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International Journal of Scientific Research in Environmental Sciences (IJSRES)

ISSN: 2322-4983

International Journal of Scientific Research in Environmental Sciences, 3(8), pp. 0291-0301, 2015
Available online at http://www.ijsrpub.com/ijsres
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http://dx.doi.org/10.12983/ijsres-2015-p0291-0301

Full Length Research Paper

Ambient Air Quality Monitoring and Audit over Athi River Township, Kenya

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Received 03 June 2015; Accepted 08 August 2015

Abstract. Monitoring of air pollution is an active area of research. A numbers of agencies; environmental, health and governments consider access to clean unpolluted air as a basic requirement for human, plant, animal and environmental health. As many countries develop and move up socio-economic scale, emissions will increase, rising pollution levels and causing health concerns. It is therefore paramount that *ad hoc* and continuous monitoring be undertaken to ascertain air pollutant levels. This study presents a statistical analysis of selected air pollutants from Athi River Township, Kajiado County in Kenya. The data was collected over three sites downwind of the township that are highly exposed to pollutants from Athi River town. The study was carried out using various gas analyzers and samplers mounted in a Mobile Air Monitoring Laboratory van. Concentration of particulate matter was generally high in the morning and late evening hours. The concentration was found to be above World Health Organisation air quality levels; the mean 24 hours of $PM_{2.5}$ was 30.74 $\mu g/m^3$ exceeding WHO limit of 25 $\mu g/m^3$.The concentration of Black Carbon was found to range from medium to extremely high concentration in the region. However, the compounds of nitrogen, sulphur and hydrogen are generally low. To improve air quality in Athi River, mitigation measures such as limiting the establishment of more high energy-consuming industries and prioritize the use of clean energy sources. The study faced challenges in categorizing the concentration of the pollutants, calling for finalisation of air quality regulations and guidelines.

Keywords: Air Quality, Athi River, Particulate Matter, Pollution

1. INTRODUCTION

Poor air quality has remained to be challenge in many parts of the world, both in the developed and developing countries, owing to anthropogenic activities (Brulfert et al., 2005; Parra et al., 2006). Ambient air quality monitoring provides knowledge on sources, chemical composition and dispersal of air pollutants. This is important in programmes aimed at controlling pollution levels in a given environment (Venkanna et al., 2015). Air pollutants are often associated with many respiratory diseases in humans and loss of plant and animal productivity (WHO, 2012; Pinto et al., 2010; Maudgalya et al., 2008; Knox, 2008; Pope et al., 2002; Yang et al., 2004). An assessment by World Health Organisation's (WHO) International Agency for Research on Cancer (IARC) in 2013 observed that outdoor air pollution is carcinogenic to humans, pointing out particulate matter (PM) component of air pollution to be most closely linked to increased cases of cancer, especially cancer of the lungs (WHO, 2013).

According to some studies (e.g., Jacobs et al., 2012; Pope and Dockery, 2006; Mcdonnell et al., 2000), PM, especially $PM_{2.5}$ affects more people than any other pollutant. The $PM_{2.5}$ is made up of metal elements, water-soluble ions, elemental carbon, and organic compounds (Viana et al., 2005; Wang et al., 2004). The most health-damaging particles of the PM are those with a diameter of 10µ or less, ($\leq PM_{10}$), which can penetrate and lodge deep inside the lungs. Chronic exposure to particles contributes to the risk of developing cardiovascular and respiratory diseases, as well as of lung cancer. There is a close, quantitative relationship between exposure to high concentrations of small particulates (PM_{10} and $PM_{2.5}$) and increased mortality or morbidity, both daily and over time (Lin et al., 2014). Urban air quality reports and monitoring serve an important role in environmental planning and management since most urban centres are characterised by large human population and the associated socio-economic activities. This is for the purposes of air quality checks and assessing exposure of air pollution levels to residents and the environment. The chemical composition, sources and transport regime of pollutants are required in order to evaluate their impacts in health, environment and ambient conditions (Castaneda-Miranda et al., 2014). However, air quality regulations and guidelines are required to effectively implement policies related to air quality monitoring. Unfortunately, Kenya, like most developing countries, does not have such guidelines (Omanga et al., 2014), although Kenya's National Environment Management Authority (NEMA) is at advanced stages of formulating the guidelines. In Kenya, there exist laws in different statutes regulating pollution levels. According to the Constitution of Kenya, Article 42, Chapter 4, the Bill of Rights, confers to every person resident in Kenya, the right to a clean and healthy environment (GoK, 2010). It is against this back ground that NEMA in conjunction with the Kenya Meteorological Service embarked on an environmental audit in Kitengela Township on the outskirts if Nairobi with the sole aim of establishing the concentration levels of various pollutants.

This work thus sought to monitor and document ambient pollutant levels by taking representative samples of various pollutants from three different sites in Athi River Township around Kitengela area.The main objective of the present work is not only to quantify the PM_{10} and $PM_{2.5}$ concentrations but also to document otherrelated gaseous pollutants: NO, NO_2, O_3, SO_2, and CO among others. The hourly and daily variations in air pollutants and information on the role of weather variables (temperature and wind speed) are also investigated.

2. MATERIALS AND METHODS

2.1. Monitoring Sites

The study area is Athi River Township, located in Kajiado County, about 20km southeast of Nairobi County, on the shores of the quasi-periodic Athi River. The area around the town is officially designated as an industrial zone with many large-scale commercial activities ranging from manufacturing, steelworks, cement production, incinerators, salt production, industrial services, long haul transport and quarrying, just to mention but a few. The area has undergone drastic land use transformation largely occasioned by privatisation and population explosion. The industrial zone cuts through two counties: Machakos and Kajiado. Air pollution from industrial activities is a major problem in Athi River. Apart from the individual industrial companies' Environmental Audits (EA) and Environmental Impacts Assessment (EAI) reports, there are no documented reports showing the effect of these activities on the general air quality within Athi River town which is home to thousands of inhabitants. According to KNBS (2010), the human population within the Kitengela area has risen exponentially in the last two decades, from about 6000 in 1989 to about 17,000 in 1999 to about 58,000 in 2009.

This study, therefore, sought to monitor and document ambient pollutant levels by taking representative samples of various pollutants from three different sites. A feasibility study was undertaken between 29th December 2014 and 6th January 2015 to identify suitable sites for monitoring. Among the activities carried out were mapping out some of the existing industries, studying their production activities and possible emissions, assessing the general prevailing meteorological conditions; wind speed and direction that might influence exposure sites and security of the mobile laboratory. The other activity included in the feasibility study was a survey from relevant parties concerned or affected with air pollution. Three sites were chosen as representative areas in monitoring quality from Athi River town. The areas are: Athi River Government of Kenya (GK) Prison, Assistant Commissioner's office and the Export Processing Zone (Table 1). The area around these locations is densely populated and considered fast rising in population (KNBS, 2010).The study also used oral survey and interviewing of selected companies as outlined in Table 2.

2.2. Sampling Methods

Various gas analysers measuring concentrations of various atmospheric pollutants and aerosols are located in a Mobile Air Monitoring Laboratory (MAML) and the van moves to the site of interest. An overview of the instrumentation installed in the mobile van is presented in Table 3. The instrumentation includes an automated weather station that is mounted on top of on the van laboratory, with the wind measurement done at 10m above the ground. The analysers generate and store data at one-minute time resolution. The inside of the laboratory is air conditioned, where temperatures is kept close to 26°C. All the one minute data measured and used in this study were visually inspected. Erroneous data were flagged as invalid. Fig. 1 shows the exterior and interior of the MAML laboratory. Table 3 summarises the type of instrumentation on the MAML.

(a) (b)

Fig.1: Mobile Laboratory, (a) Exterior (b) Interior

Table 1: Location of the monitoring sites

Site	Latitude	Longitude	Elevation	Description
Athi River GK Prison	1° 28.432'S	36° 56.781' E	5191ft	Located downwind of major cement factories and to the West of Athi River
Assistant Commissioner's Office	1° 28.318'S	36° 57.586' E	5166ft	Located downwind of major factories and to the South of Athi River
Export Processing Zone (EPZ)	1° 27.952'S	36° 58.200' E	5195ft	Located downwind of major factories and to the East of Athi River

Table 2: Factories sampled

No.	Company	No.	Company
1	Mineral Enterprise limited	10	Alpha Rama ltd
2	Rhino Cement Building Africa	11	Steel Makers ltd
3	Apex Steel Limited	12	Mombasa Cement ltd
4	SAJ Ceramics Ltd	13	Athi River Tanneries Ltd
5	DEVKI Steel LTD	14	ATHI Steel ltd
6	Associated Battery Manufacturers	15	Top Tank ltd
7	Technosteel Industries ltd	16	London Distillers Kenya ltd
8	Auto spring ltd	17	ORBIT Chemicals ltd
9	East Africa Portland Cement		

Table 3: Instrumentation in the Mobile Air Monitoring Laboratory

Instrument Model	Parameter (s) measured
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 station	Ambient and screen temperatures, Solar radiation, precipitation, Atmospheric pressure, relative humidity, wind speed and direction

Table 4: Summarised values of $PM_{2.5}$, PM_{10} and black carbon at GK Prison

	PM2.5 ($\mu g/m^3$)	**PM10** ($\mu g/m^3$)	**Black carbon** ($\mu g/m^3$)
24 hr mean	30.74	69.64	2755.19
Max value	111.23	463.31	10412.60
Min value	10.30	13.51	701.91
Day mean	27.132	67.062	2457.140
Night mean	35.005	72.683	3107.438
WHO 24 hr AQG	25.00	50.00	

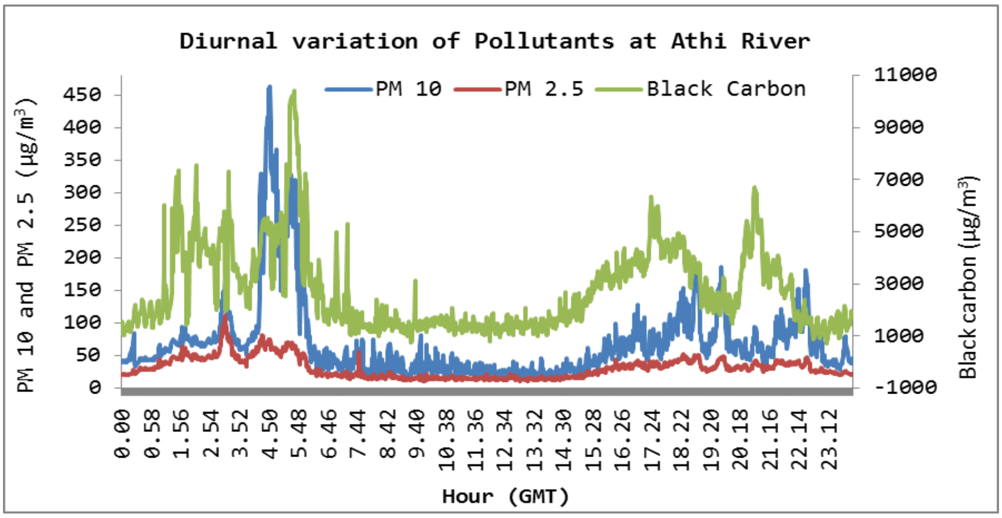

Fig. 2: Diurnal variation of PM_{10}, $PM_{2.5}$ and Black Carbon over Athi River

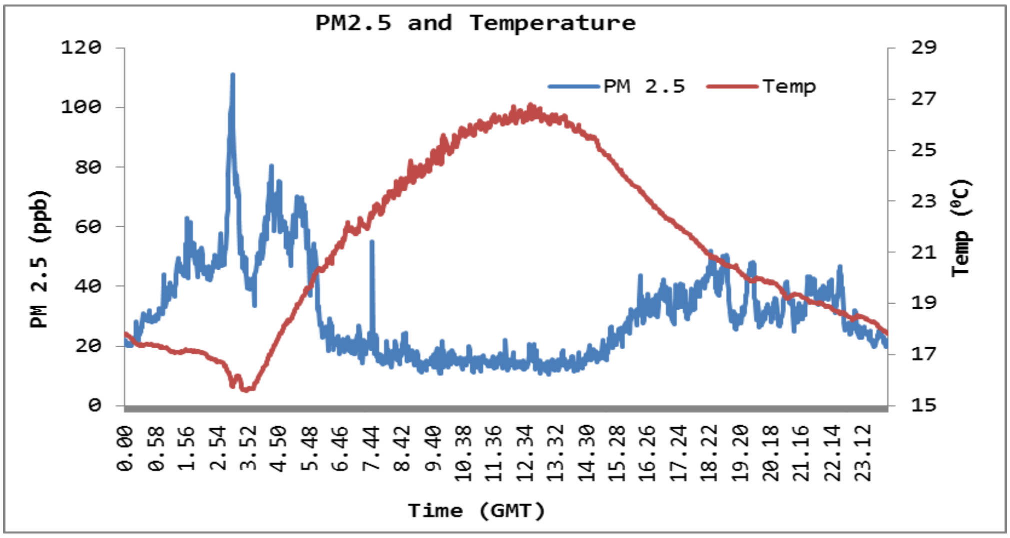

Fig. 3: Diurnal variation of $PM_{2.5}$ and ambient temperature over Athi River

Table 5: General ranges of BC

Range ($\mu g/m^3$)	**Description**	**Sources**
0-200	Extremely low	Very remote areas
200-500	Low	Remote areas, long range transport of aged EBC
500-1000	Medium	Countryside with close sources of traffic, industries, wood burning etc.
1000-5000	High	At the source e.g. Busy street, wildfires,
5000-10,000	Very high	Behind a vehicle, near a fire
>10,000	Extremely high	

(Adopted from Bond et al., 2013)

There are two distinct peaks of high concentration of pollutants in a day (Fig. 2). The first peak is realised early in the morning between 1.00 GMT (4.00 a.m.) and 5.50 GMT (8.50 a.m.). However, within this peak, there is an apparent low experienced at 4 GMT (7.00 a.m.). The second peak is in the night between

15 GMT (6.00 p.m.) and 22.15 GMT (1.00 p.m.). Low concentrations for the three pollutants are realised mainly during the day.

The observed trends 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 minimal atmospheric mixing leading to high concentrations around ground level. The converse is true during the daytime hours, generally by both high temperature and higher wind speeds during the day as indicated in Figs. 4 and 5. The results are in agreement with a study by Liu et al. (2015) on sseasonal and diurnal variation in particulate matter in Beijing. Liu et al. (2015) observed pronounced diurnal variations found for PM_{10} and $PM_{2.5}$, which both displayed a bimodal pattern with peaks between 7:00 and 8:00 a.m. as well as 7:00 and 11:00 p.m.; a minimum generally appeared at approximately noon. Similar results were made by DeGaetano and Doherty (2004) over New York City. However, the observations in the two cities were attributed to enhanced anthropogenic activity during rush hour especially in the morning.

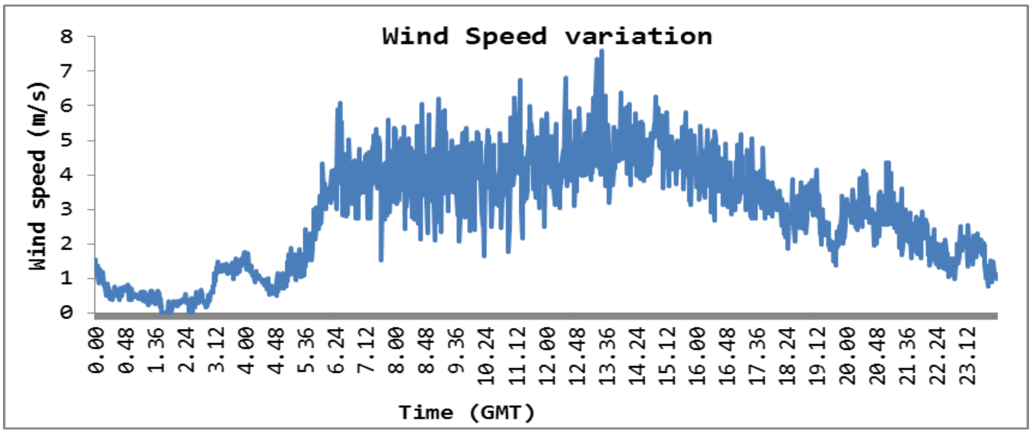

Fig. 4: Diurnal variation of wind speed (m/s) over Athi River

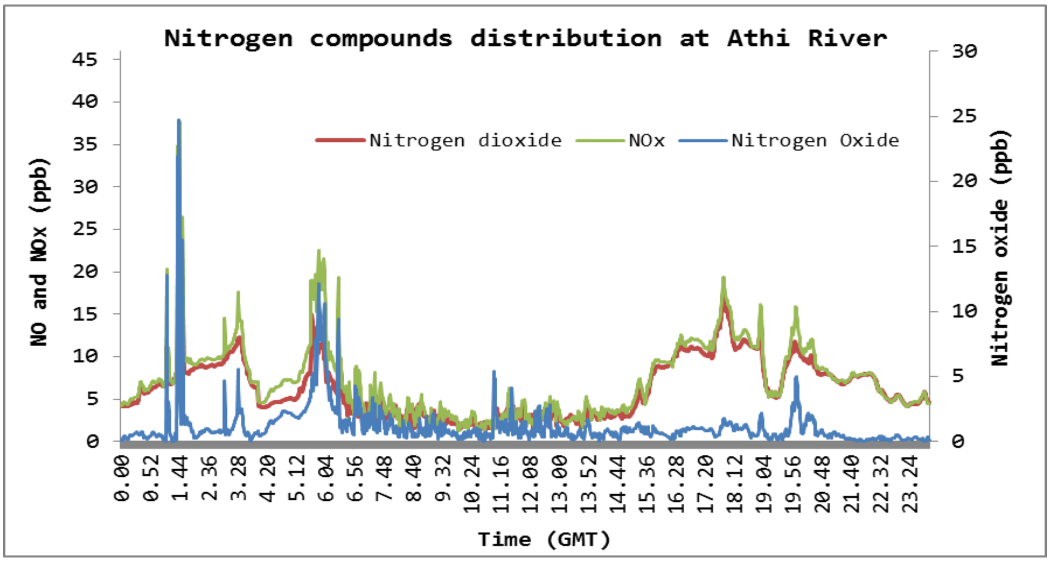

Fig. 5: Diurnal variation of NO_2, NO and NOx

Meteorological conditions generally play an important in the study of PM (Pateraki et al., 2008). To examine the factors that influence aerosol behavior, the relationships between the $PM_{2.5}$ and meteorological parameters (i.e., temperature and wind) are plotted in Figs.3 and 4. Fig.3 indicates that the temperature variation is inversely proportional to the particulate matter concentration at the sites. Similar observations were made by Liu et al. (2005) over Beijing. The observation suggested that the secondary particles from photochemical activity do not play a major role in the mass variation of PM.

The maximum temperature is observed around 10 – 14 GMT, coinciding with the time when the least concentration of $PM_{2.5}$ is recorded. The opposite was reported between 3 – 4 GMT. Diurnal wind speed is presented in Fig. 4. Greater wind speeds are observed during the day with an average of 4-6 m/s and almost calm conditions at night time particularly early morning. The diurnal wind speed pattern is in inverse pattern as that of the concentration of $PM_{2.5}$. According to earlier studies (e.g., Marcazzan et al., 2001; Liu et al., 2015), this was expected due to horizontal mixing caused by wind.

Table 6: Hourly mean of NO_2

Hr	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
ppb	5	8	9	10	5	8	6	4	3	3	2	3	3	3	3	6	10	12	12	8	9	7	6	5

Table 7: Summary of the concentration of all pollutants

Pollutant	Max.	Min.	Day Mean	Night Mean	24 hr mean	Recommended
O_3 (ppb)	34.330	2.685	18.515	8.313	13.839	51ppb 8 hr mean
SO_2(ppb)	12.220	0.185	0.812	2.687	1.671	10ppb 24hr mean
H_2S(ppb)	10.81	0.23	1.68	1.67	1.68	
NO_2(ppb)	19.935	1.243	4.422	8.348	6.221	102ppb 1 hr mean
NO(ppb)	24.72	0.02	1.56	0.74	1.15	
NO_X(ppb)	44.65	0.88	6.69	7.53	7.11	
CO(ppm)	1.52	0.24	0.53	0.44	0.48	
CO2(ppm)	404.16	349.75	373.36	381.34	377.35	
CH4(ppm)	0.24	0.13	0.16	0.15	0.16	
NH3(ppb)	89.39	8.82	27.11	17.94	22.53	
NMHC(ppm)	0.19	0.08	0.11	0.10	0.10	
THC(ppm)	0.19	0.05	0.10	0.10	0.10	

Table 8: Measurements of Meteorological Parameters

Parameters	Max.	Min.	Day Mean	Night Mean	24 Hr Mean
Wind speed (m/s)	7.600	0.000	3.598	2.152	2.935
Temperature(°C)	26.79	15.57	22.818	19.391	21.25
Solar radiation(W/m^2)	946.05	152.59	507.885	227.819	379.52
Relative humidity (%)	82.30	37.16	53.337	67.995	60.06
Rainfall (mm/hr)	0	0	0	0	0
Pressure(hPa)	847.83	843.25	845.701	846.292	845.97
Enc. Temp.	31.84	22.92	26.76	26.79	26.78

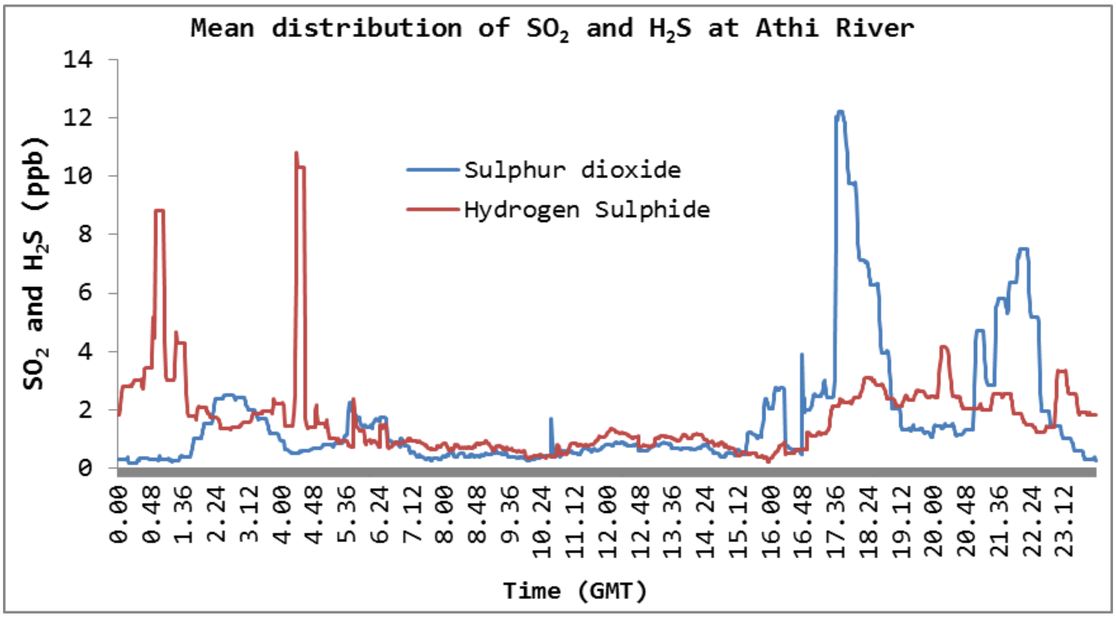

Fig. 6: Mean Hourly concentration of SO_2 and H_2S over Athi River

WHO 2005 Air Quality Guideline (AQG) for $PM_{2.5}$ and PM_{10} for 24 hour duration are 25 and 50 $\mu g/m^3$ respectively. The guideline limits aim to achieve the lowest concentrations of PM possible since small particulate pollution have health impacts even at very low concentrations, no threshold has been identified below which no damage to health is observed. Table 4 shows that the mean 24 hours WHO AQG has been exceeded for both $PM_{2.5}$ and PM_{10} at both observational sites. The GK Prison site $PM_{2.5}$ has a 24 hour mean value of 30.74 $\mu g/m^3$, exceeding the 25 $\mu g/m^3$ limit. The PM_{10} concentration is 69.64 $\mu g/m^3$

that is in excess of allowed limit of 50 μg/m^3. These results indicate that the residents are exposed to high levels of particulate matter than recommended by WHO. The BC affects both human health and contributes to climate change (WHO, 2011; UNEP/WMO, 2011; Bond et al., 2013; IPCC, 2013). Table 4 shows average mean concentration of BC and the PM.

The BC is a light-absorbing, carbon-containing constituent of particulate matter formed by the incomplete combustion of fossil fuels, biomass and bio fuels. BC is directly emitted into the air. Major sources include vehicles (particularly diesel driven road vehicles), non-road mobile machinery (e.g. forest and industrial plant machines), ships, residential heating (e.g. small coal or wood burning stoves) and open biomass burning (e.g. forest fires or burning of agricultural waste). As regards its climate-related impacts, BC scatters and absorbs solar radiation (light) entering the Earth's atmosphere. It is the component of airborne PM which most absorbs light and is viewed as a major contributor to climate change (Bond et al., 2013). The BC acts over a much shorter period than classic greenhouse gases (GHG) such as carbon dioxide (CO_2) because it has a shorter life time in the air. According to current research BC contributes to the warming of the atmosphere (Ramanathan and Carmichael, 2008; Bond et al., 2013).

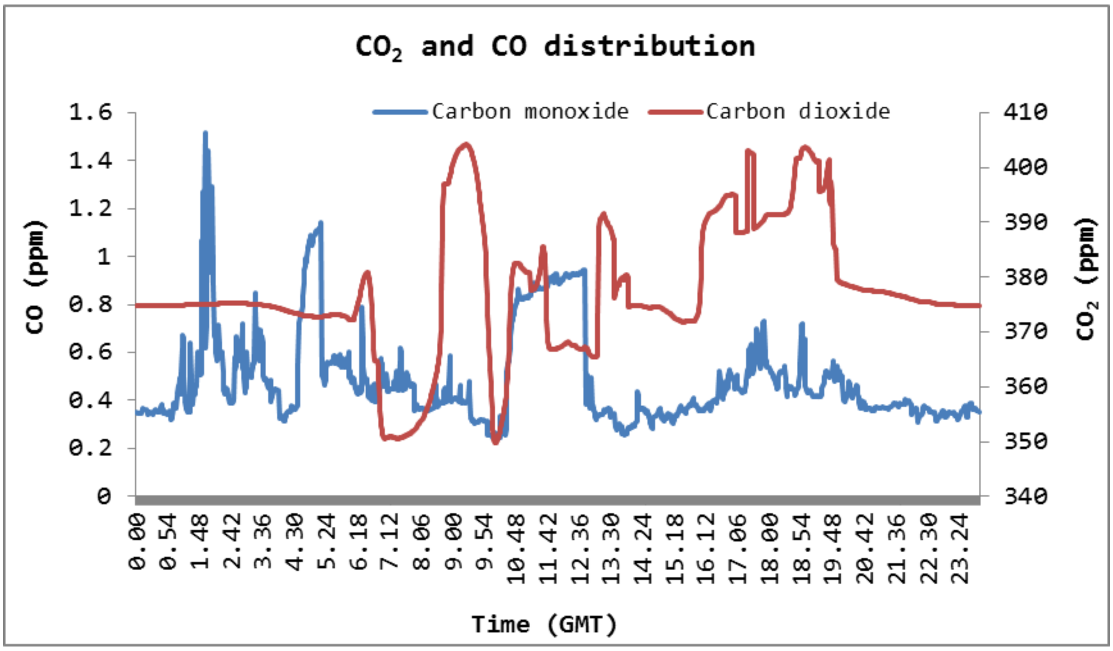

Fig. 7: Mean Hourly concentration of CO_2 and CO over Athi River

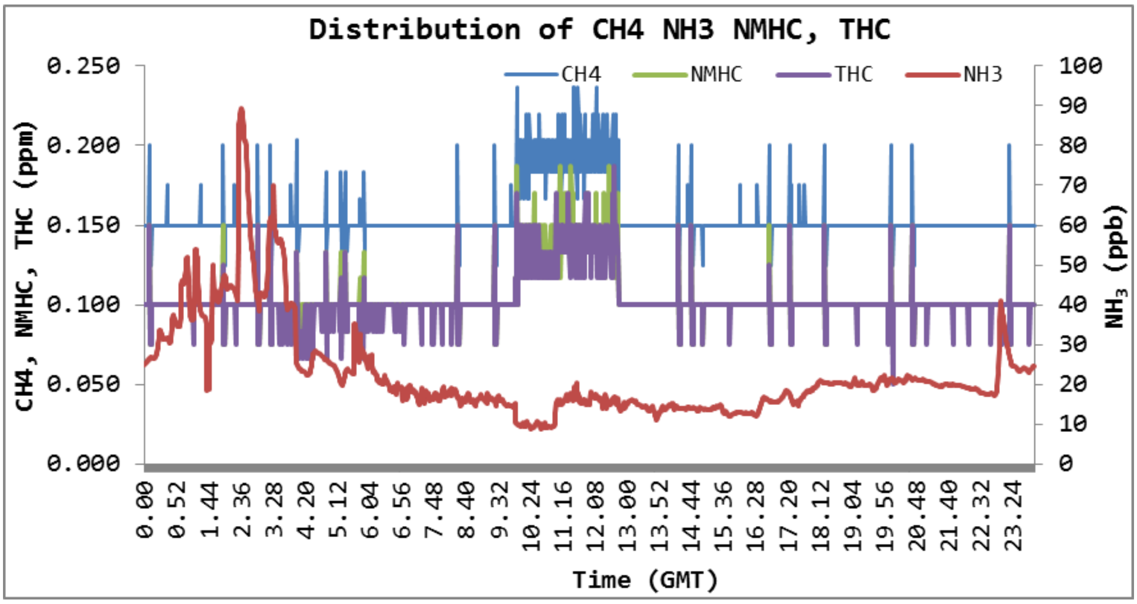

Fig. 8: Mean Hourly concentration of CH_4, NMHC, THC and NH_3 over Athi River

Despite intensive efforts over the past decades, no widely accepted standard measurement method exists for the determination of BC or light absorbing carbon. However, Table 5 shows the general ranges and likely sources of BC (Bond et al., 2013). Table 4 indicates a wide range of BC values at GK Prison; ranging from medium to extremely high concentration. It shows a 24-hour mean value of 2755.19μg/m^3. The night time concentration (3107.438 μg/m^3) of BC is higher than the day time (2457.140 μg/m^3). These values are both in the high range.

3.2. Nitrogen Compounds

The pollutants in Fig. 5 depict two maxima. The morning peaks are well defined between about 0.00 GMT and about 06.00 GMT. A low is realised during the day before an evening peak between 15.30 GMT and 21.30 GMT. There were high values of nitrogen oxide at about 1.56 GMT. The figure further indicates low values of all the pollutants during the day between 6.46 and 15.28 GMT. A number of short-term experimental human toxicology studies have reported acute health effects following exposure to 1-hour NO_2 concentrations in excess of 500 μg/m^3 (Laumbachet al., 2012). Although the lowest level of NO_2 exposure to show a direct effect on pulmonary function in asthmatics in more than one laboratory is 560 μg/m^3, studies of bronchial responsiveness among asthmatics suggest an increase in responsiveness at levels upwards from 200 μg/m^3 (102ppb), which is WHO Air Quality Guideline for NO_2. From Table 6, the highest and lowest hourly means are 12 and 2ppb respectively. The results thus indicate that NO_2 concentration in Athi River is very low since it far much below the WHO AQG.

3.3. Sulphur Dioxide and Hydrogen Sulphide

Fig. 6 generally indicates low concentration of both SO_2 and H_2S between 5.00 – 15.00 GMT. The H_2S shows well defined bimodal distribution pattern with peaks between 00 – 5.00 GMT. SO_2 on the other hand exhibits two peaks between 15.00 – 23.30 GMT. The 24-hour mean for SO_2 is 1.671 ppb. This is far much below the WHO AQG of 10 ppb for 24 hours.

3.4. Carbon Dioxide and Carbon Monoxide

Atmospheric carbon dioxide (CO_2) is a greenhouse gas, the concentrations of which have been increasing due to human activities such as the burning of fossil fuels and deforestation (IPCC 2013). In urban areas, huge amounts of fossil fuels are consumed by the large numbers of people living there. Fig. 7 shows a high fluctuation of CO_2 between 6.00 and 20.00 GMT, during the remaining hours, CO_2 concentration is relatively constant close 380 ppb, just below the now global average of 400ppb. This variation may be attributed to the enhanced human activities during the day time. This includes the variation in mobile and stationary emissions from fuel consumption and meteorological condition. The 24 hour mean is 377.35 ppm as indicated in Table 7.Diurnal variation of CO depicts no clear discernible patterns. However, there is a broad maximum in CO early in the morning and in the late afternoon as the consequence of CO primary sources, likely by local traffic. The CO 24 hour mean is 0.48 ppm.

The diurnal concentrations of CH_4, NMHC, THC and NH_3 are low as indicated in Fig.8. The mean 24 hour values of CH_4, NMHC, THC and NH_3 are 0.16 ppm, 0.1ppm, 0.1ppm and 22.53 ppb respectively.

3.5. Hydrocarbons

Table 7 presents a statistical analysis of the mean values registered while meteorological conditions are summarised in Table 8. During the study period, there was no rainfall recorded hence no wet deposition of pollutant realised.

4. CONCLUSION AND RECOMMENDATION

Air pollutants including $PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3, CO, H_2S, and CH_4 were measured in December 2014 and January 2015 over Athi River. Results obtained indicate that there is high concentration of PM_{10} and $PM_{2.5}$, especially in the morning and late evening hours. Although the other pollutants are below the WHO set standards, there is need to reduce the prevalence of dust particles, particularly, exposure to residents over considerable longer time duration. Since the measurements were taken over a short period of time, there is a risk of this sampling to under-represent or over represent the possible number of exceedences during the full year cycle. This can only by overcome by operationalization of continuous data collection to give a good representation of pollution levels. However, the current state of the air is poor; this is following high concentration of PM in it. In the effort to improve air quality in Athi River, effective and practical mitigation measures should be adopted including limiting the establishment of energy-consuming industries and prioritize the use of clean energy sources should be designed to reduce emissions from local industrial sources.

The study outcome provides first state-of-the-art scientific appraisal of air quality conditions of Athi River Township, as well as the scientific basis for action and need to conserve and sustainably grow our industries. The NEMA in collaboration with other state and non-state agencies should hasten the development and formulation of an air quality framework and guidelines to regulate, legally, disbursement of air pollutants in the atmosphere. It is also necessary for NEMA to frequently undertake ad hoc measurements of the emissions at various sites in different counties in order to profile pollution levels within the country.

ACKNOWLEDGEMENT

The air quality monitoring exercise was supported by National Environmental Management Authority (NEMA) and Kenya Meteorological Department (KMD). The authors express their gratitude to their colleagues from NEMA and KMD who provided insight and expertise that greatly assisted the research. Special thanks also go to the institutions that allowed us to position our laboratory on their grounds particularly the Athi River G.K Prisons, the Assistant County Commissioners office and the Export Processing Zone (EPZ).

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