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Elemental Analysis in Airborne Particulate Matter in Njoro Area of Nakuru County, Kenya

W. O. Machuka[1], C. M. Nguta[2], D. M. Maina[3] and S. M. Ngari[1]

[1]Egerton University, Faculty of Science, P.O. Box 538 Egerton

[2]Laikipia University, School of Science and Applied Technology, P.O. Box 1100 Nyahururu

[3]University of Nairobi, Institute of Nuclear Science, P.O. Box 30197, Nairobi (Kenya)

Abstract

Nakuru County has witnessed notable changes in land use patterns and industrial activities in recent years. These changes have the potential to release heavy metals into the atmosphere through various anthropogenic processes, including industrial emissions, vehicular traffic, and agricultural activities. The presence of heavy metals in the air can lead to a range of environmental problems, such as soil and water contamination, and it can pose health risks to the local population through inhalation exposure. Therefore, the objective of this study was to determine heavy metal in airborne particulate matter in Njoro Area of Nakuru County, Kenya. Sampling was conducted within Njoro Division, Nakuru, in close proximity to the Nakuru-Mau Narok Road, typically within a distance of 1-5 meters from the road's edge. The sampler was positioned at a height of 1.6 meters above ground level. During the sampling period; the average rainfall for the whole period of sampling was measured. The wind direction and speed were also determined using wind vane and wind scope respectively. The daily temperature and humidity readings were also recorded since this also affect the distribution of airborne particulate matter. The elemental composition was determined by Energy Dispersive X-ray Fluorescence (EXDRF) technique. The results revealed fluctuations in pollutant levels over time, and the study also demonstrated that various sources, such as vehicles and agricultural activities, contributed to specific pollutant concentrations. However, there is clear evidence suggesting that vehicles constitute the primary source of emissions. This conclusion is drawn from the detection of Lead (4.13 ± 0.61 ng/m3) and Bromine (0.25 ± 0.08 ng/m3) on 8.0μ and 0.4μ filters, respectively, during both the dry and wet seasons. Nevertheless, it's noteworthy that the concentrations of lead in aerosols and gases in the local ambient air, as determined in this study, were found to be below the recommended levels of 5μg/m^3established by the World Health Organization (WHO) in 2006. Other elements detected were Fe: 35.9±2.44, 32.22±2.48; Mn, 3.67±1.15, 2.97±1.12, Cu, 2.24±0.99, 1.05±0.48, Cr, 2.61±1.29, 2.38±1.19 for dry and wet seasons of sampling respectively. The study recommends that there is need to implement a comprehensive and continuous monitoring system for heavy metal concentrations in airborne particulate matter in Nakuru County and promote the adoption of cleaner technologies and emission reduction measures in industries and transportation to minimize the release of heavy metals into the atmosphere. Further, public awareness campaigns should be conducted to educate the local population about the potential health

risks associated with exposure to airborne particulate matter and trace elements. This includes disseminating information about protective measures and health advisories.

Keywords: Energy Dispersive X-ray Fluorescence (EXDRF), heavy metals, vehicular emission

Correspondence: wamachuka@yahoo.com

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Introduction

Air pollution affects populations and ecosystems in a variety of ways on a local, regional and global scale (De Marco et al., 2019; Huismans, 1999; Barker & Tingey, 2012). The response to air pollution problems varies from country to country. The potential air quality problems facing developing nations, Kenya being one of them, are enormous (Ahmad et al., 2021; deSouza, 2020; Odhiambo et al., 2010). This is reflected by the lack of inventories and empirical data on emissions, of definite and consistent and indigenous research-oriented problem.

Particulate matters also include ambient heavy metals in traces (Hieu & Lee, 2010; Heidari-Farsani et al., 2013). These potentially toxic trace metals include lead (Pb), arsenic (As), cadmium (Cd), selenium (Se) and Mercury (Hg) (Xing et al., 2020). In view of the persistence of heavy metals as micro-pollutants and of their adverse impacts, proposals have been advanced which aim at reducing, or even eliminating, the release of such elements to the environment. The overall objective is to adopt risk reduction strategies on a co-operative basis.

Metal smelting and coal combustion are the main sources of the metals in the atmosphere (Wang et al., 2021; Zhang et al., 2018; Lu et al., 2019). There is a distinct correlation between the trace metal content of sediments and coal production (Chen et al., 2016; MARC, 1985; Halim et al., 2013). Trace metal emission rates have generally decreased over the past decade in line with overall global reduction in the emission of particulates by industry (Charvát et al., 2020).

Some of the study conducted in Kenya shows high levels of heavy metals (Were et al., 2012; Ericson et al., 2019; Mwashote, 2003; Akenga et al., 2020; Ndeda & Manohar, 2014; Odhiambo et al., 2010). A study done by Onyari, Uresa 1991) about the levels of lead in streets soils of Nairobi and Mombasa demonstrated high values of lead exceeding WHO guidelines. The results showed that, Pb contamination of roadside soils decreases exponentially with distance from the kerb, dropping to background levels at between 50-60 m. Also, according to Mutuku, (2003) lead concentrations in soil is seen to be highest alongside the busy Thika-Nairobi highway and decreases with distance from the roadside and city centres. This study therefore was conducted to determine heavy metal in airborne particulate matter in Njoro Area of Nakuru County, Kenya. Understanding the composition and levels of heavy metals in airborne particulate matter in the Njoro Area is essential for effective environmental management and public health protection. The study also provided a baseline information on air quality in Nakuru County.

Methodology

The air samples were collected in Njoro Sub County, Nakuru County. Njoro is an agricultural town located approximately 20 kilometers southwest of Nakuru County in the Rift Valley region.

Samples were collected at locations within a range of 1-5 meters from the Nakuru-Mau Narok Road to capture potential variations in heavy metal concentrations due to road traffic emissions. The sampler was positioned at a height of 1.6 meters above ground level.

Sampling was done using "Gent" stack filter unit (SFU), which uses the concept of separating matter into at least two size fractions by partial filtration dating back in the 1950's as used by the United States navy during atmospheric testing on nuclear weapons (Odhiambo, et al., 2010).

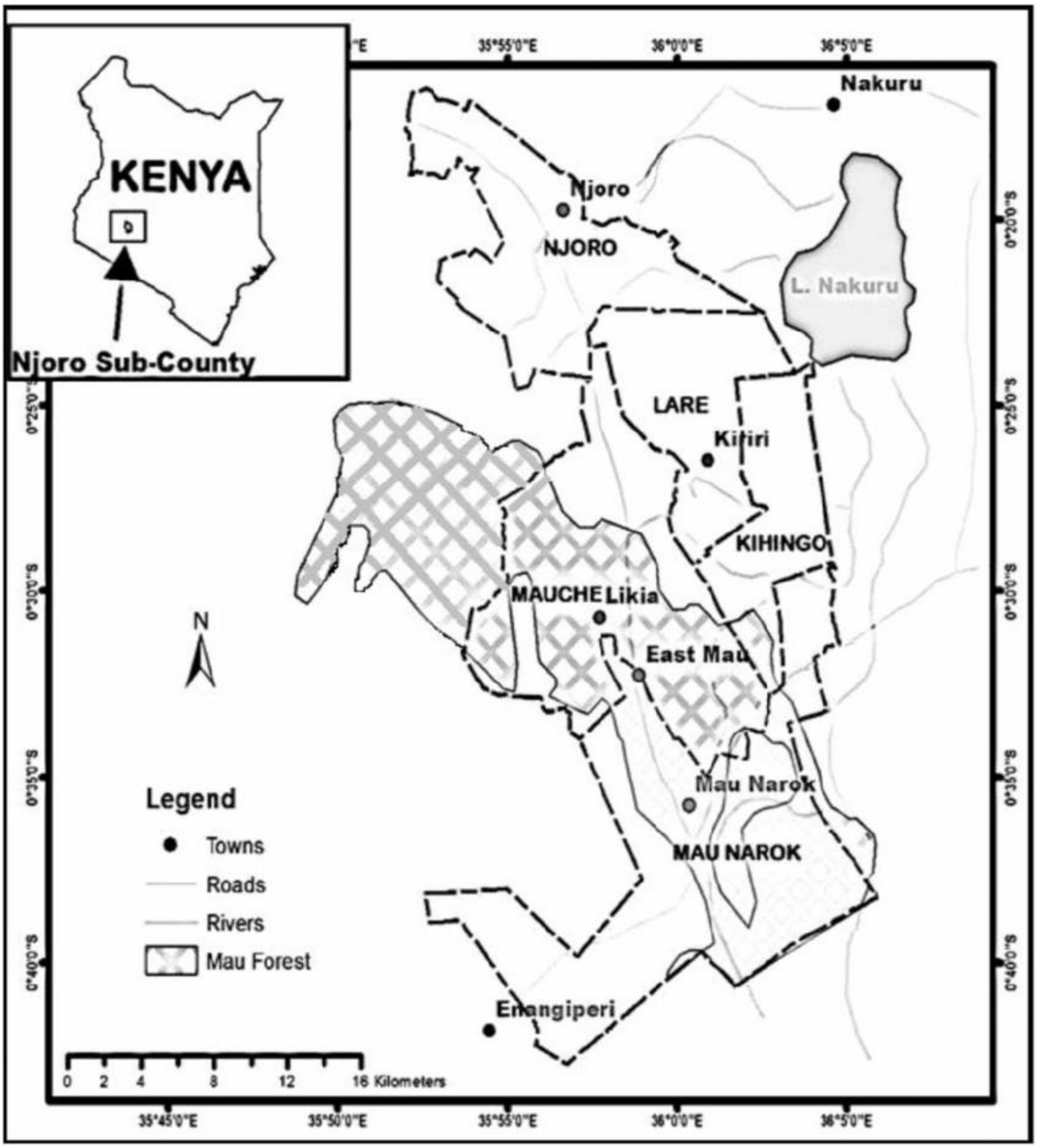

Figure 1: Map of Njoro Subcounty
Source: Kirianki et al. (2018)

Sampling was conducted during both dry (October to November, 2006) and wet seasons (February, 2007) to capture seasonal variations. Throughout the sampling period, meteorological data were recorded, including daily temperature, humidity levels, and wind direction and speed using instruments such as wind vanes and wind scopes. These data are crucial as they can influence the distribution of airborne particulate matter. The samples were then analysed at the Institute of Nuclear Science in Nairobi University after Rigaku NEX CG Energy Dispersive X-Ray Fluorescence system used in this study as described by Kinyua (1982). The excitation source used is annular source of ^{109}Cd and ^{55}Fe among other radioisotope sources.

The laboratory procedure started with the optimisation of the X-ray fluorescence system. This involved setting the optimum bias voltage, shaping time constant for the best detector resolution and optimum irradiation time for the loaded filters. The pulse shaping time was observed to vary with the resolution of the detector with a maximum being attained at shaping time constant of 6µs. the value was set and utilised for all the measurement of the study. The energy resolution, full- with-at Half Maximum (FW HM) at, 5.9keV Mn Kα (energy) peak varied from 170-200eV for the entire analysis period. Optimum irradiation time of the filters was found to be about 50,000 second. Descriptive statistics, such as mean, standard deviation, and variance, were calculated for heavy metal concentrations to understand their distribution and variations over time and across seasons. Heavy metal concentrations were then compared to relevant environmental quality standards by the World Health Organization (WHO), to assess compliance and potential health risks.

Results and discussion

Trace element variation in aerosols

An X-ray spectrum of a coarse particle (PM_{10}) for one sample (CE5D) acquired using S100 software is presented in Fig 1. Figure 1 presents the results obtained by EDXRF analysis for size fractioned aerosol collected during rainy and dry season. The result gives the levels of major element Fe and trace elements namely; Pb, Br, Zn, Mn and Cu and Cr, for both coarse and fine particles

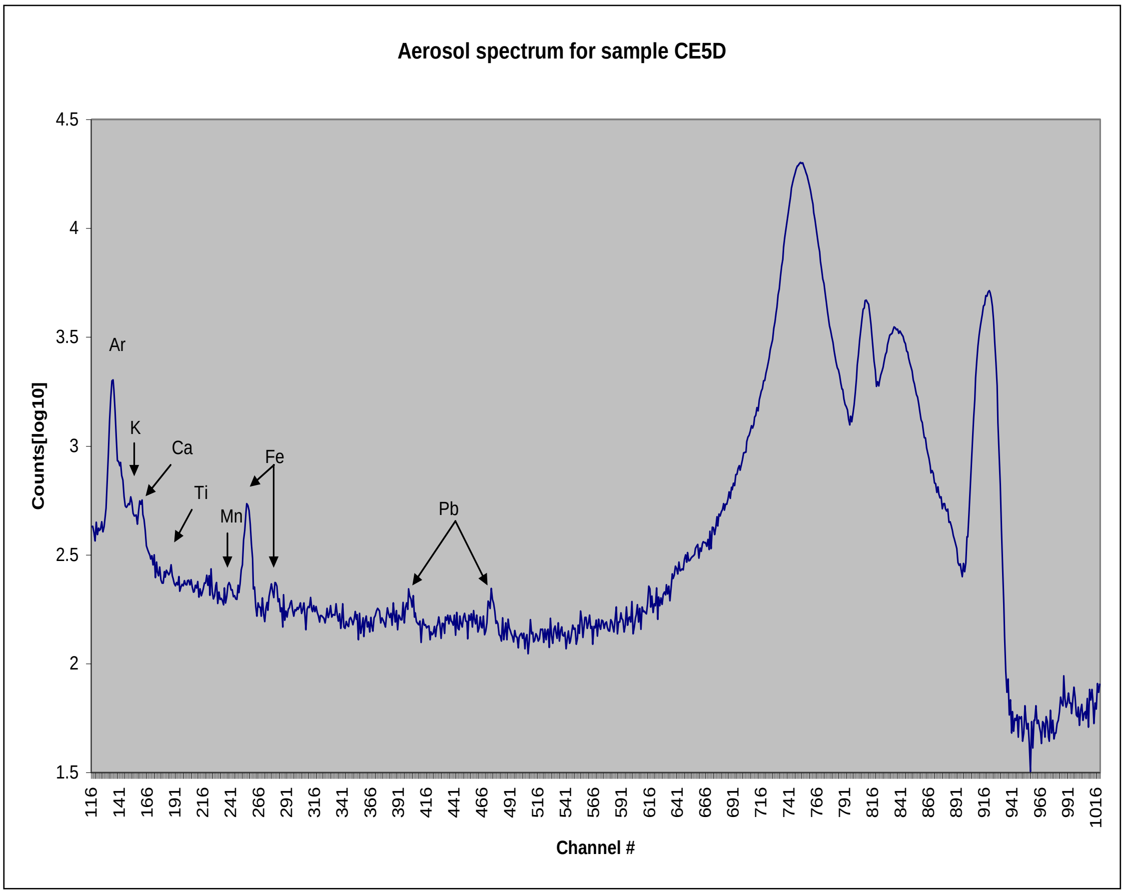

Figure 1: Example of an aerosol spectrum for collected sample

Pb variation in aerosols

The results of trace element Pb variation in aerosols during the dry season are presented in Fig 2 from which the following observations were noted

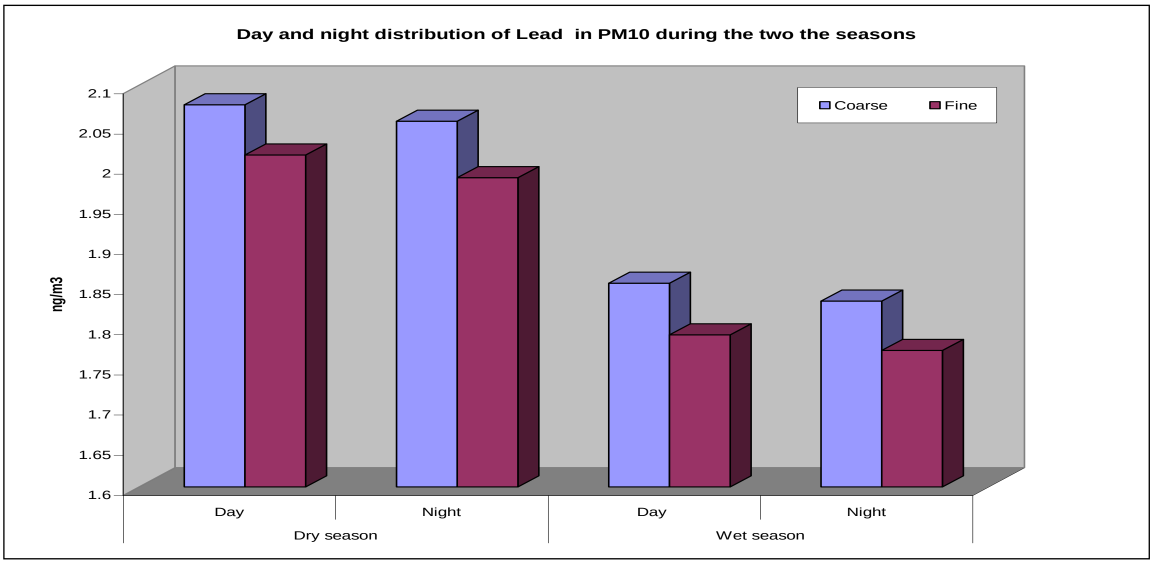

Figure 2: Comparison of coarse to fine concentration of Lead in aerosol sampled during dry season

There were higher levels in coarse (2.08 ng/m3) and (2.06 ng/m3), compared to fine (2.01 ng/m3) and (1.99 ng/m3) during days and nights respectively. This was also the case during the wet season where there were high levels in coarse (1.85 ng/m^3) and (1.83 ng/m^3) compared to fine (1.79 ng/m^3) and (1.77 ng/m^3) during the days and nights respectively. The variation was however not much during the two seasons. Anthropogenic sources, vehicular emissions were probably the sources of these particles. In general, Pb levels in aerosols were high during the dry season than wet season for both coarse and fine particles. The results of this research were in alignment with the outcomes reported by Odhiambo et al. (2010), who observed comparable lead levels (ranging from 0.051 to 1.106 µg/m3) when assessing air pollution from motor vehicles in Nairobi, Kenya. In contrast, Mutua et al. (2021), in their research on the dispersion and amounts of heavy metals within tropospheric suspended particulate matter (PM10) in Nairobi City, Kenya, recorded elevated levels of lead particles.

Br variation in aerosols

In Fig 3 the results of Br variation in dry and rainy season sampling are represented.

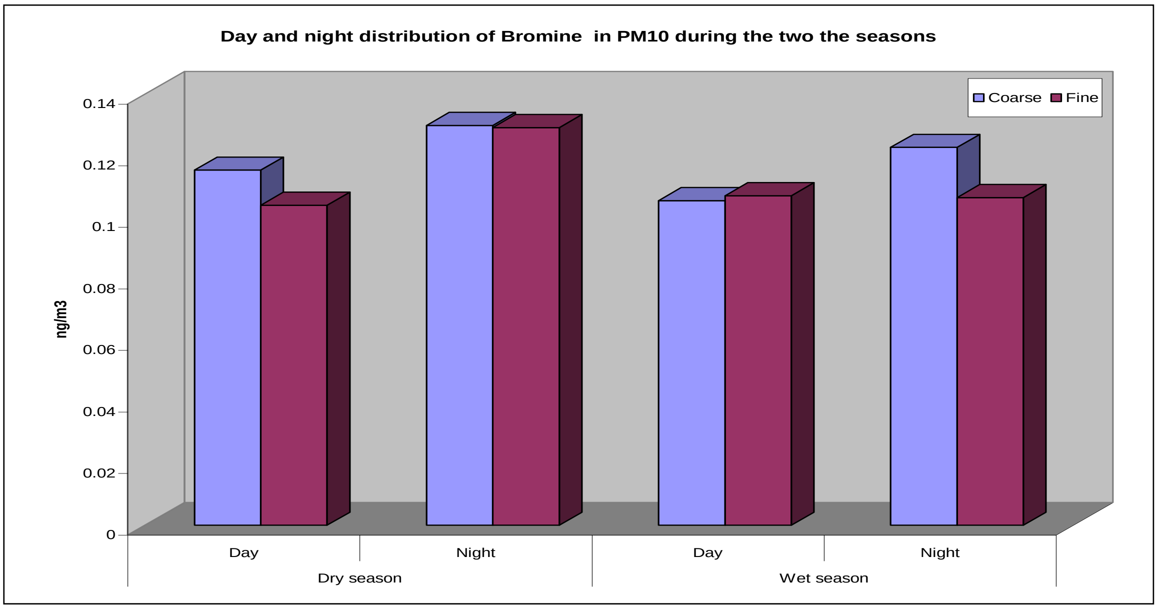

Figure 3: Comparison of coarse to fine concentration of Br in aerosol sampled during wet season

During the dry season, it was observed that the levels of Br in coarse particles were higher during the day (0.12 ng/m3) compared to fine particles (0.10 ng/m3), indicating that the difference is not high. This was not the case during the night for both coarse and fine particles that had an equal value of 0.13 ng/m^3. Generally during day, levels of Br were seemingly higher than during night. This trend indicates a potential diurnal variation in bromine levels, with daytime conditions potentially contributing to higher concentrations. During wet season, Br levels measured in both fractions were the same, 0.11 ng/m^3. However, at night levels slightly changed with coarse raising to 0.12 ng/m^3 and fine remaining at 0.11ng/m^3. It should also be noted that during some days, in wet season, Br levels was below the detection limit (0.001µg/filter). In general Br levels were observed to be higher during the dry season (coarse-.0.25±0.08 ng/m^3 and Fine-0.23±0.06 ng/m^3) than wet season (coarse-0.23±0.06 ng/m^3 and fine- 0.21 ±0.04 ng/m^3). The findings of this study concur with those of Gao et al. (2010) found lower levels of bromine in aerosols in Shanghai, China, while observing the concentration characteristics of both bromine and iodine.

Zn variation in aerosols

The levels of Zn concentration in aerosols for both dry and rainy season sampling are presented in Fig 4.

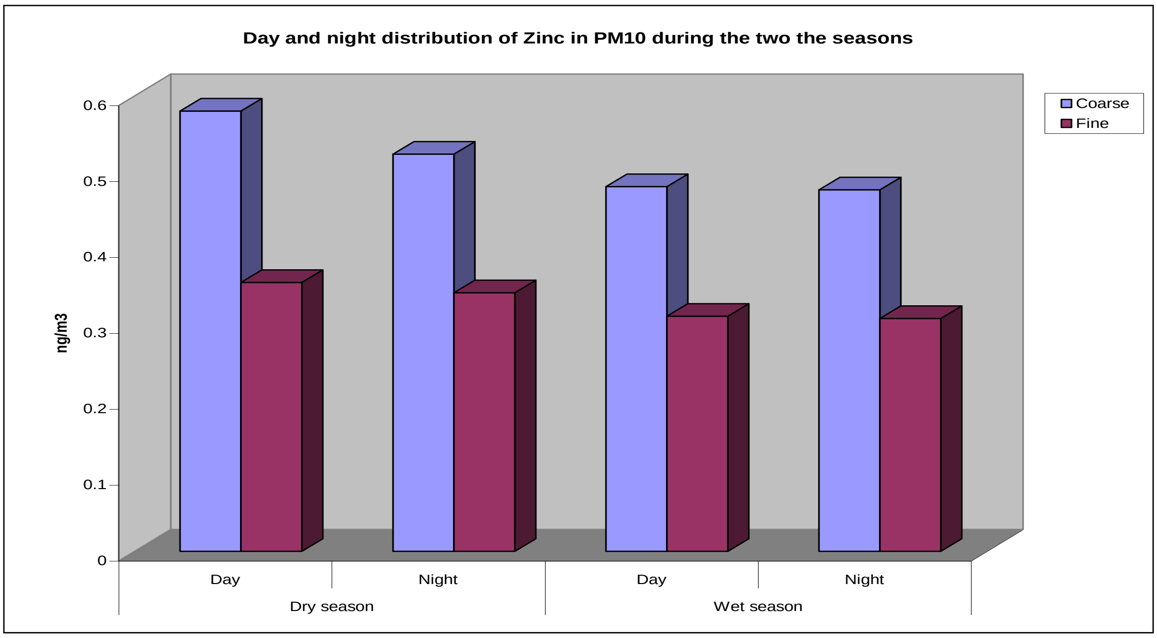

Figure 4: Comparison of coarse to fine concentrations of Zn in aerosols sampled during the dry and wet seasons

Zn level in coarse particles during dry season sampling was 1.10 ± 0.19 and 0.96 ± 0.17 ng/m^3 for the rainy season. There was no much variation noted for Zn in fine particles during the sampling for this study with values of 0.70 ± 0.08 ng/m^3 and 0.62 ± 0.08 ng/m^3 for dry and rainy season respectively. The consistent and minimal variation in zinc (Zn) levels observed between the two seasons, both for coarse and fine particles, suggests that seasonal factors may not have a significant impact on the sources of Zn emissions in the Njoro Area. This stability in Zn concentrations is noteworthy, as it suggests that Zn pollution levels in airborne particulate matter are relatively consistent throughout the year and may be attributed to a combination of agricultural activities involving Zn-containing substances and geological factors. The findings are consistent with those of Hao et al. (2007) who while assessing seasonal variations and sources of various elements in the atmospheric aerosols in Qingdao, China reported elevated levels of Zn.

Variation of Fe in aerosols

The results of Fe in aerosols are presented in Fig 5. During dry season, Fe values in coarse particles did not vary much over the day and night, with values ranging from 20.57-23.23 ng/m^3. This was also the case for fine particles where little variation during day and night was observed 12.89-15.11ng/m^3. Values of 19.42±1.34 ng/m^3 and 12.8 ± 1.14 ng/m^3 were obtained for coarse and fine particles during rainy season.

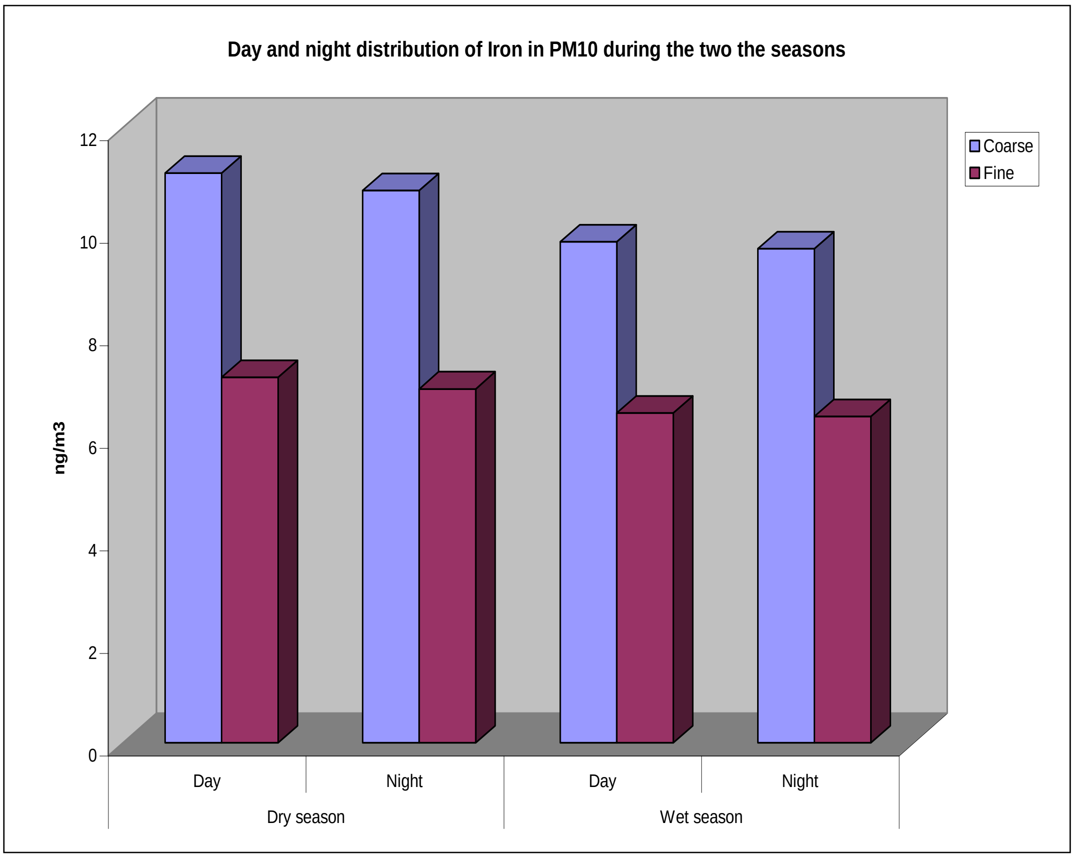

Figure 5: Comparison of coarse to fine concentration of Fe in aerosol sampled during wet season

The results of Fe in fine particles were seen to be low in both dry and rainy season. The overall results showed that Fe had high levels (~ order of 10) compared to other elements. This is a tribute to the high Fe concentrations in Kenyan soils. Kenya has a high amount of red soil and this type of soil is characteristic of high content of Fe oxides (Gatari et al., 2006). The resuspension of road dust would most probably give an increase in Fe concentration in the aerosols. Also, the decrease in Fe levels during the rainy season may be attributed to various factors, including wet deposition and reduced emissions from specific sources. Rainfall can effectively remove particulate matter from the atmosphere, leading to decreased concentrations of certain elements, including Fe. Additionally, changes in environmental conditions during the rainy season may influence emission patterns. The findings are consistent with the research findings of Jandacka and Durcanska (2021) who examined the seasonal variation, chemical composition, and PMF-derived sources identification of traffic-related PM1, PM2.5, and PM2.5–10 in the air quality management region of Žilina, Slovakia. In their study, Jandacka and Durcanska reported lower concentrations of Fe.

Summary of elements in sampled aerosols

Results for trace element analysis are shown in Table 1.

Table 1: summary of concentration elements in aerosol sampled during dry and rainy season (ng/m3) using various filters

Dry Season(ng/m^3)		Rainy Season(ng/m^3)			
8.0µ filters	0.4 µ filters	8.0 µ filters	0.4 µ filters	Dry Season µ	Wet Season µ
0.25±0.08	0.23±0.06	0.23±0.06	0.21 ±0.04	0.48±0.14	0.44±0.1
1.35 ± 0.63	1.26 ± 0.66	1.22±0.58	1.16 ± 0.61	2.61±1.29	2.38±1.19
1.21± 0.55	1.03 ± 0.44	1.05±0.48	<DL	2.24±0.99	1.05±0.48
21.9 ± 1.33	14.0 ± 1.11	19.42±1.34	12.8 ± 1.14	35.9±2.44	32.22±2.48
1.90 ± 0.62	1.77±0.53	1.50 ±0.60	1.47 ± 0.52	3.67±1.15	2.97±1.12
4.13 ± 0.61	4.00 ± 0.59	3.69±0.62	3.56 ± 0.58	8.13±1.2	7.25±1.2
1.10 ± 0.19	0.70 ± 0.08	0.96 ± 0.17	0.62 ± 0.08	1.8±0.27	1.58±0.25

<DL means the element was below detection limit

During the dry season, the Mn level had an average of 1.90 ± 0.62 ng/m^3 and 1.77±0.53 ng/m^3 for coarse and fine particles respectively. However, Mn was found to be below detection limits during the rainy season. Cu level in aerosol varied throughout the sampling period with coarse particles having an average of 1.21± 0.55 ng/m^3 and 1.05±0.48 ng/m^3 during dry and rainy season respectively. In fine particles Cu was below detection limit during rainy season. Cr had nearly the same level in both dry and rainy sampling ~1.35 ± 0.63 ng/m^3 and 1.26 ± 0.66 ng/m^3 for coarse and fine particles during dry season and ~1.22±0.58 ng/m^3 and 1.16 ± 0.61 ng/m^3 during the rainy season. Even though they were low, trace elements were detected in almost all samples. These results agree with those of Karue et al. (1992) who reported lower levels of Mn while measuring components in total suspended particulate matter in an urban area of Kenya.

Conclusion and recommendation

This study has assessed the levels of heavy metals in particulate matter, in Njoro Sub-County, Nakuru County, hence giving an insight of the levels of heavy metals as air contaminants around that area. The levels are within the recommended WHO levels. The data collected will also make it possible for a reasonable evaluation of long-term trends of average concentrations hoping that monitoring trend will be initiated soon in the country.

The increase in global population and the associated industrialization, and motorization have inevitably led to a greater demand for energy, which in turn has caused an increase in emission of air pollutants especially in urban areas. In order to address the problems of urban air pollution, it is necessary to develop an air quality management strategy, which will reduce emissions of harmful pollutants in a city and consequently improve the air quality.

The range of pollutants, pollution sources and methods of imposing emissions controls are extremely wide. If the most appropriate and cost-effective measures to limit emissions are to be implemented, it is first necessary to identify and obtain the information, which is required for accurate decision-making. Only once this has been achieved can this information be applied to produce an air quality management strategy so that the national and international decisions can be based on sound information. Further, public awareness campaigns should be conducted to educate the local population about the potential health risks associated with exposure to airborne particulate matter and trace elements. This includes disseminating information about protective measures and health advisories.

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