Landhies road and Pangani Roundabout) and a site in Industrial Area. The selection was done after a feasibility assessment that mapped out busy and potential monitoring sites considering witnessed traffic jams, possible elevated emissions and assessing the general prevailing meteorological conditions that influences pollution levels. Nairobi is Kenya's capital city is located within 1°9'S, 1°28'S and 36°4'E, 37°10'E and covers an area of 684 km^2. The climate is warm and tropical occasionally becoming cool and cloudy June through July yearly. Over the past decades Nairobi has undergone significant land use and land use change transformation largely occasioned by city expansion, industrialization, mushrooming high rise residential estates and a rising population curve. The current road expansion network, therefore, is a necessity to pass, fast and efficiently, the resulting attendant traffic for human, vehicular, goods and services. Such recently expanded roads include; Thika Road, Southern and Northern by-passes and the ongoing Outering Road.

Data and methodology

The data was collected every one minute using various gas analyzers from Kenya Meteorological Department (KMD). The analyzers are shown in Table 1. The meteorological parameters were measured by an automated weather observing stations.

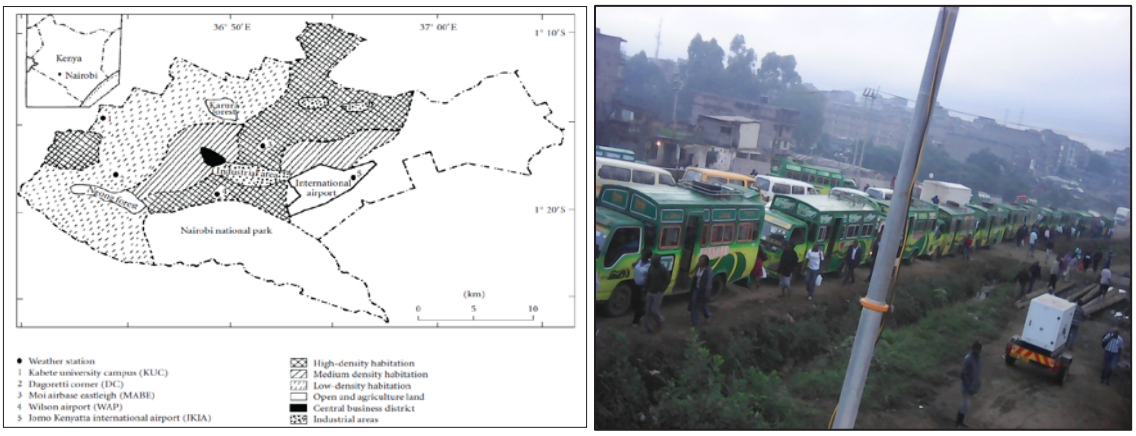

Figure 1: Map of buildup of traffic along outering road. The map is adopted from [20].

Instrument model	Parameter
EcotechSerinus 51	Hydrogen Sulphide and sulphur dioxide
EcotechSerinus 44	Nitrogen Oxides and Ammonia
EcotechSerinus 10	Surface ozone
EcotechSerinus 30	Carbon Monoxide
Ecotech EC 9820 Series	Carbon dioxide
Environmental Dust Monitor Model 180	PM_{10} and $PM_{2.5}$
Aethalometer	Black Carbon
Automated weather observing station	Ambient and screen temperatures, Solar radiation, precipitation, Atmospheric pressure, relative humidity, wind speed and direction

Table 1: Summary of instrumentation used in the study.

An aethalometer is a foremost instrument for the real-time measurement of optically-absorbing black or elemental carbon aerosol particles. It has been applied by other researchers in different settings [16,17]; it has also been used in extended applications in the area of public health and epidemiological studies, by allowing for real-time measurements of carbon particulate concentrations. Aethalometers provide fully automated data collection operation. The sample is collected as a spot on a roll of quartz fiber filter tape and performs a continuous optical analysis, while the sample is collecting, during this process, the tape does not move. The tape only moves forward when the spot has reached a certain density. Aethalometer draws the air sample through the inlet port, typically at a flow rate of a few liters per minute, using a small internal pump. The flow rate is monitored by an internal mass flow meter and is stabilized electronically to the set point value entered in software [17].

The optical method in the aethalometer is a measurement of the attenuation of a beam of light transmitted through the sample when collected on the fibrous filter. When calculated as expressed in equation 1, this quantity is linearly proportional to the amount of BC in the filter deposit;

$$ATN=100 * In\left(\frac{I_o}{I}\right) \quad (1)$$

Where I_0 is the intensity of light transmitted through the original filter, I as the intensity of light transmitted through the portion of the filter on which the aerosol deposit is collected and ATN is optical attenuation while the factor 100 is for numerical convenience. This measurement is affected by the wavelength of the light with which it is made, provided that the particle size is somewhat smaller than the wavelength. The absorption of light by a broad band absorber such as graphitic carbon is inversely proportional to the wavelength of the light used. Thus, for a given mass of black carbon [BC], the optical attenuation at a fixed wavelength (λ) may be written as given in equation 2.

$$ATN\ (\lambda)=\sigma(1/\lambda)^* [BC] \quad (2)$$

Where (BC) is the mass of black carbon, and σ (1/ λ) is the optical absorption cross-section that is wavelength dependent, and which is referred to as specific attenuation.

Environmental dust monitor

The environmental dust monitor model 180 was used for measuring PM_{10} and $PM_{2.5}$. The ambient-air, to be analyzed, is drawn into the monitor via an internal volume-controlled pump at a rate of 1.2 liters/minute. The sample passes through the measuring cell, past the laser diode detector and is collected onto a filter. The pump also generates the necessary clean sheath air, which is filtered and passes through the sheath air regulator back in to optical chamber. This is to ensure that no dust contamination with the laser-optic assembly. The sample flow is 1.2 l/min. Then a fine dust filter removes all the particles from the sample air. A membrane pump sucks the clean air through a valve, a protection filter, an orifice and a three way valve to the sample outlet. The sample flow is controlled by a flow controller which monitors the pressure drop over the orifice. A part of the cleaned air is used to supply the measuring chamber with rinsing air to keep the optic and the measuring chambers clean [18]. This clean air is also used during the functional self-test to calibrate the system for zero particles.

Nitrogen oxides were measured with EcotechSerinus 44 analyzer. The measurement of the $NO/NO_2/NOX/NH_3$ is performed via the gas phase chemiluminescence method. Sample air is drawn into the reaction cell via three separate (alternating) channels the NO, NOX and NX. The NOX channel travels through a delay coil enabling the same sample of air to be sampled for NO, NO_2 and NOX. The NOX channel passes through an NO_2 to NO converter, NO_2 is converted to NO. The analyzer also draws in air through an external converter (NX channel) which converts NH_3 into NO (and some NO into NO_2). This is then passed through the molyconverter to convert any NO_2 into NO. The other ecotech series instruments are described in detail in the operating manual GC 50003/2013.

Results and Discussion

The 24 h mean for all parameters sampled are presented in Table 2, while the morning and evening mean are show in Table 3 and the average meteorological parameters that were measured for all sites are presented in Table 4. From the findings the PM_{10} and $PM_{2.5}$ levels were found to be less than the recommended WHO guidelines, the levels were higher in the evenings and morning hours when the motor vehicle movement is higher. As Boman and Thynell [2] observed there

Pollutants	PM_{10}	$PM_{2.5}$	BC	SO_2	NO	NO_2	O_3	CO	CO_2
Units	ug/m³	ug/m³	ng/m³	ppb	ppb	ppb	ppb	ppm	ppm
Nakumat Junction	10.9	7.26	6474.66	0.46	10.44	9.21	7.39	0.61	368.94
Landhis Road	21.58	14.56	26115.54	0.82	54.89	17.41	4.11	0.97	368.74
Pangani	19.17	10.79	14446.53	1.08	36.99	15.73	5.64	1.72	385.51
Industrial Area	15.93	12.31	5996.32	0.78	4.53	8.37	10.34	0.57	379.51

Table 2: 24 h mean of pollutants.

Pollutants	PM_{10}	$PM_{2.5}$	BC	SO_2	NO	NO_2	O_3	CO	CO_2
Units	ug/m³	ug/m³	ng/m³	Ppb	ppb	ppb	ppb	ppm	ppm
Nakumat Junction (Morning)	22.0	15.01	14008.13	0.25	15.18	8.24	4.41	0.84	387.02
(Evening)	20.3	11.52	9835.37	0.53	20.25	15.34	1.84	1.06	377.54
Landhis Road (Morning)	16	14.84	29855.8	0.69	67.48	20.13	2.16	1.16	385.06
(Evening)	32.3	23.02	33778.66	1.65	90.42	23.28	2.09	1.33	358.62
Pangani (Morning)	16.96	14.75	29855.84	0.57	0.84	67.4	2.14	1.13	385.05
(Evening)	32.25	22.94	33778.58	1.57	1.15	90.41	2.21	1.32	358.53
Industrial Area (Morning)	33.21	24.93	12007.57	1.13	19.45	13.74	3.13	0.75	403.65
(Evening)	25.82	19.65	8702.74	1.5	4.07	12.35	3.66	0.99	378.72

Table 3: Morning/evening peaks of pollutants.

is a significant difference between roadside concentrations and urban background concentrations. The Boman study finds that 24 h $PM_{2.5}$ background concentration in the city center site as 22 μg/m³. This compares well with the present study that finds a city center site (Ladhis road) recording an average of 21.58 μg/m³ daily. This study found the each concentrations of $PM_{2.5}$ at the sampling sites varied with highest levels observed at the site within the CBD.

Nakumat junction site

Figure 2 depicts 24 h mean of PM_{10}, $PM_{2.5}$ and black carbon at Nakumatt Junction near Dagoretti Corner. The wind direction was mainly easterly (Figure 3) with mean speed of 2.4 m/s as indicted in Table 3. The wind regime compares well to fin dings by Ongoma et al. [19]. Figure 2 shows two distinct peaks, one in the morning and the other in the evening for the PM_{10}, $PM_{2.5}$ and BC. These peaks can be attributed to vehicular emission during the morning and evening rush hours. The mean morning peak concentrations were 20.3, 11.5 μg/m³, 9835.3 ηg/m³ for PM_{10}, $PM_{2.5}$ and black carbon respectively, while the evening peaks were 22.0, 15.0 μg/m³, 14008.1 ηg/m³ for PM_{10}, $PM_{2.5}$ and black carbon respectively. It is important to note that the

Parameters	Wind Speed	WD	Temp	RH	AP	Precip	SR
	m/s	degrees	°C	%	hPa	mm/hr	W/m²
Nakumat Junction	2.364	97.173	18.3	72.49	825.74	0.016	350.064
Landhis Road	2.169	92.946	19.19	78.26	839.52	0.091	302.19
Pangani	1.894	107.228	19.61	72.12	839.12	0.000	362.017
Industrial Area	3.566	129.614	22.21	61.84	838.9	0.517	380.187

Table 4: Average weather parameters (24 h mean).

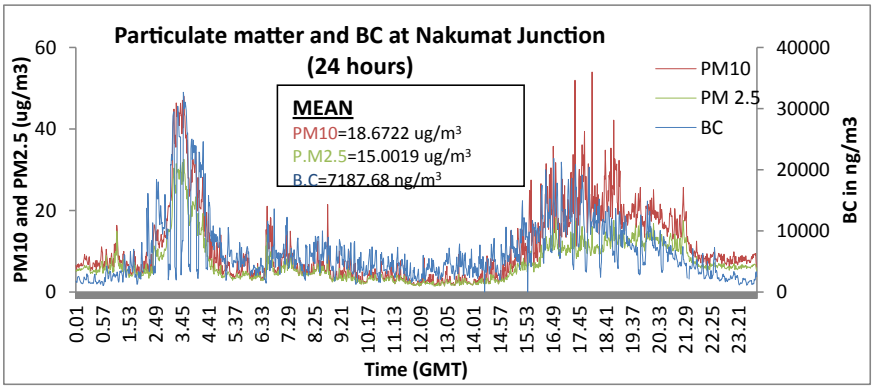

Figure 2: Diurnal variation particulate matter.

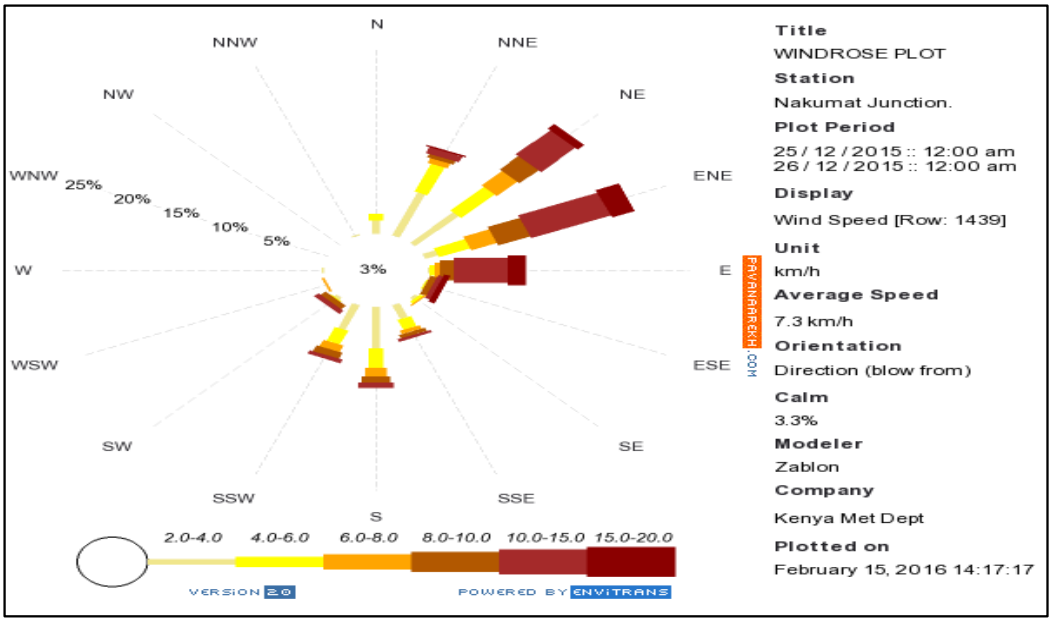

Figure 3: Nakumat junction windrose and frequency.

measurements were taken around Christmas and end year holidays when the volume of vehicles on the road was low. According to World Health Organization (WHO) Air Quality Guideline (AQG) of 2005, the levels for $PM_{2.5}$ and PM_{10} for 24 h duration are 25 and 50 μg/m^3 respectively. For this site the levels were 7.26 and 10.90 μg/m^3 for $PM_{2.5}$ and PM_{10} respectively consequently not exceeding WHO limits. Black carbon levels were noted to be very high, where by the 24 h mean was 6474.7 ŋg/m^3 while the morning and evening means were 14,008 and 9,835 ŋg/m^3 respectively (Table 5).

Figure 4 shows diurnal distribution NO_2 and nitric oxide (NO) at Junction Site. The 24 h mean are 10.4 and 9.2 ppb for NO and NO_2 respectively. There are two pronounced peaks in the morning and evening. The morning and evening peaks for NO and NO_2 are 15.1 and 20.2, and 8.2 and 15.3 respectively. The peaks are associated with the morning and the evening rush hours since motor vehicles account for over 50% of the total NO_2 generated. The highest hourly concentration of NO_2 was 17.5 ppb, far much below the WHO limit of 102 ppb.

The 24 h concentrations of SO_2, CO_2 and CO are shown in Figure 5. They also depict same characteristic as the other pollutant whereby, they have two peaks in the morning and evening and it is attributed to the build-up in traffic at those times. These three parameters are generated from fossil fuels among other sources. Consequently, the two peaks in concentration realized in the morning and evening.

The diurnal amount of SO_2 is generally low averaging at 0.46 ppb. This is far much below the WHO 10 ppb for 24 h, while that of carbon dioxide was 368.94 ppm, which is also below the global annual average of 402 ppm. However, ambient guidelines for CO_2 do not exist. The global annual mean concentration of CO_2 in the atmosphere has increased by more than 40% since the start of the Industrial Revolution, from 280 ppm in the mid-18th century to 402 ppm as of 2016. The present concentration is the highest in at least the past 800,000 years and likely the highest in the past 20 million years. The increase has been caused by anthropogenic sources, particularly the burning of fossil fuels and deforestation. Global background concentrations of carbon monoxide range between 0.06 and 0.14 mg/m^3 (0.05-0.12 ppm). The mean 24 h amount of CO was 0.62 ppm which is slightly above the background concentration. In the streets, the carbon monoxide concentration varies greatly according to the distance from the traffic; it is also influenced by topography and weather conditions. In general, the concentration is highest at the leeward side of the street, and there is a sharp decline in the concentration from pavement to rooftop level. Figure 6 depicts the diurnal variation of ozone at NJ. The figure generally shows low amount in the early morning and at night with the peak realized during the day. The peak in midday is due to the fact that surface ozone is produced by photochemical oxidation of CO, CH_4 and non-methane volatile organic carbons (NMVOCs) in the presence of NOx. The eight h mean was 10.3 ppb which is below the WHO mean of 51 ppb.

Site	Ozone 8 Hour Mean (PPB)
Nakumatt Junction	10.3
Landhies	7.8
Pangani	10.1
Industrial Area	20.2

Table 5: Ozone 8 h mean values.

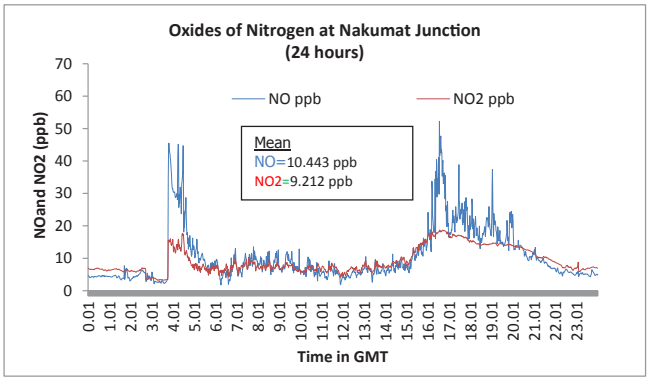

Figure 4: Oxides of nitrogen.

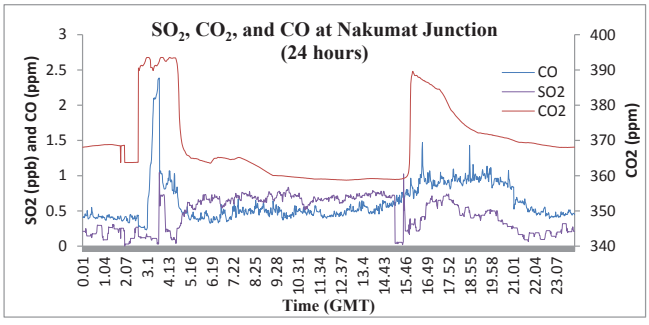

Figure 5: Diurnal SO_2, CO_2 and CO at Nakumat Junction (The mean for SO_2, CO_2 and CO is 0.4630 ppb, 368.9391 ppm and 0.6174 ppm respectively).

Results for ladhis road

Figure 7 depicts generally extremely high values of BC during the day which went beyond the upper limit of the instruments (50,000

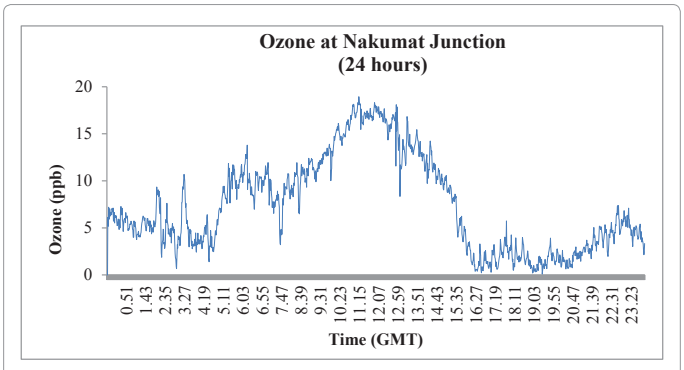

Figure 6: Diurnal variation of ozone.

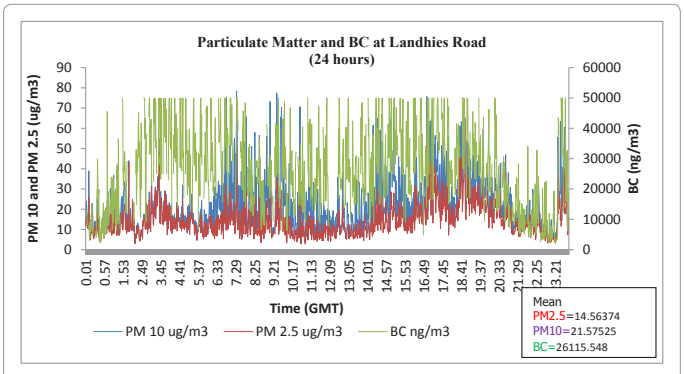

Figure 7: Diurnal variation of PM.

ŋg/m^3). The 24 h mean were 26,115.5 ŋg/m^3, with the mid-morning and evening peaks at 29,855.8 and 33,778.6 ŋg/m^3 respectively. These are high values as indicated in Table 4 which have negative impact on human health. The $PM_{2.5}$ and PM_{10} 24 h mean was 14.6 and 21.6 µg/m^3 respectively consequently not exceeding WHO limits. Observation at Ladhis road shows the wind direction was mainly northeasterly (Figure 8) with mean speed of 2.2 m/s as indicted in Table 5. The diurnal distribution of both NO_2 and nitric oxide (NO) are shown in Figure 9. The 24 h mean are 54.9 and 17.4 ppb for NO and NO_2 respectively (Table 4). This mean is lower than the Kenyan tolerance limit of 100 ppb. There are two pronounced peaks in the morning and evening. The morning and evening peaks for NO and NO_2 are 67.4 and 90.4 and 20.1 and 23.2 respectively as indicated in Table 5. The peaks are associated with the morning and the evening rush h. The highest hourly concentration of NO_2 was 44.4 ppb, which is far much below the WHO limit of 102 ppb and Kenyan limit of 200 ppb.

Figure 10 depicts the mean 24 h concentration of SO_2 and CO. These pollutants are generated from fossil fuels among other sources. Consequently, the peaks realized in the morning and evening, were attributed to the build-up in traffic. The diurnal amount of SO_2 is generally low averaging at 0.82 ppb. This is far much below the WHO 10 ppb for 24 h and Kenyan limit of 48 ppb. Global background concentrations of carbon monoxide range between 0.06 and 0.14 mg/m^3 (0.05-0.12 ppm). The mean 24 h amount of CO was 0.97 ppm which is way above the background concentration. Figure 11 depicts the diurnal variation of ozone. The figure generally shows low amount in the early morning and at night with the peak realized during the day. The peak in midday is due to the fact that surface ozone is produced by photochemical oxidation of CO, CH_4 and non-methane volatile organic carbons (NMVOCs) in the presence of NO_2. The eight h mean was 7.8 ppb which is below the WHO mean of 51 ppb.

Results for pangani round about site

The mean wind speed was 1.9 m/s with predominant wind direction of 107.2° as indicated in Table 5 and Figure 12. The mean temperature was 19.6° with no rainfall recorded. Figure 12 shows the diurnal mean of particulate matter in Pangani Roundabout. There is no discernible pattern. However, high values were observed for the three pollutants between 1.49 and 19.49 GMT with the remaining time indicating low values. The 24 h mean of $PM_{2.5}$ and PM_{10} were 10.8 and 19.2 ug/m^3 respectively which are both below WHO and Kenyan limit. The black carbon mean was 14,446.5 ng/m^3 which is extremely high (Figure 13). Figure 14 shows diurnal distribution of both NO_2 and nitric oxide (NO). The 24 h mean are 37.0 and 15.7 ppb for NO and NO_2 respectively. The mean 24 h of NO_2 is below Kenyan limit of 100 ppb. There are two pronounced peaks in the morning and evening with sustained relatively high values during the day. The morning and evening peaks for NO_2 and NO are 17.9 and 24.1 and 67.4 and 90.5 ppb respectively. The peaks are associated with the morning and the evening rush h. The highest hourly concentration of NO_2 was 52.2 ppb, which is below both WHO and Kenyan limits of 102 and 200 ppb respectively.

Figure 15 depicts the mean 24 h concentration of SO_2 and CO. At this site, there are no pronounced peaks in the morning and evening.

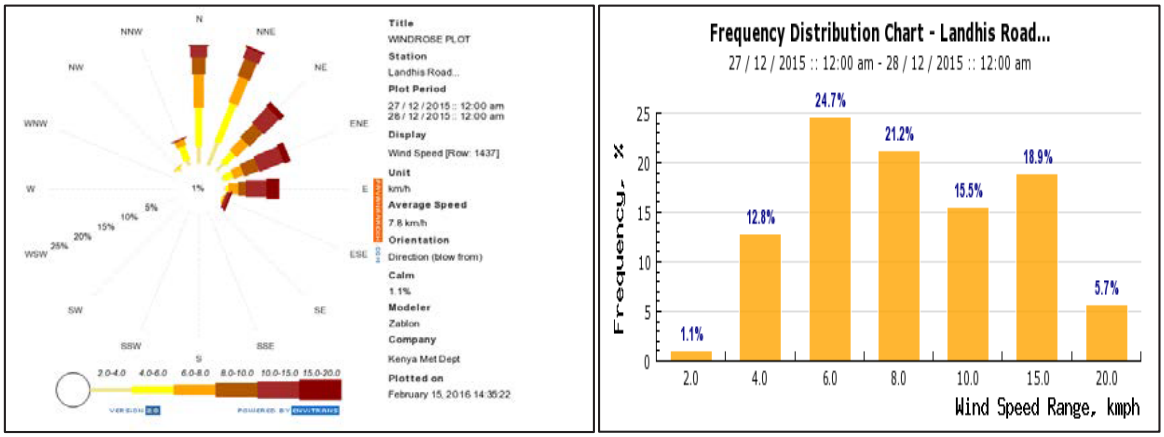

Figure 8: Landhis road windrose and frequencies.

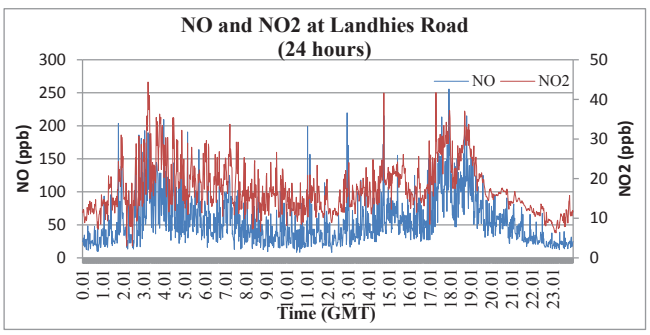

Figure 9: Diurnal variation of oxides of Nitrogen.

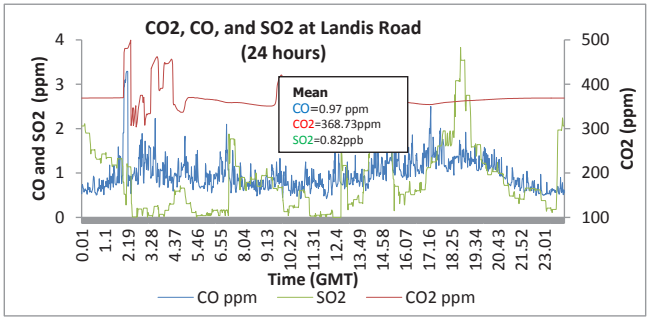

Figure 10: Diurnal SO_2, CO_2 and CO at Ladhis road.

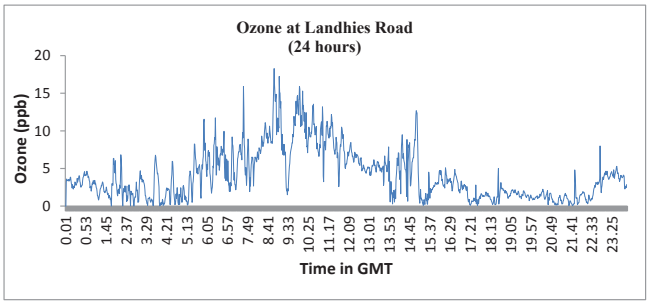

Figure 11: Diurnal variation of ozone.

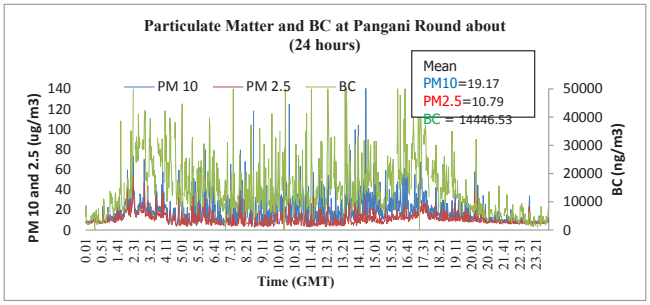

Figure 12: Diurnal variation of particulate matter.

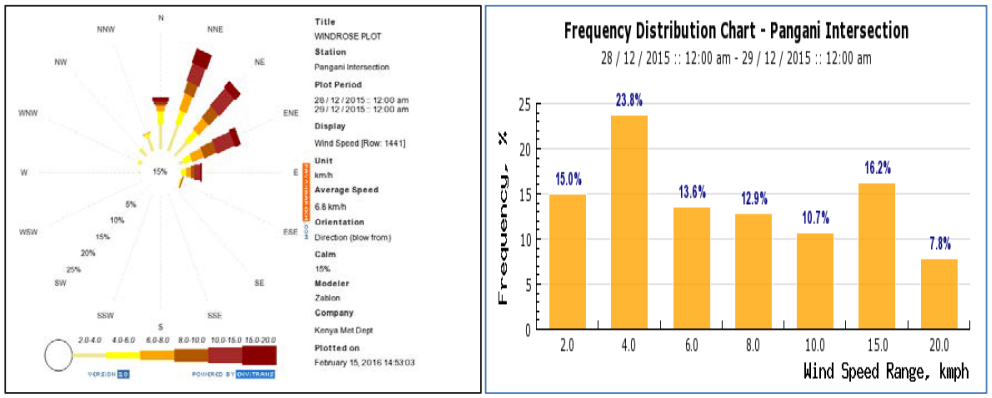

Figure 13: Wind rose and frequency for Pangani site.

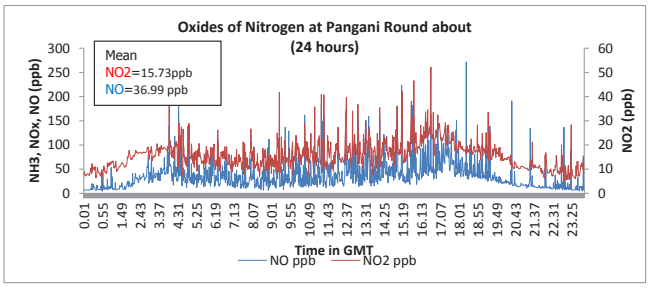

Figure 14: Diurnal variation of Oxides of nitrogen.

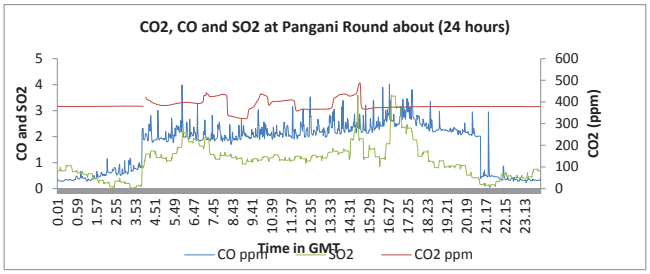

Figure 15: SO_2 and CO at Pangani Round about.

However, high values are dominant during the day with low values experienced at night. This can be attributed to the high numbers of vehicles during the day. The diurnal amount of SO_2 is generally low averaging at 1.08 ppb. This is far much below the WHO 10 ppb for 24 h. Global background concentrations of carbon monoxide range between 0.06 and 0.14 mg/m^3 (0.05-0.12 ppm). The mean 24 h amount of CO was 1.73 ppm which is above the background concentration.

Figure 16 depicts the diurnal variation of ozone. The figure generally shows low amount in the early morning and at night with the peak realized during the day. The peak in midday is due to the fact that surface ozone is produced by photochemical oxidation during the day. The eight h mean was 10.1 ppb which is below the WHO mean of 51 ppb.

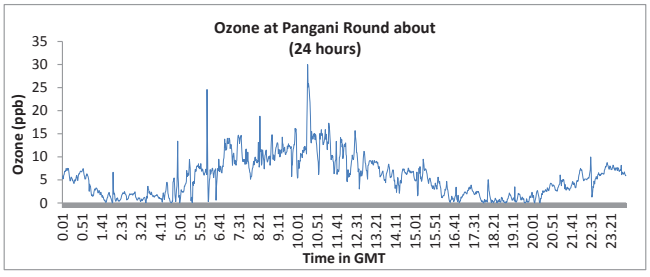

Figure 16: Diurnal variation of ozone at Pangani round about.

Results for industrial area region

The wind direction was mainly Southeasterly (Figure 17) with mean wind speed and direction of 3.6 m/s and 129.6° as indicted in Table 5. A drizzle of 0.52 mm/h was experienced during the monitoring duration.

Figure 18, shows low concentration of the pollutants between 8.00 AM and 6.30 PM. The rest of the time, which is generally during the night, indicates high values. The observed variation can be associated with low and high rate of dispersion at night (stable atmospheric conditions) and daytime (unstable atmospheric conditions) respectively. With both low temperature and wind speed experienced at night, the dispersion rate of pollutant is low due to less atmospheric mixing and therefore higher concentrations around surface level. The converse is true with both high temperature and higher wind speeds during the day. The 24 h means for $PM_{2.5}$ and PM_{10} were 12.3 and 15.9 µg/m^3 respectively consequently not exceeding WHO limits, while that of black carbon is 5,996.3 ŋg/m^3 which is very high as indicated in Table 5.

Figure 19 shows diurnal distribution of both NO_2 and nitric oxide (NO). It indicates two peaks, one in the morning and the other in the evening. The morning is more pronounced especially for NO while the evening peaks are broader for both parameters. The 24 h mean are 4.5 and 8.4 ppb for NO and NO_2 respectively (Table 4). The morning and evening peaks for both NO and NO_2 are 19.5 and 4.1 and 13.7 and 12.3 respectively (Table 5). NO and NO_2 are mainly produced by fossil fuel with motor vehicles accounting for over 50% of the total NO_2 generated. The peaks can therefore be attributed partly to the buildup of traffic near the monitoring site. The low concentration in the day is due to unstable atmospheric conditions which increase the dispersion rate of pollutants. The highest hourly concentration of NO_2 was 18.9 ppb, far much below the WHO limit of 102 ppb.

Figure 20 shows the diurnal concentration of SO_2, CO_2 and CO. The pollutants are generated from fossil fuels among other sources. Consequently, the two peaks in concentration realized in the morning and evening were attributed partly to the build-up in traffic from the nearby roads. The high values observed during the night may be attributed to stable atmospheric conditions. Consequently, the dispersion rate of pollutant is low due to less atmospheric mixing and therefore higher concentrations around surface level. The diurnal amount of SO_2 is generally low averaging at 0.78 ppb. This is far much below the WHO 10 ppb for 24 h and Kenyan limit of 48 ppb. Global background concentrations of carbon monoxide range between 0.06 and 0.14 mg/m^3 (0.05-0.12 ppm). The mean 24 h amount of CO was 0.57 ppm which is slightly above the background concentration.

Figure 21 depicts the diurnal variation of ozone. The figure generally shows low amount in the early morning and at night with high amount of ozone throughout the day. The peak in the day is due to the fact that surface ozone is produced by photochemical oxidation of CO, CH_4 and non-methane volatile organic carbons (NMVOCs) in the presence of NOx. The high values of ozone show that there is high concentration of ozone precursors in this site. The eight h mean was 20.2 ppb which is below the WHO mean of 51 ppb. However, this is the highest recorded amount of the four sites (Figure 4).

Conclusion and Recommendation

At Nakumatt Junction site particulate matter depicted two distinct peaks, one in the morning and the other in the evening. The peaks in pollutant concentration were attributed to vehicular emission during the rush hours. However, in Landhies road and Pangani Roundabout,

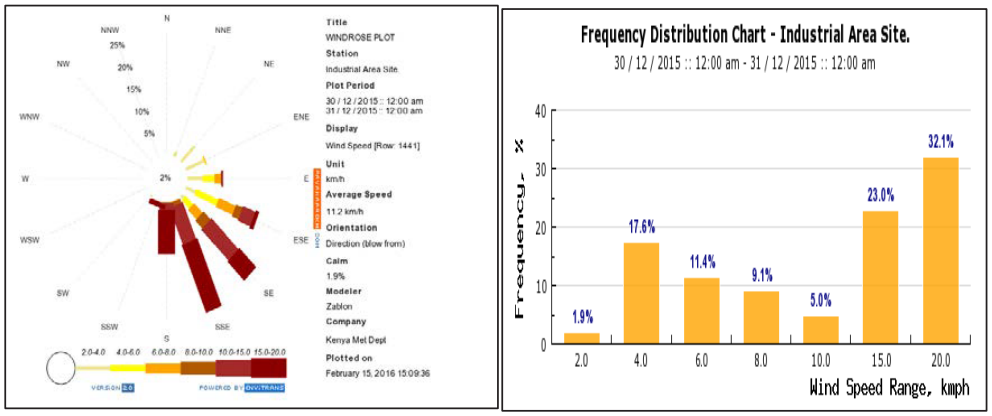

Figure 17: Wind rose and frequency for Industrial area site.

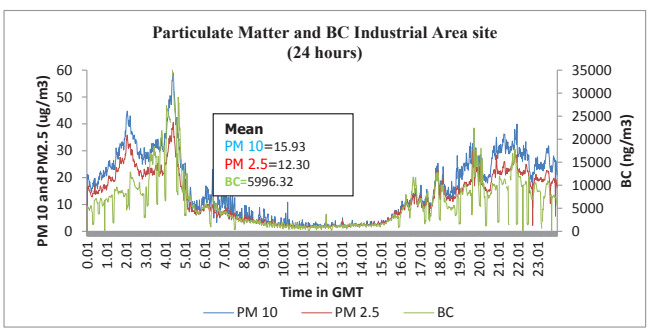

Figure 18: Diurnal variation of particulate matter and black carbon.

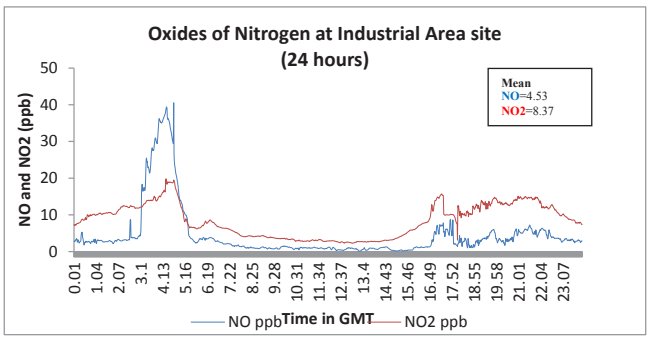

Figure 19: Diurnal distribution of both NO_2 and nitric oxide (NO).

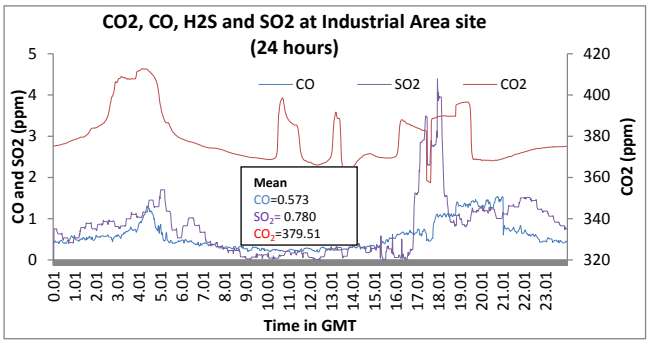

Figure 20: Diurnal concentration of SO_2, CO_2 and CO.

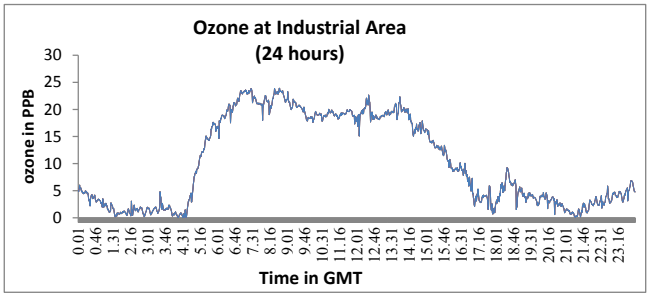

Figure 21: Diurnal variation of ozone.

the peaks were not discernible due to the high volume of vehicles throughout the day. Industrial Area site particulate matter showed high and low concentration during the night and day respectively The observed trends was associated with low and high rate of dispersion at night (stable atmospheric conditions) and daytime (unstable atmospheric conditions) respectively.

None of the four sites exceeded the WHO 24 h limit for both PM10 (50 µg/m^3) and PM2.5 (25 µg/m^3). The 24 h mean of PM10 in the three sites also did not exceed the ambient air quality tolerance Kenyan limit of 100 µg/Nm^3 and 150 µg/Nm^3 in Industrial Area. Extremely high values of black carbon which went beyond the upper limit of the instruments (50,000 ŋg/m^3) were observed during the day in Landhies road. Nakumatt Junction recorded extreme values of Black carbon (14,008 ŋg/m^3) in the evening peaks while Pangani Roundabout, the diurnal mean value was extreme (14,446.5 ng/m^3). In all the monitoring sites, Oxide of nitrogen showed two pronounced peaks, one in the morning and the other in the evening. NO and NO_2 are mainly produced by fossil fuel with motor vehicles accounting for over 50% of the total NO_2 generated. The peaks are therefore associated with the morning and the evening rush h even in Industrial Area due to the nearby roads.

None of the site exceeded the Kenyan 24 h mean ambient air quality tolerance limit of NO_2 (100 ppb). Pangani Roundabout recorded the highest hourly concentration of NO_2 (52.2 ppb) which is far much below the WHO and Kenyan limits of 102 and 200 ppb respectively.

The SO_2 and CO exhibited two peaks in concentration realized in the morning and evening. This trend was attributed to the build-up in traffic since the two parameters are generated from fossil fuels among other sources. The diurnal mean of SO_2 over the four sites was generally low with the highest amount of 1.08 ppb recorded at Pangani Roundabout. This amount is far much below both WHO and Kenyan limit of 10 and 48 ppb respectively. The global background concentration of carbon monoxide ranges between 0.06 and 0.14 mg/m^3 (0.05-0.12 ppm). The mean 24 h amount of CO in all the sites was above the background concentration with Pangani Roundabout recording the highest amount of 1.73 ppm.

The diurnal variation of Ozone in Nakumatt Junction, Landhies road and Pangani Roundabout showed low amount in the early morning and at night with the peak realized during the day. The peak in midday is due to the fact that surface ozone is produced by photochemical oxidation of CO, CH_4 and non-methane volatile organic carbons (NMVOCs) in the presence of NOx. The eight h means for the three sites were below WHO mean of 51 ppb. In Industrial Area, low amount of ozone were realized in early morning and at night with high amount observed throughout the day. The high values of ozone show that there is high concentration of ozone precursors in this site. The eight h mean was 20.2 ppb which is below the WHO mean of 51 ppb. However, this is the highest recorded amount of ozone in the four sites.

Kenya seeks to be industrialized by the year 2030, at a time when world over, policymakers and the general public are concerned with the degradation of air quality, especially in urban centers. She has to come up with adequate strategies of tackling air pollution, which has direct health impacts upon her increasing population. Therefore, concerted efforts have to be made to find a sustainable balance between industry, human health and environmental protection. The study recommends that;

- Further monitoring of air pollution to be conducted along major roads in Nairobi.
- Develop an atlas of air pollution levels in major cities in Kenya
- Enhancement of ad hoc air pollution monitoring in different counties in order to profile pollution levels within the country.

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