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Motor Vehicles Air Pollution in Nairobi, Kenya

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Abstract: Air quality monitoring in most developing countries is not routinely conducted, and in some urban areas such information does not even exist, though signs of deteriorating air quality and health problems related to air pollution are visible. By measuring air pollutants (i.e., Nitrogen Oxides, ozone, suspended particulates matter (PM10), and trace elements e.g. lead), this study investigated air quality in Nairobi, one of the largest cities in eastern Africa and the capital of Kenya. Sampling was done once a week from February to April 2003. Hourly average concentrations of NOx and O_3 were measured using a technique that is based on "chemiluminiscent" reaction at a site connecting two main highways in Nairobi (University and Uhuru) from 9:00 a.m. to 5:00 p.m. PM10 was collected using "Gent" Stacked Filter Unit (SFU) air sampler fitted with nucleopore filters (0.4 and 8.0 mm pore size for fine and coarse filters, respectively) that were analyzed for trace elements by Energy Dispersive X-ray Fluorescent (EDXRF) technique. An automatic vehicle counter was used for determining the vehicle density at the sampling site. Results show that most pollutants, for example, lead (0.05 1 to 1.106 $\mu g/m^3$), bromine (LLD to 0.43 $\mu g/m^3$), NO_2 (0.011-0.976 ppm), NO (0.001-0.2628 ppm) and O_3 (LLD-0.1258 ppm) are within the WHO guidelines. PM10 levels (66.66 - 444.45 $\mu g/m^3$) were above the WHO guidelines for most of the days, with coarse particulate accounting for more than 70%. Strong correlation ($r = 0.966$) between fine (0.4 µm) particulates, NOx, and motor vehicle density, indicate the importance of traffic as a common source for both fine particulates and NOx.

Key words: EDXRF, gaseous pollutants, motor vehicles, PM10, trace elements, urban air pollution

INTRODUCTION

In both developed and developing nations urban air pollution is increasingly being recognized as a major public health and environmental issue (Schwartz, 1994; Schwartz *et al*., 1996; Salvi *et al*., 1999; WHO, 2001; Brunekreef and Holgate, 2002).

Poor or deteriorating air quality in many cities results from high levels of energy consumption by industry, transport and domestic use (UNEP/WHO, 1992). The nature of air pollution is dependent on the source profile of the city, the presence of sunlight to promote production of secondary pollutants, such as ozone, through photochemical reactions, the altitude, which affects combustion processes and global air circulation patterns.

The two sources of air pollutants ubiquitous in most urban areas are transportation and fuel combustion by stationary sources, including industrial heating (WHO, 2001). However, motor vehicle emissions, seems to be the dominant source of air pollutants especially in areas with high traffic densities and industrial activities (Seinfeld, 1989). In recent years the public concern is being aroused due to the wide publicity on the damage to human health from the inhaling of gaseous pollutants and fine particulates. It has also been suggested that high incidences of respiratory health in urban areas may be associated with inhaling noxious gases and particulates in the air (Pope III, 2004).

Response to air pollution problem varies from country to country. Unlike the industrialized countries where much research has been done, little seems to have been done in developing countries, especially in Africa with regard to motor vehicle air pollution. The little information available on transport related pollution in Nairobi city indicates high pollutant emissions (Gatebe, 1992; Gatebe *et al*., 1996; Karue *et al*., 1992). High concentrations of Pb were found in edible portions of a variety of crops and soil within the vicinity of busy arterials (Dickinson *et al*., 1987; Freeman, 1991; Onyari *et al*., 1991). Lead levels of up to 127 µg/g against

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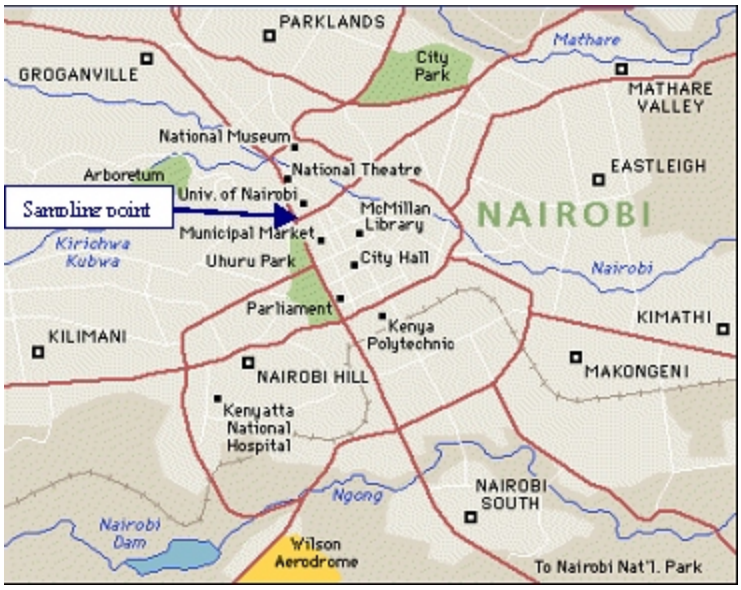

Fig. 1: Map of central Nairobi showing the sampling area. Source: (http://kenya.rcbowen.com/cities/nairobi.html)

the normal range of 0.1 to 10 µg/g were found in vegetables and cereals (Dickinson *et al*., 1987). PM10 levels have been shown to be above WHO guidelines of 150 µg/m^3(Gatebe *et al*., 1996; Gitari, 2000). Exposure to air pollution to the general populace in Nairobi is mainly due to economic activities. A high proportion of city residents' work in open areas known as "*jua kali"* that are adjacent to major urban roads. There are also numerous street vendors at road junctions (Freeman, 1991), while dust fallout in offices has been shown to range from 6.5-41.2 mg/day (Kinyua *et al*., 1998).

That motor vehicles are becoming an emerging threat as pollutants was recently highlighted in Awange and Obera (2007) who studied the effects of motor vehicles pollution in the lake city of Kisumu (Kenya). In order to assess air pollution levels in Nairobi and to help develop appropriate air quality management plans for the city, it is necessary to have reliable information of the source(s) and the extent of air pollution. This study was therefore carried out with the main aim of determining the concentrations of *ozone* (O_3), *suspended particulate matter* (PM10) and the trace element content therein and the *nitrogen oxides* (NO_2 and NO). It is hoped that the findings will highlight the contribution of motor vehicle to air pollution and that the results will assist in formulation of motor vehicle pollution reduction measures, particularly in developing countries.

MATERIALS AND METHODS

Study area: This study was carried out in Nairobi, Kenya from February 2003 to April 2003 at a roundabout connecting two major highways. Nairobi, situated at 1.17ºS, 36.49ºE in the highlands of the southern part of the country, is the capital city of Kenya. It is Kenya's principal economic and administrative centre and is one of the largest and fastest growing cities in Africa. Manufactures include food processing, textiles, clothing, building materials, and communications and transportation equipment. The city has the highest urban population in East Africa, estimated at between 3 and 4 million (CBS, 1999 (The latest census results (2009) are yet to be released)). The administrative area of Nairobi, according to the 1999 Census is inhabited by 2 143 254 living within 684 km^2.

At 1661 m above sea level, Nairobi has a fairly moderate climate, with chilly nights in June/July season when air temperature sometimes drop to 10ºC. The warmest periods are experienced between December and March when temperatures averages are about 25ºC. There are two rainy seasons and the cloudiest part of the year is just after the first rainy season experienced around July to September when conditions are usually overcast with drizzle. The timing of sunrise and sunset do not vary tremendously throughout the year, due to Nairobi's close proximity to the equator.

Sampling: Air samples were collected at the roundabout connecting University and Uhuru highways (Fig. 1). The two highways represent some of the busiest roads in the city. The inlets of the sampling tubes were positioned at a height of about one and half meters from the ground, so as to sample air that is breathed by people walking on the streets.

Sampling was done for a period of three months (February to April 2003). Measurements were carried out once per week for 8-hour durations from 9:00-5:00 p.m. Background data was obtained from a location far removed from main highways in Nakuru, at an open space more than 4 km from the nearest highway. Motor vehicle density was determined using an automatic vehicle counter (Model SYX-RRL).

PM10 Sampling: Measurement of PM10 was done with a "Gent" Stacked Filter Unit (SFU) air sampler (Gatebe *et al*., 1996; Maenhaut and Jan, 1994; Maenhaut *et al*., 1995). The "Gent" SFU is specifically designed using the principle of sequential filtration and collects airborne particulate matter in the inhalable (PM10) size fraction. The sampler uses an "open face" type stacked filter unit, in which two 47 mm nucleopore polycarbonate filters (8.0 and 0.4 mm pore sizes for "coarse" and "fine" particles, respectively) are used for the collection of the particulate matter.

The SFU was cleaned with ethanol to remove any particles that may have previously embedded inside. The filter membranes were handled with care using clean plastic tweezers to avoid any form of trace metal contamination. They were weighed in an air-conditioned laboratory at 50% relative humidity and 20ºC. An a-emitting source, 241Am (5 mCi), was used to remove electrostatic build up from the filters. Prior to weighing, all filters were left to equilibrate for 24 h.

The fine and coarse fraction mass concentrations were obtained through gravimetric analysis. Weighing of the filters was done prior to, and after exposure using Ainsworth weighing balance (Type 24 N). The sum mass concentration of the fine (PM2.5) and coarse particulates gives the PM10 concentration. The SFU sampler was operated at a flow rate of 18 litres per minute at a pressure of -0.2 mbars.

Trace elements analysis: Trace elements were analysed using the energy dispersive x-ray fluorescence method (Kinyua, 1982). The samples were irradiated with 109Cd radioisotope (l0 mCi) and run for 50,000 seconds to achieve reasonable statistical accuracy. Si(Li) detector with an energy resolution range of 160-180 eV at 5.9 KeV Mn Ka-line was used to detect characteristic x-rays. Spectrum fitting and data analysis was done using QXAES (Kump, 1995) and the AXIL software (QXAS, 1995).

Background assessment due to filter membrane inhomogenity was monitored routinely by using filter membranes that were sampled randomly from the container pack supplied by the manufacturer. These blanks were analyzed the same way as the field samples. The average background elemental intensities of the blanks were then subtracted from each elemental intensity. Quality control and assurance was assessed by analyses of urban dust standard reference material (SRM 1648) from the IAEA and analysis of thin micromatter paper standards.

Gaseous pollutants (NO_2 and NO) were measured using a technique that is based on a "chemilumiscent" reaction at a site connecting two main highways in Nairobi (University and Uhuru) from 9:00 a.m. to 5:00 p.m. The equipment used was Thermo-Electron's Model 14B, NO-NO_2-NOx Analyser. For the ozone measurement, UV absorption technique was utilized with DASIBI UV Ozone Monitor, Model 1003 AH.

Pertinent meteorological data such as temperature, humidity, solar exposure, cloud cover and rainfall was obtained from the Kenya Meteorological Department (KMD).

RESULTS AND DISCUSSION

Suspended Particulate Matter (PM10): The mean weekly concentrations for suspended particulate matter, ozone and nitrogen oxides (NOx) are shown in Table 1 and Fig. 2. There are five significant findings from this study.

First, the PM10 levels were found to be higher than the recommended WHO guidelines; in some cases, over 150% higher (WHO, 1987). The mean PM10 was 239±126 μg/m^3 with a range of 66.7-444.4 μg/m^3. These values are higher than those obtained in most cities in developed countries, but compares closely with those obtained by other researchers in large cities in the developing countries with less strict pollution control measures (UNEP/WHO, 1992, 1994).

Secondly, concentrations of coarse particulates were higher when there was little or no rain, and accounted for more than 70% of PM10. Resuspension of dust particles especially due to motor vehicles movement contributes to high levels of coarse particulate matter.

Thirdly, there was positive correlation (r = 0.31) between vehicle density and course particulates (Table 5). The correlation is however not very strong and this indicates that other sources, such as re-suspended dust particles and industrial emissions, do contribute to the particulate concentration. There is, however, a strong positive correlation between fine particles and motor vehicles density (r = 0.93). Motor vehicle exhaust is therefore the most probable source of the fine, particles.

Fourthly, there is a high correlation (r = 0.97) between fine particulates and NO indicating that fine particulates may have similar emission source(s) to NO. This is further supported by the strong correlation of NO and motor vehicle density (r = 0.94), and PM10 and motor vehicles (r = 0.93).

Fifth, the background PM10 values obtained from Nakuru (at a site located about 4 km away from the main

Table 1: Weekly concentration of pollutants and vehicle count in Nairobi

Sample	O_3	NO	NO_2	PM10*	Fine*	Coarse*	Vehicles
FW1#	0.0720	0.0496	0.0101	66.7	23.8	42.9	6301
FW2	0.0775	0.0557	0.0182	165.5	57.9	107.6	8240
FW3	0.0813	0.0590	0.0067	179.8	63.8	116	13218
FW4	0.0747	0.0659	0.0062	259.1	74.1	185	10810
MW2	0.0802	0.0767	0.0365	413.2	196.8	216.4	15204
MW3	0.0624	0.0530	0.0117	162.0	50.9	111.1	8204
MW4	0.0712	0.0607	0.0097	142.4	68.3	74.1	8120
MW5	0.0682	0.0908	0.0143	444.4	206.	238.4	18042
AW1	0.0064	0.0928	0.0133	243.1	217.69	25.5	18824
AW3	0.0490	0.0749	0.0119	395.8	155.1	240.7	13682
AW4	0.0216	0.0726	0.0125	157.4	138.9	18.5	13214

*: Concentrations are in μ/m^3, #: The first letter in the sample code refers to the month in which the sample was collected and the second letter refers to the week of sampling

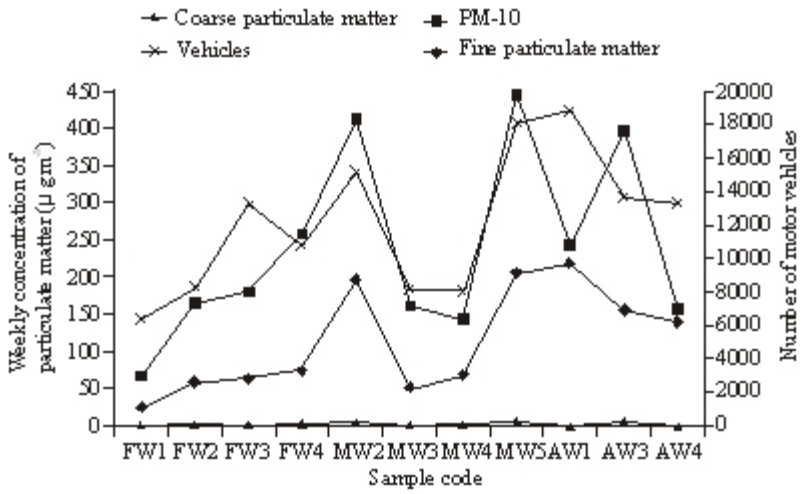

Fig. 2: Weekly concentrations ($\mu g/m^3$) of particulate matter

highway) are far below the WHO limits. The levels ranged from Lower Limit of Detection (LLD) to a maximum of 27.78 $\mu g/m^3$. These low values can be attributed to the fact that at this sampling point there was little influence of vehicular emissions. This shows the importance of motor vehicles as sources of fine particulate matter in urban centers

Trace elements: Results for trace elements are presented in Table 2 and those of the EDXRF analysis of the SRM 1648 elements shown in Table 3. The results of the analysis of the SRM 1648 supplied by the International Atomic Energy Agency (IAEA) show that the EDXRF analytical procedure produced reliable data given that there was no significant difference between the results obtained through EDXRF analysis and the values in the SRM.

Even though the levels of most of these metals are within the WHO limits, Pb and Mn values were found to be higher than those previously recorded in most urban centers in Europe and U.S. (UNEP/WHO, 1994). The mean concentration for Pb was 0.455 ± 0.015 $\mu g/m^3$ with a range of 0.051 to 1.106 $\mu g/m^3$, Fe, 1.454 ± 0.530 $\mu g/m^3$ (0.149-3.154 $\mu g/m^3$); Mn, 0.121 ± 0.012 $\mu g/m^3$ (0.002-0.526 $\mu g/m^3$); Cu, 0.112 ± 0.010 $\mu g/m^3$, (LLD to 0.15 $\mu g/m^3$); Br, 0.193 ± 0.012 $\mu g/m^3$ (LLD-0.430 $\mu g/m^3$); Zn, 0.097 ± 0.015 $\mu g/m^3$, (LLD-0.140 $\mu g/m^3$ and Ca, 3.796 ± 1.260 $\mu g/m^3$ (2.180 to 5.389 $\mu g/m^3$). These results compare with those previously reported (Tripathi *et al*., 1989; Ward, 1990; Karue *et al*., 1992). The values are also comparable with those values reported in urban areas of many developing countries (UNEP/WHO, 1994). Measurements in Bombay, India found high Pb concentrations in areas with high vehicular traffic (UNEP, 1987) or major industrial areas (i.e., 0.75-1.1 $\mu g/m^3$). In Taipei, Taiwan, a high correlation was found between the decrease in the use of Pb gasoline and the monthly air Pb concentrations (UNEP/WHO, 1992). The major source of heavy metals in urban centers is vehicular emissions. Correlation analysis between vehicular density and trace elements concentration was carried and results shown in Table 4. From the correlation analysis, it can be seen that there is high correlation between traffic volumes with Pb concentration ($r = 0.892$). There is also high correlation between Pb and Br ($r = 0.930$), while Fe, Ca and Mn are also positively

Table 2: Concentrations (μg/m^3) of the trace elements studied

Sample	Pb	Fe	Br	Zn	Cu	Ca	Mn	Pb/Br ratio
FW1c	0.051±0.034	1.176±0.040	BDL	BDL	BDL	3.092±0.401	0.081±0.002	
FW1f	0.417±0.015	1.169±0.050	1.112±0.012	0.100±0.014	0.092±0.008	2.604±0.320	BDL	0.368
FW2c	0.230±0.014	2.147±0.050	0.112±0.010	0.058±0.008	BDL	4.230±0.389	0.182±0.012	0.487
FW2f	0.419±0.010	0.149±0.055	0.182±0.012	0.102±0.012	0.101±0.017	2.982±0.402	0.014±0.002	0.434
FW3c	0.056±0.030	2.583±0.055	0.133±0.008	BDL	BDL	4.365±0.457	0.106±0.010	0.375
FW3f	0.453±0.015	0.471±0.055	0.176±0.010	0.104±0.012	0.113±0.015	4.098±0.389	BDL	0.389
FW4c	0.231±0.013	2.612±0.101	0.097±0.008	BDL	BDL	4.389±0.443	0.012±0.004	0.420
FW4f	0.480±0.015	0.947±0.038	0.199±0.008	0.107±0.013	0.104±0.010	3.937±0.40	BDL	0.415
MW2c	0.268±0.013	2.625±0.054	0.104±0.013	0.021±0.018	BDL	4.390±0.374	0.104±0.011	0.388
MW2f	0.821±0.012	0.268±0.062	0.291±0.009	0.131±0.022	0.140±0.016	2.625±0.320	0.024±0.004	0.354
MW3c	0.276±0.013	2.545±0.055	0.199±0.010	0.037±0.021	BDL	4.313±0.382	0.323±0.011	0.321
MW3f	0.382±0.014	0.549±0.045	0.158±0.008	0.098±0.012	0.137±0.012	2.812±0.384	BDL	0.414
MW4c	0.420±0.015	1.898±0.049	0.163±0.010	0.102±0.012	0.082±0.008	4.310±0.382	0.113±0.012	0.388
MW4f	0.559±0.026	1.008±0.050	0.219±0.015	0.116±0.020	0.097±0.010	3.827±0.820	BDL	0.392
MW5c	0.382±0.013	2.756±0.085	0.160±0.012	0.049±0.010	0.102±0.014	4.293±0.424	0.301±0.057	0.419
MW5f	1.032±0.010	1.137±0.040	0.391±0.013	0.131±0.014	0.142±0.021	3.065±0.42	0.270±0.040	0.379
AW1c	0.401±0.018	1.147±0.045	0.134±0.008	0.068±0.006	0.091±0.024	4.272±0.401	BDL	0.334
AW1f	1.106±0.013	0.634±0.040	0.430±0.011	0.140±0.018	0.143±0.016	3.920±0.389	0.226±0.024	0.390
AW3c	0.423±0.015	3.154±0.062	0.176±0.012	0.099±0.013	0.061±0.012	5.389±0.543	0.526±0.041	0.416
AW3f	0.630±0.015	0.834±0.043	0.190±0.010	0.125±0.035	0.133±0.021	2.180±0.820	0.083±0.010	0.302
AW4c	0.376±0.014	1.261±0.050	0.165±0.011	0.065±0.020	0.102±0.015	4.0995±0.461	0.283±0.011	0.439
AW4f	0.602±0.015	0.927±0.050	0.269±0.010	0.118±0.012	0.150±0.021	4.04±0.456	BDL	0.447

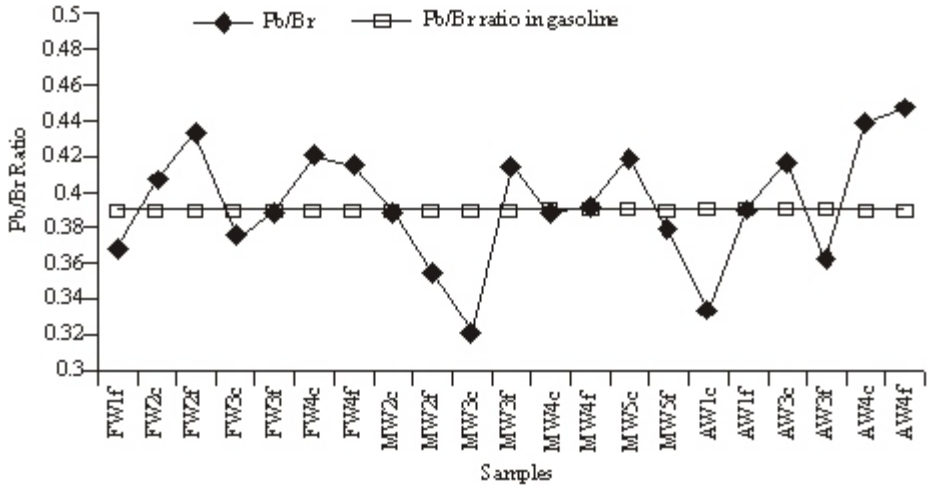

Fig. 3: Lead/Bromine (Pb/Br) ratio variations in the samples

Table 3: EDXRF analysis SRM 1648 element

	Element Concentrations (μg/m^3)	
	Experimental	Certified
Fe	3.8±0.1	3.9
Zn	0.05±0.01	0.06
Pb	0.61±0.01	0.66

correlated with the coarse particulate matter. The strong correlation between Pb, Br and motor vehicles suggests their main source as being motor vehicle emission. This is further supported by the Br/Pb ratio (Table 2 and Fig. 3), which ranges from 0.321 to 0.447, with most values falling about ~0.386 (the Br/Pb ratio in gasoline; Seinfeld, 1989). Ca, Fe and Mn are most probably from the resuspended soil dust since they correlate well with coarse particles. Higher correlation values were also obtained for these metals in the fine particulate matter. The correlation between Pb and Br in the fine particle range was, r = 0.96; Pb and Zn, 0.88; Pb and Cu, 0.62. The fine particles correlate highly with the motor vehicles (r = 0.93). The motor vehicles exhaust is mostly the source of these pollutants. The fine particulate matter is from fuel combustion as opposed to coarse particulates that are mainly from resuspended dust particles and tires wear or wind blown dust (Ogunsola *et al*., 1994).

Fe, Ca and Mn are poorly correlated with motor vehicles density but highly correlated with coarse particles. These metals are also well correlated with one another, suggesting similar source. The correlation coefficient between Ca and Fe is, r = 0.73; that between Fe and Mn, r = 0.58 and Ca and Mn, r = 0.49. There is also high correlation between coarse particles and Fe (r = 0.91), as well as Ca (r = 0.67). These metals are mainly associated with the earth crust from which the resuspended dust particles are released into the atmosphere. This can either take place through wind blowing or turbulence caused by vehicular movements.

Table 4: Correlation matrix of the trace elements and vehicles density

	Pb	Fe	Br	Zn	Cu	Ca	Mn	Vehicles
Pb	1							
Fe	- 0.507	1						
Br	0.924	- 0.449	1					
Zn	0.790	- 0.625	0.645	1				
Cu	0.662	- 0.619	0.660	0.553	1			
Ca	- 0.318	0.726	- 0.250	- 0.487	-0.553	1		
Mn	0.079	0.584	0.185	- 0.338	-0.300	0.492	1	
Vehicles	0.822	0.112	0.826	0.581	0.685	0.397	0.453	1

Table 5: Correlation matrix of the gaseous pollutants, particulate matter and motor vehicles

	O_3	NO	NO_2	PM_{10}	Fine	Coarse	Vehicles
O_3	1						
NO	- 0.5488	1					
NO_2	0.1357	0.2856	1				
PM_{10}	0.0256	0.7326	0.4813	1			
Fine	- 0.5079	0.9663	0.4849	0.7805	1		
Coarse	0.4690	0.2871	0.3156	0.8481	0.3307	1	
Vehicles	- 0.4745	0.9453	0.2787	0.7238	0.9298	0.3047	1

Table 6: Results of pertinent meteorological parameters obtained from Kenya Meteorological Department

Sample code	Temp. (°C) Max./Min.		Relative humidity	Rainfall (%)	Radiation exposure (Mm) (MJ/m^2)
FW1	26.7	10.2	54	NIL	29.63
FW2	30.5	15.2	30	NIL	30.31
FW3	28.6	10.3	33	NIL	30.90
FW4	25.4	10.8	42	NIL	29.88
MW2	27.1	11.8	52	NIL	29.80
MW3	24.8	13.5	46	<0.1 mm	24.94
MW4	25.5	12.3	60	NIL	23.45
MW5	26.0	12.6	41	1.0	24.04
AW1	24.2	14.0	56	2.5	22.53
AW3	23.5	12.0	55	NIL	20.77
AW4	24.0	12.8	69	15.6	19.01

Table 7: Cloud cover amount in Nairobi during the experiment

	Cloud Cover (Oktas) at time T (UTC)						
Sample code	03:00	06:00	09:00	12:00	15:00	18:00	21:00
FW1	6	5	4	4	4	5	6
FW2	5	4	4	3	0	5	5
FW3	2	4	3	1	1	3	4
FW4	6	5	4	4	4	5	6
MW2	4	5	3	2	3	4	3
MW3	7	6	5	4	5	6	6
MW4	5	5	5	4	3	4	4
MW5	6	5	5	4	4	5	6
AW1	6	4	5	5	7	7	8
AW3	6	6	7	5	5	7	7
AW4	8	7	7	5	7	6	7

Gaseous Pollutants (NO, NO_2 and O_3): Table 1 and Fig. 4 show the concentrations of NO, NO_2 and O_3. A diurnal cycle for ozone and nitrogen oxides is observed, with O_3 peak noted mainly around midday and most part of the afternoon. Exceptions to this diurnal distribution were observed especially on the days when the sky was overcast (i.e., when cloud cover was over 7 Oktas, Table 7). This is most likely due to the dependence of O_3 concentration on solar intensity, which plays a key role in photochemical reactions through which O_3 and other photochemical oxidants are formed. Correlation analysis between O_3 and solar radiation is high (r = 0.77) as is the case with air temperature (r = 0.66) (results not shown). This shows the important role of solar exposure (total solar energy for a day given in units of megajoules per square meter - MJ/m^2) and temperature in ozone formation. The relationship between ozone concentrations and humidity, however, is negatively correlated (r = -0.62) (results not shown). In Fig. 5 and Table 6, the weekly variations of pertinent meteorological parameters are shown.

Highest levels of nitrogen oxides were recorded in the morning (around 9:00 a.m.) and late evening (4:00-5:00 p.m.). This coincides with the morning and evening

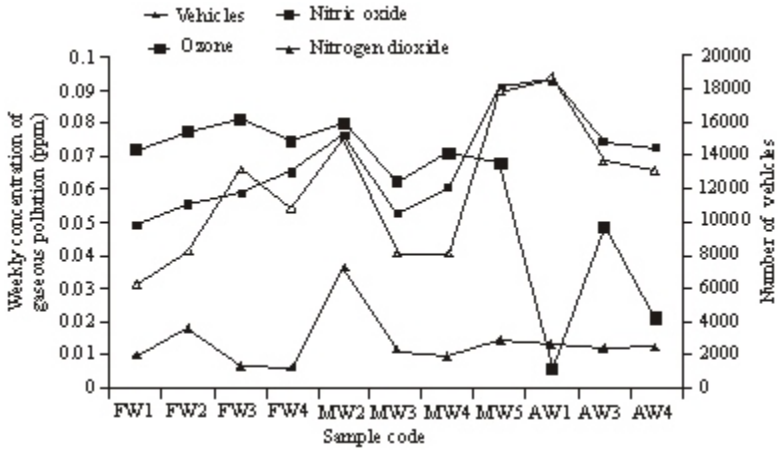

Fig. 4: Weekly concentrations (ppm) of gaseous pollutants

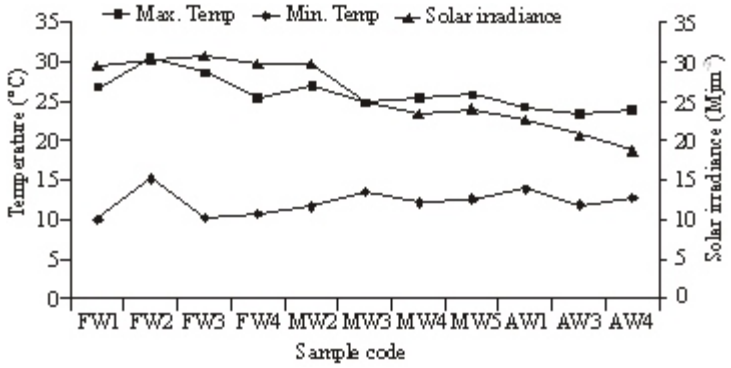

Fig. 5: Weekly variations of pertinent weather parameters

rush hour traffic. Motor vehicles are probably the main source of these gaseous pollutants; directly for NOx and indirectly for ozone, by way of photochemical reactions on NOx. The concentration of ozone increased with a decrease in concentration of NO. This could be a result of the scavenging effect of NO on ozone at high NO level (Seinfeld, 1989). NO is also used up in the photochemical production of ozone, thus low concentration at high ozone levels.

The high correlation between NO and motor vehicle density (r = 0.94) is a further indication that motor vehicle exhaust contributes a high proportion of NO (Table 5). Similarly, high correlation is found between fine particles and NO (r = 0.97). Ozone and NO_2, however, show weak or inverse correlation with vehicle density. The coefficients of correlation for ozone being r = -0.47, and that of NO_2, r = 0.28. This could be as a result of the fact that these two pollutants are not directly emitted from motor vehicle exhausts, but are secondary pollutants, formed by the reaction of the gases emitted directly from the exhaust (Seinfeld, 1989).

The concentrations of gaseous pollutants are found to be negatively correlated with the wind speed (results not shown). During the highest O_3 concentrations, lower wind speeds were observed. This has the effect of reducing the dilution and transport of the pollutants. Variations in ozone concentration were associated with strong solar radiation and clear sky (low cloud cover). There was also high correlation between mean monthly temperatures and O_3 concentrations. This indicates an oxidation dependent solar radiation resulting in O_3 formation with a maximum at around midday when intensity of solar radiation is highest. This agrees with the results of Pandey *et al.* (1992) who showed a significant positive correlation between O_3 concentrations, temperature and solar radiation.

Compared to other gaseous pollutants, NO_2 recorded low concentrations throughout the sampling period. This is quite contrary to expectation since higher NO_2 emissions are anticipated at roundabouts and on approaching traffic lights when idling vehicles will emit higher proportions of NO_2 than during free flowing traffic

(WHO/ECOTOXICOLOGY, 1992). Slow conversion of NO to NO_2 could also be the reason for this anomaly.

CONCLUSION

This study shows that the city of Nairobi has some pollutants that need to be investigated continuously and in more than one site. Of major concern are the very high levels of suspended particulate matter within the inhalable range. The mean PM10 was 239±126 μg/m^3 while the range was 66.66 to 444.45 μg/m^3. These levels are high when compared to other polluted cities like Bombay, London, Los Angeles etc. The WHO limit for PM10 is 150 μg/m^3. There was also strong correlation between fine particulates and motor vehicles (r = 0.93), indicating that vehicular exhaust is the main source of fine particles. Most vehicles in Nairobi are second-hand and poorly maintained; and this could be the main reason behind the high levels of particulate matter. Thick smoke billowing from most vehicles exhausts is a common site in the city. Tougher regulations including regular motor vehicles inspection should be enforced by the relevant authorities.

The gaseous pollutants, namely O_3, NO, and NO_2 were for most part within the WHO guidelines, except for the peak hours when higher levels were detected. However, these values should be treated with caution because constant calibration of the gas detector was not possible due to unavailability of calibration gases even though the unit had been initially calibrated by California Air Resource Board (CARIB) before use for these measurements.

The levels of nitrogen oxides were low for most part except during the morning and evening traffic peak hours which clearly shows that motor vehicles are the most probable source of these gaseous pollutants within the city centre. This is further supported by the high positive correlation (r = 0.94) obtained between NO and motor vehicles.

The values obtained for trace elements are comparable to previous results (Onyari *et al*., 1991; UNEP/WHO, 1992; Tripathi *et al*., 1989; Karue *et al*., 1992) and within the WHO guidelines. Lead was highly correlated with Br (r = 0.92), Zn (r = 0.87) and Cu (r = 0.74), suggesting similar source. These metals also correlate well with motor vehicle density. Hence, vehicular exhaust fumes are the most likely source for these trace metals. At the time of this study, most vehicles in Nairobi were using leaded gasoline, which may explain the slightly high levels of lead in the air samples.

Consistent correlation between elevated ambient PM10 levels and an increase in mortality rates, respiratory infections, number and severity of asthma attacks and the number of hospital admissions have been observed in different parts of the U.S. and elsewhere in the world (Pope and Dockey, 1992; Pope *et al*., 1995, 1991; Morgan *et al*., 1998; Gauderman *et al*., 2004). Although the concentrations and/or combinations of pollutants are significantly different in these studies, most of the PM10 levels recorded in these studies are lower than those observed in Nairobi. These studies showed that inhaling particulate matter of l0 mm or less over long periods of time caused premature death, aggravation of respiratory and cardiovascular diseases, changes in lung function and structure, and changes in the ability of the lungs to fight infection. A study in which 1759 children from schools in 12 Southern California communities were exposed to O_3, acid vapour, NO_2 and particulate matter showed clinically and statistically significant deficits in forced expiratory volume in one second (Gauderman *et al*., 2004); thereby providing robust evidence that lung development from the ages of 10 to 18 is reduced in children exposed to higher levels of ambient air pollution. However, the mechanisms through which these happen have not been well understood.

The high values of fine and coarse particulates obtained in this study could therefore result in adverse health problems as most studies have associated high levels of particulates, especially those in the fine range (PM2.5), with respiratory and cardiovascular diseases (Schwartz, 1993; Hertel *et al*., 2001).

Alongside the busy highways in the city are offices, churches and colleges, which are occupied by many people during the working hours. These people are likely to suffer direct exposure to the particulate matter suspended in air, predisposing them to adverse health effects.

Considering the adverse health effects associated with these pollutants, and the high levels in which they are present in the ambient air in the city, it is critical that appropriate measures be taken to address this problem before situations similar to those experienced in other cities such as London smog of 1952 happens (Pope III, 2004). In this study, motor vehicles are suspected to be the main source of pollutants studied. This call for control measures that would help alleviate pollution problems associated with motor vehicle emissions. The use of cleaner fuels (e.g., non-leaded gasoline), regular vehicle inspection and maintenance as well as strict enforcement of environmental legislation should be a priority.

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REFERENCES

Awange, J.L. and B. Obera, 1987. Motor vehicles: are they emerging threats to Lake Victoria and its environment? Water Air Soil Poll., 182: 43-56.

Brunekreef, B. and S.T. Holgate, 2002. Air pollution and health. Lancet, 360(9341): 1233-1242.

Central Bureau of Statistics (CBS), 2000. Kenya population census. Ministry of Planning and National Development. Central Bureau of Statistics, Nairobi Kenya. Retrieved from: http://www.cbs.go.ke. (Accessed date: March 27, 2007).

Dickinson, N.M., N.W. Lepp and G.T.K. Surtan, 1987. Lead and potential health risks from subsistence food crops in Urban Kenya. Environ. Geochem. Health, 9(2): 37-42.

Freeman, D.B., 1991. A City of farmers; informal urban agriculture in the open spaces of Nairobi, Nairobi. McGill-Queen's University Press, Nairobi, pp: 281.

Gatebe, C.K., 1992. Estimation of Carbon Monoxide, Hydrocarbons and Oxides of Nitrogen from motor vehicles in Nairobi. M.Sc. Thesis, University of Nairobi.

Gatebe, C.K., A.M. Kinyua, M.J. Mangala, R. Kwach, L.N. Njau, E.A. Mukolwe and D.M. Maina, 1996. Determination of suspended particulate matter of major significance to human health using nuclear techniques in Kenya. J. Radioanal. Nucl. Ch., 203(1): 125-134.

Gitari, M.W., 2000. Determination of levels of heavy metals in suspended particulate matter (SPM) in Kibera (Nairobi). M.Sc. Thesis, University of Nairobi.

Gauderman, W.J., E. Avol, F. Gilliland, H. Vora, D. Thomas, K. Berhane, R. McConnell, N. Kuenzli, F. Lurmann, E. Rappaport, H. Margolis, D. Bates and J. Peters, 2004. The effect of air pollution on lung development from 10 to 18 years of age. New England J. Med., 351(11): 1057-1067.

Hertel, O., S.S. Jensen, H.V. Andersen, F. Palmgren, P. Wahlin, H. Skov, I.V. Nielsen, M. Sorensen, S. Loft and O. Raaschou-Nielsen, 2001. Human exposure to traffic pollution. experience from danish studies. Pure Appl. Chem., 73(1): 137-145.

Quantitative X-ray Analysis System (QXAS), 1995. International Atomic Energy Agency (IAEA) Vienna, Austria. Retrieved from: http://www.iaea.org/OurWork/ST/NA/NAAL/pci/ins/xrf/downloads/QXAS_Manual.pdf (Accessed date: June 5, 2010).

Karue, J., A.M. Kinyua and A.H.S. El-Busaidy, 1992. Measured components in total suspended particulate matter in a Kenyan Urban Area. Atmos. Environ. B-Urb., 26(4): 505-511.

Kinyua, A.M., 1982. Multi-element analysis of liquid and solid samples by X-Ray Fluorescence (XRF). M.Sc. Thesis, University of Nairobi, Kenya.

Kinyua, A.M., M.J. Mangala, C.K. Gatebe, G.N. Kamau, R. Kwach, W.G. Mugera, I. Korir, E.A. Mukolwe and L.N. Njau, 1998. Suspended particulate matter in Nairobi and the impact on health. Proceedings of the Kenya Meteorological Society (KMS) Workshop on Meteorological Research Applications and Services, Nairobi, Kenya, pp: 416-423.

Kump, P., 1995. Quantitative X-Ray Analysis of Environmental Samples. IAEA, Vienna.

Maenhaut, W. and C. Jan, 1994. Applied research in air pollution using Nuclear Related Analytical Techniques. Report NAHRES 19, IAEA, Vienna, pp: 249.

Maenhaut, W., I. Saline and C. Gilot, 1995. Atmospheric Aerosol Studies using the 'Gent' Stacked Filter Unit and other aerosol collectors with multi-elemental analysis of the sample by Nuclear Related Techniques. A paper presented in the 2nd IAEA coordinators Meeting on Applied Research and Air Pollution Using Nuclear Related Analytical Techniques, 27-31 March, Austria Vienna.

Morgan, G., S. Corbett, J. Wlodarczy, C. Stephen, W. John and P. Lewis, 1998. Air-Pollution and Hospital Admissions in Sydney, Australia, 1990-1994. Am. J. Public Health, 88(12): 1761-1766.

Ogunsola, O.J., A.F. Oluwole, O.I. Asubiojo, M.A. Durosinmi, A.O. Fatusi and W. Ruck, 1994. Environmental impact of vehicular traffic in Nigeria - health-aspects. Sci. Total Environ., 147: 111-116.

Onyari, J.M., S.O. Wandiga, G.K. Njenga and J.O. Nyatebe, 1991. Lead contamination in street soils of Nairobi-City and Mombasa Island, Kenya. Bull. Environ. Contam. Tox., 46(5): 782-789.

Pope III, C.A., 2004. Air pollution and health-good news and bad: (Editorial). New England J. Med., 351: 1132-1134.

Pope, C.A., D.W. Dockey, J.D. Spengler and M.E. Raizenne, 1991. Respiratory health and PM10 pollution - a daily time-series analysis. Am. Rev. Resp. Dis., 144(3): 668-674.

Pope, C.A. and D.W. Dockey, 1992. Acute health-effects of PM10 pollution on symptomatic and asymptomatic children. Am. Rev. Resp. Dis., 145(5): 1123-1128.

Pope, C.A., M.J. Thun, M.M. Namboodiri, D.W. Dockery, J.S. Evans, F.E. Speizer and C.W. Heath, 1995. Particulate air-pollution as a predictor of mortality in a prospective-study of US adults. Am. J. Resp. Crit. Care, 151(3): 669-674.

Pandey, J., M. Agrawal, N. Khanam, D. Narayan and D.N. Rao, 1992. Air pollutant concentrations in varanasi, India. Atmos. Environ. B-Urban, 26(1): 91-98.

Salvi, S., A. Blomberg, B. Rudell, F. Kelly, T. Sandstrom, S.T. Holgate and A. Frew, 1999. Acute inflammatory response in the airways and peripheral blood after short-term exposure to diesel exhaust in healthy human volunteers. Am. J. Resp. Crit. Care, 159: 702-709.

Seinfeld, H.J., 1989. Air Pollution, Physical and Chemical Fundamentals. McGraw-Hill, New York.

Schwartz, J., 1993. Particulate air-pollution and chronic respiratory-disease. Environ. Res., 62(1): 7-13.

Schwartz, J., 1994. Air pollution and morality: Review and metaanalysis. Environ. Res., 64: 36-52.

Schwartz, J., D.W. Dockery and L.M. Neas, 1996. Is daily mortality associated specifically with fine particles? J. Air Waste Manage. Assoc., 46: 927-939.

Tripathi, R.M., R.N. Khandekar, R. Raghunath and U.C. Mishra, 1989. Assessment of atmospheric-pollution from toxic heavy-metals in 2 cities in India. Atmos. Environ., 23(4): 879-883.

UNEP, 1987. Environmental Data Report. Blackwell Inc., Oxford, pp: 3-104.

UNEP/WHO, 1992. Urban Air Pollution in Megacities of the World. Blackwell Publishers, UK, pp: 230.

UNEP/WHO, 1994. GEMS/AIR Methodology Reviews. Vol: 1, Quality Assurance in Urban Air Quality Monitoring. WHO PEP 94.X UNEP/GEMS 94.X UNEP, Nairobi, pp: 68.

Ward, N.I., 1990. Multielement contamination of British Motorway Environments. Sci. Total Environ., 93: 393-401.

WHO, 2001. World Health Organization (WHO) Strategy on Air Quality and Health Occupational and Environmental Health Protection of the Human Environment. World Health Organization, Geneva.

WHO, 1987. World Health Organization Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. World Health Organization, WHO, Geneva, Switzerland.

WHO/ECOTOXICOLOGY, 1992. Motor Vehicles Air Pollution, Public Health Impact and Control Measures. World Health Organization (WHO), Geneva, pp: 115.

Wikipeda, 2007. Retrieved from: http://en.wikipeda.org/wiki/Nairobi (Accessed date: March 27, 2007).