

1 **Source apportionment and seasonal variation of PM_{2.5} in a**
2 **Sub-Sahara African city: Nairobi, Kenya**

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12

1 **Abstract**

2 Sources of airborne particulate matter and their seasonal variation in urban areas in Sub-
3 Sahara Africa are poorly understood due to lack of long-term measurement data. In view of
4 this, filter samples of airborne particulate matter (particle diameter $\leq 2.5 \mu\text{m}$, $\text{PM}_{2.5}$) were
5 collected between May 2008 and April 2010 at two sites (urban background site and
6 suburban site) within the Nairobi metropolitan area. A total of 780 samples were collected
7 and analyzed for particulate mass, black carbon (BC) and thirteen trace elements. The
8 average $\text{PM}_{2.5}$ concentration at the urban background site was $21 \pm 9.5 \mu\text{g m}^{-3}$ whereas the
9 concentration at the suburban site was $13 \pm 7.3 \mu\text{g m}^{-3}$. The daily $\text{PM}_{2.5}$ concentrations
10 exceeded $25 \mu\text{g m}^{-3}$ (the World Health Organization 24 h guideline value) 29% of the days
11 at the urban background site and 7% of the days at the suburban site. At both sites, BC, Fe, S
12 and Cl accounted for approximately 80% of all detected elements. Positive matrix
13 factorization analysis identified five source factors that contribute to $\text{PM}_{2.5}$ in Nairobi,
14 namely; traffic, mineral dust, industrial, combustion and a mixed factor (composed of
15 secondary aerosol and biomass burning components). Mineral dust and traffic factors were
16 related to approximately 74% of $\text{PM}_{2.5}$. Identified source factors exhibited seasonal variation
17 though traffic factor was prominently consistent throughout the sampling period. Weekly
18 variations were observed in all factors with weekdays having higher concentrations than
19 weekends. The results provide information that can be exploited for policy formulation and
20 mitigation strategies to control air pollution in Sub-Saharan African cities.

21 **KEYWORDS:** $\text{PM}_{2.5}$, source profiles, urban air quality, Sub-Saharan Africa

22

1 **1. Introduction**

2 The air quality in major cities within Sub-Saharan Africa (SSA) is deteriorating due to
3 several factors which include an increasing urban population, unregulated traffic activities,
4 poorly maintained vehicles, inadequate regulations and air pollution control policies
5 (Zachariadis et al., 2001; van Vliet and Kinney, 2007; UN, 2010). In order to draft
6 environmental regulations to control air pollution, high-quality and long-term measurement
7 data are required. However, such data are not readily available in the SSA region due to a
8 lack of long-term air pollution monitoring (Petkova et al., 2013; UNEP, 2013). Most studies
9 on aerosols in cities within SSA are limited and usually based on short-term measurements
10 (Gatari et al., 2009; Mkoma et al., 2010; Odhiambo et al., 2010; Sawyer, 2010). As a result,
11 there is poor understanding of long-term variations of airborne particulate matter (PM) and
12 little is known about their sources, elemental constituents and seasonal variation.

13 Vehicular related emissions (both exhaust and non-exhaust) account for a large portion of
14 urban air pollution in developing countries (van Vliet and Kinney, 2007; Kinney et al.,
15 2011). A study conducted in Nairobi by Kinney et al. (2011) reported that concentration
16 levels of PM_{2.5} at street level, next to a city road, frequently exceeded the World Health
17 Organization (WHO) 24 h guideline of 25 µg m⁻³. This poses serious questions concerning
18 health risks for people who frequent the city on a daily basis. Vehicular related emissions in
19 the SSA region are exacerbated by the import of second-hand vehicles which for instance in
20 Kenya can be up to eight years old (KEBS, 2013a). In addition, the road network in Nairobi
21 is progressively improving and this has translated into increased motorized traffic activities
22 with a large part of the increased traffic load coming from old and poorly maintained
23 vehicles. This improving road network has led to severe congestion problems and air
24 pollution exposure to the many pedestrians especially during morning and evening rush
25 hours (Graeff, 2010). Recently, there has been a rapid increase (from 50 000 units in 2008 to
26 140 000 units in 2011) in import and use of motorcycles in urban and rural areas (KEBS,
27 2013b).

28 Mineral dust accounts for a significant portion of PM and comes from unpaved road
29 surfaces as well as wind-blown dust during dry seasons (Boman et al., 2009; Reeves et al.,
30 2010; Lindén et al., 2012). The natural background concentration of mineral dust in Africa is
31 bound to be influenced by increasing episodes of droughts (WMO, 2013) as well as

1 increased anthropogenic activities which are related to economic growth. This will pose a
2 challenge to formulation of strategies aimed at mitigating mineral dust effects on air quality.
3 However, quantification of the contribution of mineral dust to urban PM will provide
4 necessary information that can be used in drafting relevant air quality legislation.

5 On a regional level, emissions from biomass burning are also significant and dependent on
6 season (wet or dry). Savannah fires account for a large percentage of carbonaceous aerosols
7 detected in regional PM as has been identified by the extensive research campaigns carried
8 out in southern African during the Southern African Regional Science Initiatives in 1992
9 and 2000 (SAFARI 1992 and SAFARI 2000) (Cahoon et al., 1992; Lindsay et al., 1996;
10 Cachier et al., 1998; Andreae and Merlet, 2001; Formenti et al., 2003; Swap et al., 2003).

11 In Kenya, there is the Draft Air Quality Regulation which is referred to as “The
12 Environmental Management and Coordination (Air Quality) Regulation, 2008” (NEMA,
13 2013). The said regulation does not set any air quality guidelines but instead proposes their
14 formulation. It is interesting to note that the draft of air quality regulations in Kenya allows
15 for burning of savannah grassland as part of cultural and traditional practices.

16 This paper presents results from a long-term measurement campaign initiated in 2008/2009
17 at two sites in the Nairobi metropolitan area. Samples were analyzed for their elemental
18 content using X-ray fluorescence spectroscopy and the results were evaluated using positive
19 matrix factorization (PMF). The results are compared with available data from previous
20 short-term studies in Nairobi and their implications for urban air pollution mitigation
21 strategies are discussed. The overall aim is to identify sources of PM_{2.5} and evaluate their
22 seasonal variations.

23 **2. Materials and Methods**

24 **2.1. Description of the sampling area**

25 Nairobi city lies some 200 km south of the equator and occupies an area of about 684 km². It
26 has a population of about 3.2 million people with a daytime population of about 4 million
27 (KOD, 2012). The larger Nairobi metropolitan area had a population of 6.1 million as of
28 2007 and it is expected to grow to over 12 million by 2030 (MoNMD, 2008). This increase
29 in population has resulted in an increase in commercial, traffic and industrial activities,

1 especially within the central business district. The peri-urban areas of the city continue to
2 experience both controlled and uncontrolled development in buildings and infrastructure,
3 especially mushrooming of informal settlements (Karanja and Makau, 2012). In these
4 settlements, solid waste is usually burned in open air and a majority of the households use
5 kerosene and biomass based fuels (charcoal, wood and vegetation) for domestic cooking
6 (Egondi et al., 2013). The city's industrial area is located to the east and south-east and
7 dominated by small and medium-sized industries which include food processing, power
8 generation, chemical processing industries, battery manufacturing and scrap metal recycling.

9 **2.2. Climate of the study area**

10 Nairobi city experiences a moderate climate even though it is located along the equator. At a
11 height of about 1795 m above the sea level, the city has a subtropical high climate according
12 to the Köppen climate classification (Peel et al., 2007) as opposed to the expected tropical
13 climate. The regional climate of East Africa is influenced by the seasonal displacement of
14 the inter-tropical convergence zone (ITCZ) (Henne et al., 2008). The north-south-north
15 annual shift of the ITCZ is driven by the apparent annual motion of the sun and results in
16 monsoon trade winds, which give rise to well-defined wet and dry seasons (KMD, 2013).
17 Severe changes in this cycle usually result in droughts or flooding in the East African region
18 (WMO, 2013). The average annual rainfall is approximately 900 mm but varies from less
19 than 500 mm to more than 1500 mm between years. The average daily temperature varies
20 from about 17 °C in July and August to 20 °C in March (KMD, 2013).

21 **2.3. Sampling sites**

22 Sampling of PM_{2.5} was carried out at two sites within the Nairobi metropolitan area. The
23 first site was at the University of Nairobi main campus (1.279° S, 36.817° E) (herein referred
24 to as university and marked S1 in Fig. 1), which is within the city center. The second
25 sampling site was established in a suburban area, within the compound of the United Nation
26 Environmental Programme headquarter (1.234° S, 36.818° E) (herein referred to as UNEP
27 and marked as S2 in Fig. 1) and about 5 km to the north of the university site.

28 Cyclone samplers (Casella, Bedford, UK) were used to collect fine particles (PM_{2.5}) on pre-
29 weighed polycarbonate filters with 0.4 µm pore size (Whatman International Ltd.,

1 Maidstone, UK). Samples were collected for 24 h per sample at a flow rate of 3 L min⁻¹,
2 except on weekends when samples were collected for 48 h per sample. At both the
3 university and UNEP sites, sampling started at 10.00 a.m., local time (UTC + 3). At the
4 university site, PM_{2.5} samples were collected from 22nd May 2008 to 2nd April 2010. The
5 cyclone sampler was mounted on the rooftop of the Engineering building at about 17 m
6 above ground level (agl). This site being at an elevated location and close to the city center
7 represents an urban background setting.

8 At the UNEP site, sampling was carried out from 16th April 2009 to 30th March 2010. The
9 cyclone setup was placed on the rooftop of the Administration block about 10 m agl. The
10 site is in a suburban area compared to the university site and it is surrounded by two local
11 forests (Karura to the east and Gigiri to the south), and comprises office blocks and low-
12 density residential houses.

13 A total of 780 valid samples were collected, of which 502 and 278 were from the university
14 and UNEP sites, respectively. Loaded filters were analyzed for PM_{2.5} mass concentration,
15 black carbon (BC) and trace elements (from S to Pb). The PM_{2.5} mass concentration was
16 determined gravimetrically using a microbalance (Mettler Toledo model TM5). Empty and
17 loaded filters were weighed after being conditioned at a relative humidity of 50 ± 10% and a
18 temperature of 20 ± 2 °C for 24 h. The BC concentration was analyzed using a BC
19 reflectometer (ESM Emberline, model FH62 1-N). The reflectometer measures the
20 absorption and reflection properties of the sample-loaded filter, whereby the reflected light
21 intensity at 650 nm is observed to non-linearly decrease as BC concentration increases on
22 the filter (Gatari and Boman, 2003; Moosmüller et al., 2009).

23 Trace elements were determined using Energy Dispersive X-ray Fluorescence (EDXRF)
24 spectroscopy. The spectrometer uses a Philips diffraction X-ray tube and a Mo secondary
25 target. The secondary target consists of a 1 mm thick Mo plate of 99.99% purity. Fluoresced
26 secondary X-rays propagate through two Ag collimators giving a relatively focused beam of
27 near monochromatic X-rays for sample excitation. The spectrometer is laboratory built
28 (University of Gothenburg, Sweden) in an optimized three axial geometry that gives good
29 signal to noise ratios for the measured elements (Boman, 1991). It was operated at a voltage
30 of 50 kV and a current of 20 mA and spectral information was acquired for a live time of
31 1000 s. The spectra were analyzed using Analysis of X-ray spectra by Iterative Least-square

1 fitting (AXIL) which is a subprogram of the Quantitative X-ray Analysis System (QXAS)
2 software from International Atomic Energy Agency (Bernasconi et al., 2000). The
3 subprogram assists in spectrum conversion and fitting. In this study, a calibration file was
4 created using single element standards. The standards were run, fitted and evaluated for
5 element's net peak area (P_A) and associated background area (B_A). The obtained P_A and B_A
6 together with the known concentration (C_A) of the element were used to calculate the
7 detection limit (DL_A ; see Table 1) using the IUPAC equation below (van Grieken and
8 Markowicz, 1993):

$$9 \quad DL_A = 3 \times C_A \times \frac{\sqrt{B_A}}{P_A}$$

10 In order to correct for the positive artefacts from organic carbon (OC), measured
11 concentration values from the field blanks were subtracted from the measured samples'
12 concentration values (Watson et al., 2009).

13 **2.4. Data treatment and analysis**

14 $PM_{2.5}$, trace element and BC concentrations were further analyzed using positive matrix
15 factorization (PMF) for purposes of source apportionment. PMF is a multivariate factor
16 analysis method that decomposes a matrix of speciated sample data into factor contributions
17 and profiles, which are then interpreted as to what source types they represent (Paatero,
18 1997). The EPA PMF 3.0 program from USEPA (Norris et al., 2008) was used for the
19 analysis. Data below the detection limit (DL) were substituted with one-half of the
20 respective DL and uncertainty was set to $\pm 5/6$ times the DL (Polissar et al., 2001). During
21 PMF analysis the number of factors was varied between three and nine factors. From the
22 analysis output, only five factors were seen to give meaningful results for possible PM
23 sources and are thus presented herein.

24 Meteorology data for this study were collected from Jomo Kenya International Airport
25 (JKIA) that is approximately 13 km to the south-east of the university site (data was
26 purchased from AccuWeather Enterprise Solutions, New York, USA). In addition, back-
27 trajectories of air masses arriving at 100 m above the sampling sites were generated using
28 the HYSPLIT_4 model (Draxler and Hess, 1998). Daily back-trajectories were run for 72 h,

1 clustered on a monthly basis and compared with monthly averages of measured wind speed
2 and direction.

3 **3. Results and discussion**

4 **3.1. Meteorology during the sampling period**

5 Sampling period was characterized by periods of long rains (mid-March to May), short rains
6 (October to November) and dry periods (from January to mid-March and from June to
7 September) in 2008 and 2010. However, in 2009 there was a pronounced drought (from
8 March to October) and as a result, lower than normal amount of rainfall were recorded
9 during the long rains season (Zwaagstra et al., 2010; Williams and Funk, 2011).

10

11 Measured wind direction mainly oscillated between north and east (Fig. 2) for the entire
12 sampling period. Average hourly wind speed for entire sampling period was 4 ms^{-1} with a
13 range of between 0 and 33 ms^{-1} . On a monthly basis, the wind direction was predominantly
14 north-easterly during the period from October to March whereas during the months of April
15 to September, the direction was mainly easterly and south-easterly. The average relative
16 humidity was 67% and varied from 10 to 100%, while the average temperature was $20 \text{ }^{\circ}\text{C}$
17 and ranged from a minimum of $8 \text{ }^{\circ}\text{C}$ to a maximum of $32 \text{ }^{\circ}\text{C}$.

18 Figure 3 shows clustered back trajectories for the sampling period and illustrates that air
19 masses arriving in Nairobi area mainly originated from the south-easterly (52%) and easterly
20 (48%) directions. From April to October, the air masses originated from the south-easterly
21 direction (back trajectories numbered 2 and 3), whereas from November to March, the
22 direction of origin was easterly and north-easterly (back trajectories 1 and 4). There was a
23 discrepancy between calculated back trajectories and recorded wind direction in the months
24 of September and October. This discrepancy between local wind directions and regional air
25 mass movement indicate that the Nairobi PM is influenced by both local wind dynamics and
26 regional air mass movement.

27 **3.2. PM_{2.5} mass and elemental concentrations**

28 Results for PM_{2.5}, BC and 13 trace elements concentrations from the university and UNEP
29 sites are presented in Table 1 and Table 2. The statistics in Table 1 are from combined data
30 sets from the two sites and depict a general picture of PM_{2.5} and its constituents in the

1 Nairobi metropolitan area. From all the filters collected, approximately 29% of the
2 elemental contents were detected with the balance of 71% attributed to the contribution from
3 organic matter, nitrates, aluminosilicates and oxides of both detected and undetected
4 elements. BC has the highest average concentration and accounted for 15% of the PM_{2.5}
5 concentration whereas trace elements accounted for 14%. Average Fe concentration is the
6 highest among the detected elements followed by S and Cl in that order. Average lead
7 concentration is well below the WHO annual guideline concentration of 500 ng m⁻³ (WHO,
8 2000). This is probably due to the phasing out of leaded gasoline in 2006 in Kenya. Due to
9 the high altitude of Nairobi a Tel-B mixture was being used (before 2006) as an anti-knock
10 additive in the gasoline resulting in a Br/Pb ratio of 0.77 in particulate matter from fresh
11 exhaust (Harrison and Sturges, 1983b).

12 Table 2 shows the comparison of PM_{2.5} and elemental concentrations at the university and
13 UNEP sites for the common sampling period (16 April 2009 to 30 Mar 2010). At the
14 university site, PM_{2.5} concentration ranges from 3 to 53 µg m⁻³ with an overall mean of 21
15 µg m⁻³. The average PM_{2.5} concentration exceeds the annual WHO guideline limit of 10 µg
16 m⁻³ by a factor of two. The 24 h WHO guideline was exceeded 29% of the total sampling
17 days. Elemental composition of PM_{2.5} at the university site is dominated by BC, Fe, S and
18 Cl. Average BC concentration accounts for 19% of the of the total PM_{2.5} concentration
19 whereas Fe, S and Cl accounted for a total of 9%.

20 At the UNEP site PM_{2.5} concentration ranges from 1.9 to 36 µg m⁻³ with an overall mean of
21 13 µg m⁻³. The average PM_{2.5} concentration is about 30% higher than the annual WHO
22 guideline. At this site, the 24 h WHO guideline was exceeded 7% of the total sampling days.
23 BC has the highest average concentration of the identified components and individually
24 accounts for 11% of the total PM_{2.5} concentration whereas all other elements account for
25 15%. The average concentration of S is the second highest followed by Cl, Fe and K in that
26 order.

27 The average PM_{2.5} concentration at the university site is about 50% higher than at the UNEP
28 site. This observed difference points to inter site variation due to factors such the location of
29 the measurement site, which in this case was that the UNEP site is in a suburban area
30 surrounded by forests (Fig. 1). The average BC concentration at the university site is more
31 than twice the BC concentration at the UNEP site. Similarly, concentrations of Ca, Mn, Fe

1 and Br show marked difference between the two sites. Albeit the close proximity of the sites
2 to each other, the university site, an urban background site, is seen to be under greater
3 influence from PM sources compared to the UNEP site. In addition, observed ranges and
4 standard deviations of PM_{2.5} and elements concentrations at the two sites indicate variability
5 of the PM sources at both sites during the sampling period.

6 **3.3. Seasonal variation of the PM_{2.5}, BC and some selected elements**

7 Figure 4 shows the seasonal variation of PM_{2.5} and some selected elements at the university
8 site. Seasonal average concentration for PM_{2.5} is highest during the cold and dry season in
9 2009 (25 µg m⁻³) and lowest during the short rainy season (8.9 µg m⁻³) in the same year. The
10 high seasonal averages in 2009 especially during the long rainy season are linked to the then
11 ongoing drought. WHO air quality guideline for a 24 h period was frequently exceeded
12 during this drought period. High BC concentrations are observed during the cold and dry
13 season in 2009 as well as during the latter part of the hot and dry season in 2009. The
14 observed individual trends for the selected elements show marked variation. Zn
15 concentrations display a variation that follows the erratic weather pattern reported in 2009.
16 Pb concentration is prominent during the 2009 indicating its relation to episodes of high
17 PM_{2.5} concentrations. Fe has a trend that is similar to that of PM_{2.5} whereas both S and Cl
18 display a similar trend to each other.

19
20 Figure 5 shows the seasonal variation of PM_{2.5} and selected elements at the UNEP site. The
21 general trend for the PM_{2.5} concentration is that of variation from high concentrations in
22 2009 to lower concentrations in 2010. Similar trend was observed for Zn, Pb, S, Fe and BC.
23 However Cl was observed to be somewhat consistent throughout the sampling period.
24 Highest seasonal average concentration (19 µg m⁻³) for PM_{2.5} is measured during the cold
25 and dry season in 2009 while the lowest seasonal average concentration is reported during
26 the hot and dry season in 2010. This observation is supported by the high number of rainy
27 days manually recorded at that site during the said period compared to the other part of the
28 sampling period.

29
30 Comparing the two sites, the observed seasonal variation is similar in 2009 but different in
31 2010. Observed trend for Pb concentrations at both sites show similarity and it is
32 intermittent probably due to decrease in airborne Pb as a result of banning the use of Pb in

1 gasoline sold in Kenya. Observed trend of BC concentrations at both sites are equally
2 similar pointing to common influence from possible local and regional sources. These
3 observed differences in variations is attributed to differences in number and influences of
4 possible PM sources, surrounding features such as forests at the UNEP and differences in
5 observed weather patterns at each site.

6 **3.4. Weekly variation of PM_{2.5}, BC and some selected elements**

7 Figure 6 shows the weekly variation of average concentrations of PM_{2.5}, BC, S, Cl, K, Fe,
8 Zn and Pb calculated from the combined data of samples collected at the university and
9 UNEP sites. In general, there is a common trend in all the indicated concentrations with
10 weekdays (Monday to Friday) having higher concentration compared to the weekends
11 (Saturdays and Sundays). This points to the influence of anthropogenic activities to airborne
12 PM in Nairobi given that there is heightened human related activities during the weekdays
13 and minimal activities during the weekends (Kinney et al., 2011). Concentrations of PM_{2.5},
14 BC, Cl, K and Fe do not display significant variations within the weekdays and this
15 observation indicates consistency of their possible sources. Concentrations of S, Zn and Pb
16 display variations within the weekdays indicating variability in their sources.

17 **3.5. Positive matrix factorization analysis and source apportionment**

18 Positive matrix factorization was applied to the combined data from the two sites to identify
19 major PM_{2.5} sources. The results from a five-factor solution are shown in Figures 7 to 11 and
20 the individual factors are discussed hereinafter.

21 The first factor is attributed to both exhaust and non-exhaust traffic emissions (Fig. 7). The
22 factor is characterized by a high contribution of BC, S, K, Fe and Zn and accounts for 39%
23 of the PM_{2.5}. The factor shows a similar pattern as the elemental profile of PM_{2.5} samples
24 collected from a traffic polluted site in Connecticut, USA (Gent et al., 2009). The factor is
25 identified with exhaust traffic emissions due to the presence of S and BC (Zachariadis et al.,
26 2001; Arku et al., 2008; Lestari and Mauliadi, 2009). The high S concentration comes from
27 diesel sold in Kenya that contains 0.5% S and the visible black smoke from the exhaust
28 pipes of many vehicles indicates incomplete combustion resulting in high emissions of BC.
29 Furthermore, there are no regulations on vehicular emissions and a majority of the cars are
30 imported as second-hand although there is an age-limit of 8 years. Non-exhaust traffic

1 emissions such as re-suspension of road dust (Fe, K, Ca and traces of Pb) and tire abrasion
2 (Zn) also contribute to this factor (Chueinta et al., 2000; Salma and Maenhaut, 2006; Pant
3 and Harrison, 2013).

4 The second factor is attributed to mineral dust (Fig. 8). It is dominated by crustal elements
5 (Fe, Ca, K and Ti) and has a pattern similar to that of elements from soil samples collected
6 across SSA which were analyzed using Total X-ray Fluorescence technique (Towett et al.,
7 2013). This factor highlights the contribution of local soil to PM_{2.5} in Nairobi. The
8 prolonged dry periods during the campaign contribute to the increased mineral dust loading
9 to the sampled PM_{2.5}. The absence of S, Zn and Pb in this factor marks the difference
10 between the origin of the mineral dust in this factor and the re-suspended road dust in the
11 first factor hence justifying both dust components as separate entities.

12 The third factor is attributed to a mixture of biomass burning and secondary aerosol
13 particles. This mixed factor accounts 13% of the mass concentration (Fig. 9). Presence of Cl
14 and S points to marine influence as shown by observed back trajectories (Fig. 3) that
15 originate from the Indian Ocean as discussed in the meteorology section. This implies that
16 marine aerosols reaching Nairobi, to some extent, undergo partial replacement of Cl by S
17 during the long-range travel from the Indian Ocean. Sea salt particles have been reported to
18 lose Cl due to reaction with acidic compounds, sulfuric acid in this case, to form sulfate
19 aerosol particles (Pio and Lopes, 1998; Nyanganyura et al., 2007). S component originates
20 from diesel and heavy fuel oil consumption within the Nairobi region. The contribution from
21 biomass burning is indicated by presence of K, Zn and Rb. Biomass burning is a common
22 phenomenon in the savannah plains that are located to the southern part of the Equator as
23 reported during the SAFARI campaigns (Lindesay et al., 1996; Formenti et al., 2003).

24 The fourth factor is attributed to combustion processes and accounts for 6% of the mass
25 concentration. It is characterized by BC, S, K and Fe (Fig. 10) and shows similarity with a
26 combustion factor from a study in Skopje, Macedonia (Kovacevik et al., 2011), which was
27 associated with biomass and fossil fuel combustion. Combustion activities that are likely to
28 contribute to PM_{2.5} in Nairobi include use of heavy fuel oil in industries and in
29 thermoelectric power generation (BC and S), solid waste burning (BC, Zn and Pb), domestic
30 charcoal/wood fires/biomass burning (BC, K and Br) in the low income households and

1 slums which account for over 80% of settlements in Nairobi metropolitan area (Karanja and
2 Makau, 2012; Egondi et al., 2013).

3 The fifth factor is attributed to industrial emissions and accounts for 7% of the mass
4 concentration (Fig. 11). It is characterized by presence of Zn, Fe, Cl and K. It is identified
5 with emissions from smelting industries that depend on scrap metals as raw materials
6 (Querol et al., 2007). These smelting industries are located on the eastern and south-eastern
7 part of the city, which coincide with the general wind and air mass flow directions (Fig. 2
8 and 3). Contribution of Pb in this factor is below 1% but high concentrations of up to $427 \pm$
9 $124 \mu\text{g m}^{-3}$ have been reported from a recycling plant at industrial area (Were et al., 2012).

10 Figure 12 summarizes the percentage composition of the identified $\text{PM}_{2.5}$ source factors. It is
11 evident that traffic and mineral dust account for approximately 74% of $\text{PM}_{2.5}$ in Nairobi.
12 This observation points to the significance of anthropogenic influence on air quality given
13 that traffic is human-related whereas mineral dust component originates from both natural
14 and human-related activities.

15 **3.6. Seasonal variation**

16 Figures 13 and 14 show the seasonal variation of the PMF factors at the university site and
17 the UNEP site, respectively. The seasons are demarcated based on the description of the
18 Nairobi climate by Kenya Meteorological department (KMD, 2013).

19 **3.6.1. University site**

20 Traffic and mineral dust factors dominate at the university site (Fig. 13) and are generally
21 inherent during the entire sampling period. It is important to note that the dip observed
22 during the short rainy season in 2009 was partly due to high uncertainty as a result of
23 majority of the filters collected at that time exhibiting concentrations below the detection
24 limit. Mineral dust factor is prominent due to the then on going drought and its seasonal
25 percentage contribution in 2009 range from 33% to 55%. The drought effect is evident in
26 that during the long rainy season in 2009, no significant change in mineral dust contribution
27 (with seasonal percentage contribution of 33%) is noted when compared with the cool and
28 dry season in the same year (seasonal percentage contribution, 40%). A low amount of
29 rainfall (223 mm) was recorded compared to the normally expected amount (450 mm).

1 The traffic factor is almost consistent throughout the sampling period except during the short
2 rainy season of 2009. During this period the seasonal percentage contribution was 11%
3 compared to other seasons, which had a range of between 35% and 69%. The factor's
4 contribution is seen to dominate in the beginning of 2010, with percentage contribution of
5 49% during the hot and dry season. Further statistical analysis of data in relation to the
6 traffic factor, shows that the average ratio of Pb to PM_{2.5} during the hot and dry season in
7 2009, deviates from the average ratio of Pb to PM_{2.5} (0.0014) obtained for all seasons.
8 Percentagewise, it is 25% higher than the average ratio. In addition, the average Br/Pb ratio
9 is 0.64 compared to a ratio of 0.77 reported from fresh vehicular exhaust by Harrison and
10 Sturges (1983a). This indicates that part of the Br from gasoline emissions was present in
11 the vapor phase, as also reported from the city of Butare, Rwanda, by Maenhaut and
12 Akilimali (1987). In addition, during this season the wind blows mainly from north-eastern
13 direction (same direction as the Thika highway and the Globe roundabout which is the entry
14 point of vehicles from central and northern Kenya). Furthermore, contribution from tire
15 abrasion was also a possibility (Salma and Maenhaut, 2006) given that many on road
16 vehicles rely on second-hand tires.

17 The mixed factor though not prominent, is consistent throughout the sampling period but
18 slightly pronounced during the short rainy season in 2009 with a seasonal contribution of
19 26%. During this season wind direction is usually easterly to north-easterly and therefore
20 vehicular emission from the city center contributes S to this factor due to the S emissions
21 from vehicles, as described in the sections above. In addition, marine influence from Indian
22 Ocean, as indicated by presence of Cl, is evident as shown in Figure 8, that back trajectories
23 of air mass arriving in Nairobi principally originate from Indian Ocean.

24 The combustion factor was not consistent through the sampling period, but was prominent
25 from the hot and dry season in 2009 with a seasonal percentage contribution of 6% and 8%
26 during the long rainy season of the same year. Thereafter the factor's percentage
27 contribution drops to 4% for the remaining seasons. This observed trend in combustion
28 factor is an indication of the complexity of combustion sources in Nairobi such as
29 unregulated burning of solid waste, extensive domestic use of kerosene and use of biomass
30 based fuels (firewood and charcoal) in slum areas for energy generation (Salma and
31 Maenhaut, 2006; Reinard et al., 2007).

1 The industrial factor showed a seasonal variation in that seasonal percentage contribution
2 was highest (10% in each season) during the cool and dry seasons in 2008 and 2009.
3 Percentage contribution was also high during the long rainy season in 2009 (8%) but was
4 significantly low (2 to 4%) during the short rainy as well as all the hot and dry seasons. This
5 observation highlighted contribution of metallurgical industries since local winds and
6 regional air masses were generally easterly to south-easterly during the seasons with high
7 percentage contributions. Thus emissions from the said industries were transported to the
8 site, which were located in the same (mainly south-easterly) direction relative to the
9 sampling site.

10 **3.6.2. UNEP site**

11 Figure 14 shows the trend in source factors at the UNEP site. Contribution of the factors is
12 highest during the cool and dry season in 2009 and is dominated by the mineral dust, traffic
13 and industrial factors. The contribution decreases towards the beginning of 2010. Wind
14 direction during the cool and dry season is generally southerly to easterly that is the same
15 direction as the city center and industrial area in relation to this site. During the hot and dry
16 season in 2010, contribution from the mineral dust factor is minimal (percentage
17 contribution, 22%). This coincided with the observation that the UNEP site recorded 19
18 rainy days during that season. This observation highlights the erratic nature of rainfall
19 pattern in Kenya during the sampling period (WMO, 2013) and its influence on the airborne
20 particulate matter levels.

21 The traffic factor is consistently distributed throughout the sampling period but prominent
22 during the long rainy season in 2009 with a seasonal percentage contribution of 40%. This is
23 identified as resulting from re-suspension of road dust from the neighboring motorways. As
24 was the case at the university site, calculated Pb/PM_{2.5} ratio shows seasonal variation.
25 However the Pb/PM_{2.5} ratio is slightly higher (about 28%) than at the university site
26 indicating significance of the road dust compared to other sources at the UNEP site. At the
27 UNEP site the Br/Pb ratio is 0.43. Even though use of leaded gasoline was banned in 2006
28 by the Kenya government, it is expected that the Pb concentration in the soil dust will last
29 for long period and somewhat be constant as reported from other world cities (Xu et al.,
30 2012; Datko-Williams et al., 2014). In absolute concentration values, the university site had
31 higher concentration ($23 \pm 16 \text{ ng m}^{-3}$) compared to the UNEP site ($17 \pm 14 \text{ ng m}^{-3}$). More so,

1 since the university site is close to the city center, it is influenced heavily by PM sources as
2 characterized by the reported 50% higher PM_{2.5} concentration than the concentration
3 reported at the UNEP site.

4 The mixed factor is prevalent during the hot and dry season in 2010 with a seasonal
5 percentage contribution of 45%. During this season the wind direction is usually north-
6 easterly and thus S component from diesel related emissions are transported from Thika
7 highway towards UNEP site and its environs. In addition, back trajectories during this
8 period are dominantly easterly and thus travelled over the city center, industrial and
9 populated regions of the Nairobi metropolitan area.

10 The industrial factor shows gradual decrease from the beginning of the sampling period
11 towards the end the period. The seasonal percentage contributions show gradual decline
12 from 14% to 12% to 8% and finally to 0%. Comparing with a similar period at the university
13 site, the observed trend is similar. Therefore, the explanation for this observation is the same
14 as that given for the university site.

15 Lastly, the combustion factor is consistent throughout the sampling period but shows
16 minimal contribution to PM_{2.5} at this site. It does not show any seasonal variability and thus
17 indicates to be dependent on contribution from regional sources. This observation is
18 attributed to the fact that the site is in a suburban area where combustion activities such as
19 solid waste burning, domestic cooking using biomass among others are not common practice
20 since the area is in uptown and has essential services such as waste collection.

21 **3.7. Weekly trend of PMF factors**

22 Figure 15 shows classification of PMF factors by days of the week. Considering individual
23 factors, the mineral dust factor shows the least difference between weekdays and weekends.
24 This observation points to the fact that contribution of dust particles to airborne PM_{2.5} is
25 influenced by both anthropogenic activities and natural phenomena. During the sampling
26 period there was heightened activities in road infrastructure and given the working pattern in
27 Kenya (working on weekdays and resting on weekends), road construction related activities
28 such as quarrying of road materials was limited to weekdays (Kinney et al., 2011).

1 Weekly trend observed for the industrial factor is similar to the weekly working pattern in
2 Kenya as explained previously. A majority of metallurgy industries in Kenya still use the
3 open-hearth furnaces inherited from the colonial periods (early 20th century).

4 The mixed factor was about 50% lower on weekends compared to weekdays and this
5 implied that the factor was greatly influenced by anthropogenic activities compared to
6 natural activities. This observation is supported by the fact that activities related to S
7 emissions (consumption of high sulfur content diesel) reduce to a minimum during
8 weekends.

9 All the five factors have lower concentrations on weekends compared to weekdays. This
10 trend is similar to observed human activities in the city center on a typical week whereby
11 weekdays are usually busy with both human and traffic activities compared to weekends
12 (Kinney et al., 2011). Therefore it can be observed that all factors are impacted by
13 anthropogenic activities.

14 **3.8. Comparison of PM_{2.5} with other studies**

15 Since there were no other long-term studies of PM_{2.5} and their elemental content in urban
16 areas of Sub-Sahara Africa to compare with, PM_{2.5}, elements and BC concentrations from
17 this study were compared with concentrations from a selection of available short-term
18 studies (Table 3).

19 PM_{2.5} concentration at the university site in the month of July 2009 was comparable to the
20 PM_{2.5} concentration reported by Gatari et al. (2009) from a study conducted at an industrial
21 background site in Nairobi during July 2001. However in the month of July 2008, the PM_{2.5}
22 concentration was 30% lower. The agreement between the PM_{2.5} concentrations in July 2001
23 and July 2009 and the difference compared to July 2008 illustrates the influence of drought
24 on PM concentration since there was a severe drought in July 2001 as was the case in 2009.
25 The abundance of PM in the air in July 2001 can be seen in the higher concentrations of
26 many elements in the study by Gatari et al. (2009) compared to the average concentrations at
27 the university site in this study. A clear exception is the concentration of Pb, which was
28 more than three times higher in 2001 compared to this study. This demonstrates the effect of
29 banning Pb from the gasoline in 2006.

1 The African cities listed in Table 3 have similar characteristics to Nairobi and are reported to
2 have their air quality influenced largely by mineral dust, combustion activities and vehicular
3 emissions. $PM_{2.5}$ concentration from this study was half of that reported from measurements
4 in 2006 and 2007 at a semi-rural area of Accra city, Ghana (Aboh et al., 2009). The main
5 difference is probably the influence of the dust filled Harmattan winds blowing from the
6 Saharan desert to Accra. The same can be seen in a comparison between this study and the
7 study in 2007 in Ouagadougou, Burkina Faso (Boman et al., 2009). In another study in
8 Accra the Harmattan wind conditions were not present during the sampling and the $PM_{2.5}$
9 concentration in this study are similar to the $PM_{2.5}$ concentration reported from a 3 week
10 study conducted in 2006 at a low income residential area in Accra city, Ghana (Arku et al.,
11 2008). The proximity to the desert is also reflected in the high $PM_{2.5}$ concentration in a nine
12 month study conducted between September 2010 and May 2011 at Cairo city center (Boman
13 et al., 2013).

14 In comparison with a two weeks' study (not in Table 3) conducted at street level in Nairobi
15 by Kinney et al. (2011), the average $PM_{2.5}$ concentration from the university site was 50%
16 lower. In addition, average $PM_{2.5}$ concentration at the university site was a factor of 15
17 lower than average $PM_{2.5}$ concentration reported from a one week measurement campaign
18 carried out along one of the major roads in Nairobi (Thika Road) by van Vliet and Kinney
19 (2007). Observations from these two comparisons point to the discrepancy between
20 background $PM_{2.5}$ concentrations and those from curb side concentrations in Nairobi city.

21 The elemental composition of $PM_{2.5}$ from the semi-rural area of Accra city had large
22 concentrations of S, K and Fe as was the case with the composition of $PM_{2.5}$ in Nairobi in
23 both this study and the study by Gatari et al. (2009) in 2001 pointing to a similarity in the
24 sources of particles. A noticeable difference between this study and the ones by Gatari et al.
25 (2009), Aboh et al. (2009) and Arku et al. (2008) is the higher concentration of Fe in the
26 $PM_{2.5}$ particles at the university site in this study. This might partly be due to a difference
27 between mineral dust compositions in the two cities but differences in measurement periods
28 also play a role. The elemental concentrations at the low income area in Accra (Arku et al.,
29 2008) are comparable to the concentrations at the UNEP site in this study, illustrating the
30 importance of the distance between the measurement site and major pollution sources, like
31 city center and busy roads.

1 In comparison to Cairo city, the elemental concentrations from this study were about 3 times
2 lower than the concentrations reported from the nine month study conducted between
3 September 2010 and May 2011 at a city center site (Boman et al., 2013). $PM_{2.5}$ in Cairo city
4 had a large contribution from Ca, Cl and S. Since the city is within the Sahara region, its air
5 quality is likely to be influenced by a mineral dust contribution from the desert. The higher
6 concentrations of S and Cl in Cairo might be due to its location close to the Mediterranean
7 Sea. The Pb concentration in Cairo is comparable to the Pb concentration in Nairobi in 2001,
8 and thus higher than in this study. Egypt is one of the few countries in Africa where leaded
9 gasoline is still allowed and the comparison points to the importance of banning leaded
10 gasoline to decrease the health burden of the city inhabitants.

11 **4. Conclusions**

12 This study has shown that traffic related emissions (both exhaust and non-exhaust) and
13 mineral dust (both natural and anthropogenic) have significant contribution to $PM_{2.5}$ in
14 Nairobi city. It can also be concluded that policies such as banning of Pb in gasoline have
15 shown positive effect on reducing Pb concentration in $PM_{2.5}$ and hence reducing the risk of
16 Pb toxicity to the urban inhabitants. Similarly a reduction of sulfur from the diesel fuel could
17 lead to an improved air quality situation in Nairobi. More so, prevailing weather and climate
18 patterns have been found to play a significant role by influencing the concentration and
19 composition of airborne PM as is the case in other cities in SSA. As shown from wind
20 direction and air mass back trajectories analysis, industrial emissions should be firmly
21 controlled, as the industrial area in Nairobi is located in the upwind direction. Since this
22 study points at factors contributing to the air quality situation in Nairobi the outcome of this
23 study can be used as a background for further policy actions. Contribution of $PM_{2.5}$ from
24 traffic factor can be controlled by inclusion of emission checks as part of annual vehicle
25 inspection and this would significantly reduce air pollution in the city. On the other hand,
26 natural background concentrations of mineral dust as well as prevailing weather conditions
27 would give guidance when formulating any policy aimed at air pollution mitigation. In
28 conclusion, the study has shown that enactment and adherence to air pollution regulations on
29 identified source factors can significantly reduce air pollution levels in cities within SSA.

30

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7

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Table 1. Summary of the results from all filter samples for the collection period 22 May 2008 to 30 March 2010 at two sites in Nairobi, Kenya which include: detection limits, range, mean concentrations (ng m^{-3}), standard deviations (SD) and percentage composition ($\% \text{PM}_{2.5}$) for detected trace elements, BC and $\text{PM}_{2.5}$. N is the number of valid samples.

Elements	Detection limit (ng m^{-3})	Mean (ng m^{-3})	SD (ng m^{-3})	$\% \text{PM}_{2.5}$	Range (ng m^{-3})	N
S	250	640	340	3.6	250-3800	459
Cl	110	480	200	2.7	110-1800	723
K	50	310	150	1.7	51-840	719
Ca	30	310	250	1.7	30-2700	713
Ti	14	54	25	0.3	14-180	570
Mn	9.5	41	23	0.2	10-190	722
Fe	10	530	350	2.9	11-1800	780
Ni	0.8	4	2	0.0	1-17	478
Cu	0.7	11	6	0.1	2-82	773
Zn	6.6	91	100	0.5	7-760	780
Br	2.5	12	21	0.1	3-340	667
Rb	0.5	2	1	0.0	1-5	383
Pb	1.5	22	18	0.1	2-160	525
BC	6	2700	1800	15	74-9900	767
$\text{PM}_{2.5}$	1000	18000	8600		1900-53000	780

Table 2. Summary of the results from the University and the UNEP site for the time period from 16 April 2009 to 30 Mar 2010: range, mean concentrations and standard deviations (SD) for detected trace elements, BC (in ng m^{-3}) and $\text{PM}_{2.5}$ (in $\mu\text{g m}^{-3}$). N is the number of valid samples.

Elements	University			UNEP		
	Range (ng m^{-3})	Mean (SD) (ng m^{-3})	N	Range (ng m^{-3})	Mean (ng m^{-3})	N
S	250 – 1600	660 (240)	132	250 – 1700	620 (280)	184
Cl	110 – 1300	520 (200)	253	110 – 1600	430 (170)	259
K	60 – 840	340 (160)	265	50 – 760	270 (160)	239
Ca	40 – 2700	340 (270)	268	30 – 1300	200 (150)	228
Ti	21 – 180	62 (27)	241	14 – 110	40 (18)	156
Mn	11 – 120	53 (23)	267	10 – 90	28 (14)	236
Fe	33 – 1700	730 (340)	270	11 – 1200	320 (240)	278
Ni	2 – 10	4 (1)	153	1 – 17	4 (2)	191
Cu	2 – 80	12 (7)	269	2 – 55	9 (4)	275
Zn	9 – 760	120 (120)	270	7 – 640	76 (97)	272
Br	3 – 340	16 (30)	240	3 – 70	7 (5)	215
Rb	1 – 5	3 (1)	160	1 – 5	2 (1)	123
Pb	2 – 80	23 (16)	202	2 – 79	17 (14)	186
BC	40 – 9500	3900 (800)	270	70 – 5700	1500 (1000)	267
$\text{PM}_{2.5}$ ($\mu\text{g m}^{-3}$)	3 - 53	21 (9.5)	270	1.9 - 36	13 (7.3)	278

Table 3. PM_{2.5}, BC, and trace element concentrations from this study (Nairobi) compared with concentration from other cities in Africa. Concentrations are in ng m⁻³. Values enclosed in brackets are the standard deviations.

Site/ Elements	This study		Gatari et al. (2009)	Aboh et al. (2009)	Boman et al. (2009)	Arku et al. (2008)	Boman et al. (2013)
	University (urban background)	UNEP (suburban)	Industrial background, Nairobi	Semi-rural area, Accra	City center, Ouagadougou	Low income area, Accra	Urban center, Cairo
S	660 (240)	620 (280)	1300 (400)	462 (290)	- -	909 (267)	1200 (870)
Cl	520 (200)	430 (170)	- -	123 (133)	960 (290)	706 (423)	2200 (2200)
K	340 (160)	270 (160)	730 (220)	377 (325)	670 (210)	694 (188)	470 (260)
Ca	370 (270)	200 (150)	70 (34)	144 (322)	1400 (570)	57 (22)	2900 (3200)
Ti	62 (27)	40 (18)	8.7 (4.4)	37.5 (64.8)	240 (81)	6 (3)	100 (89)
Mn	53 (23)	28 (14)	12 (3.9)	7.6 (11.4)	61 (25)	6 (2)	24 (20)
Fe	730 (340)	320 (240)	130 (43)	289 (504)	3000 (1400)	69 (27)	1000 (1000)
Ni	4 (1)	4 (2)	2.6 (1.1)	3.2 (2.8)	- -	- -	6.8 (1.7)
Cu	12 (7)	9 (4)	3.5 (2.2)	4.1 (3.9)	19 (6.4)	9 (15)	16 (9.8)
Zn	120 (120)	76 (97)	100 (69)	6.5 (5.7)	45 (35)	32 (13)	200 (180)
Br	16 (30)	7 (5)	36 (18)	5.9 (3.5)	7.3 (2.7)	30 (16)	21 (15)
Rb	3 (1)	2 (1)	1.56 (0.5)	1.4 (1.4)	4.2 (1.9)	2 (1)	4.4 -
Pb	23 (16)	17 (1)	76 (30)	2.5 (1.7)	8.8 (4.2)	18 (25)	86 (180)
BC	3900 (800)	1500 (1000)	4800 (1800)	1900 (1100)	4900 (1700)	- -	3700 (2100)
PM _{2.5}	21000 (950)	13000 (7300)	30000 (9400)	40800 (54400)	86000 (42000)	22700 (5700)	51000 (39000)

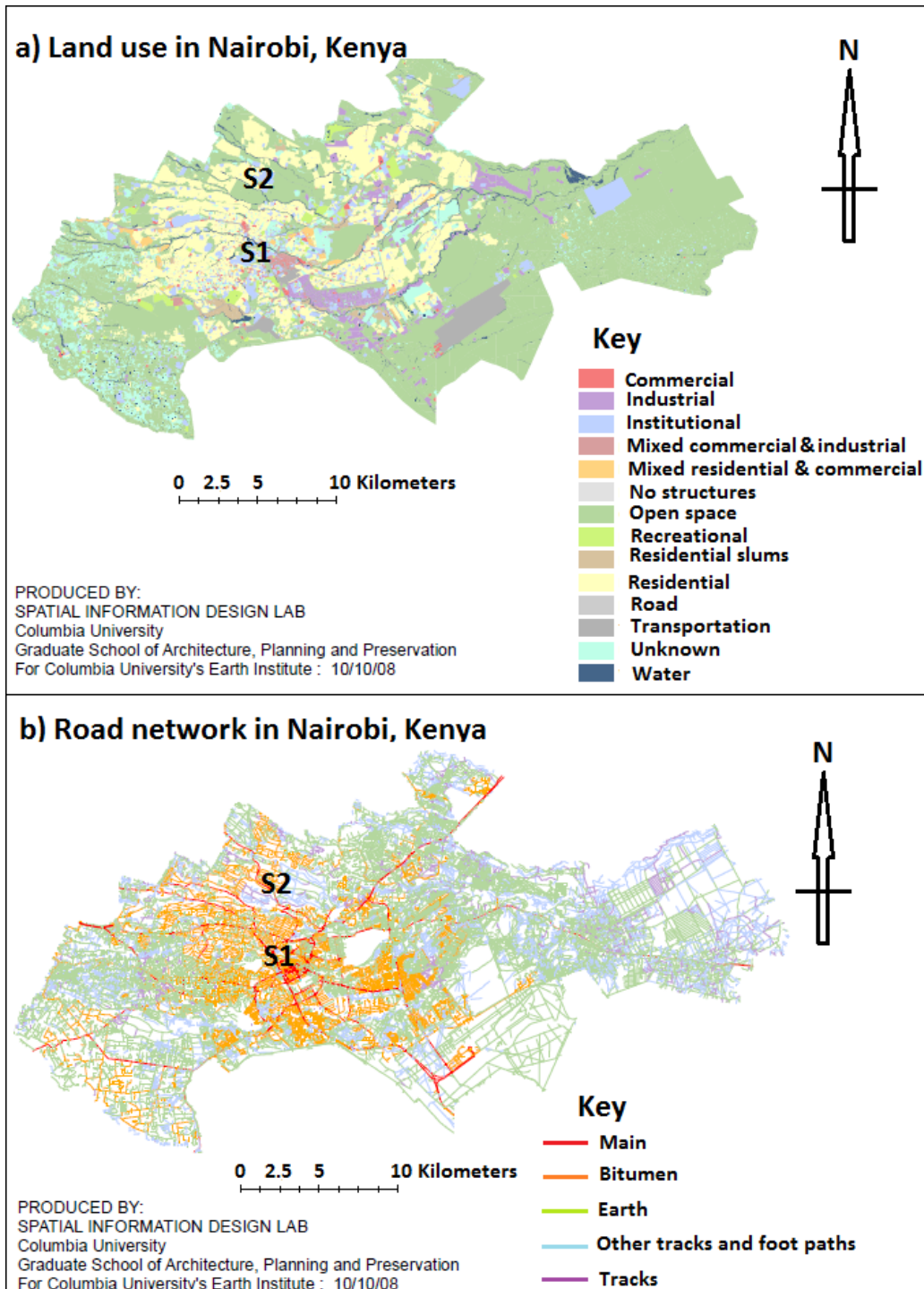


Fig. 1. GIS map of the Nairobi metropolitan area showing land use pattern (a) and transportation network (b). Original maps were modified to include sampling sites as shown on both maps; University of Nairobi (S1) and United Nations Environmental Programme (UNEP) headquarters (S2). (Original maps reproduced from Center for Sustainable Urban Development's Nairobi GIS maps and database website (CSUD, 2010).

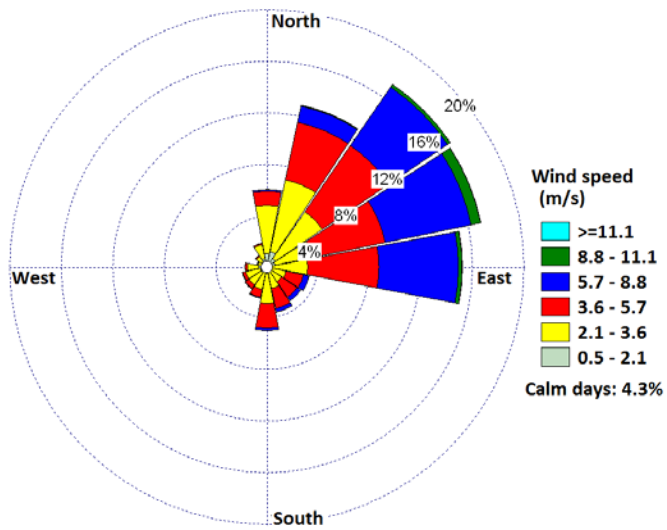


Fig. 2. Wind speed and direction during the sampling period i.e. from 22 May 2008 to 30 March 2010. The wind data was measured at Jomo Kenyatta International Airport (JKIA), Nairobi, which was approximately 12 km south-east of the city center.

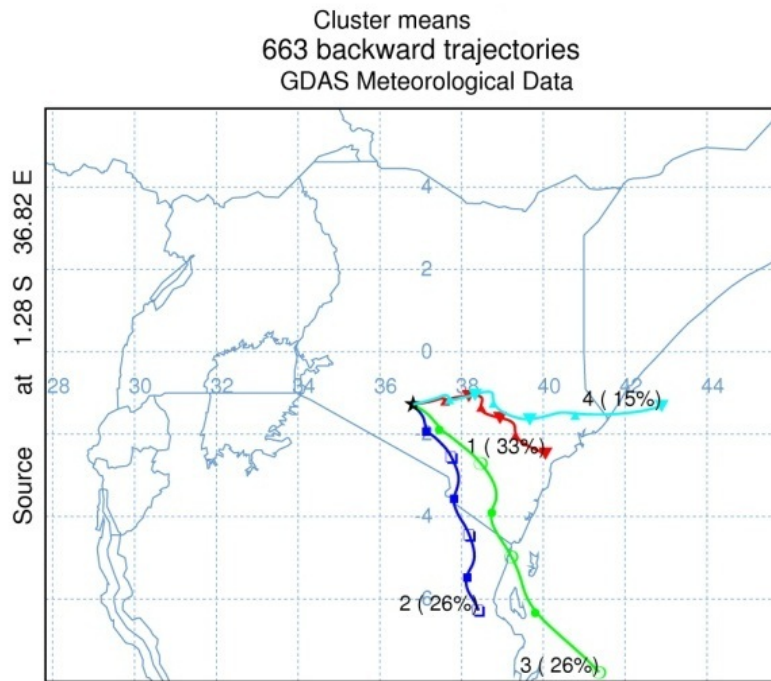


Fig. 3. Clustered 72 h back trajectories ending in Nairobi at 100 m height above the ground for the period, 22 May 2008 to 30 March 2010. Calculated back trajectories originate principally from south-east (trajectories 2 and 3) and east (trajectories 1 and 4).

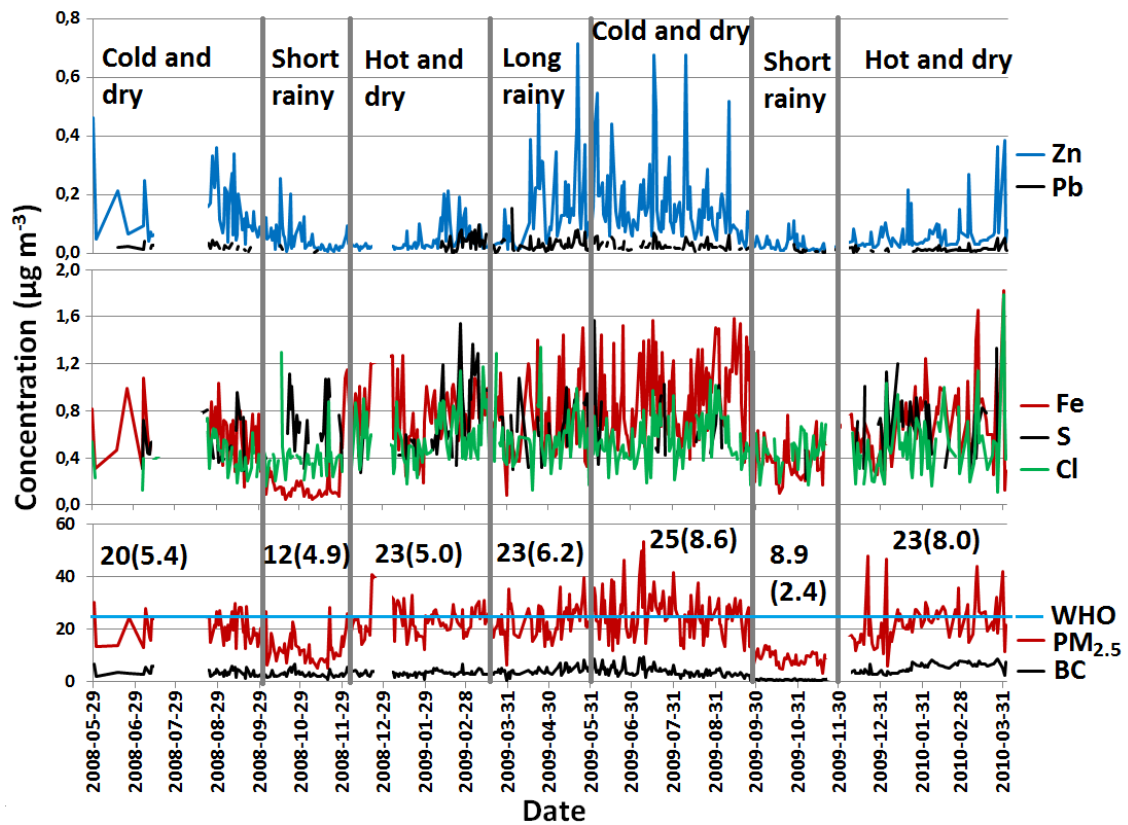


Fig. 4. Seasonal variation of $\text{PM}_{2.5}$ and some elements sampled at the university site. Included in the figure are the seasonal averages and standard deviations (enclosed in brackets) as well as the World Health Organization air quality guideline for a 24 h period.

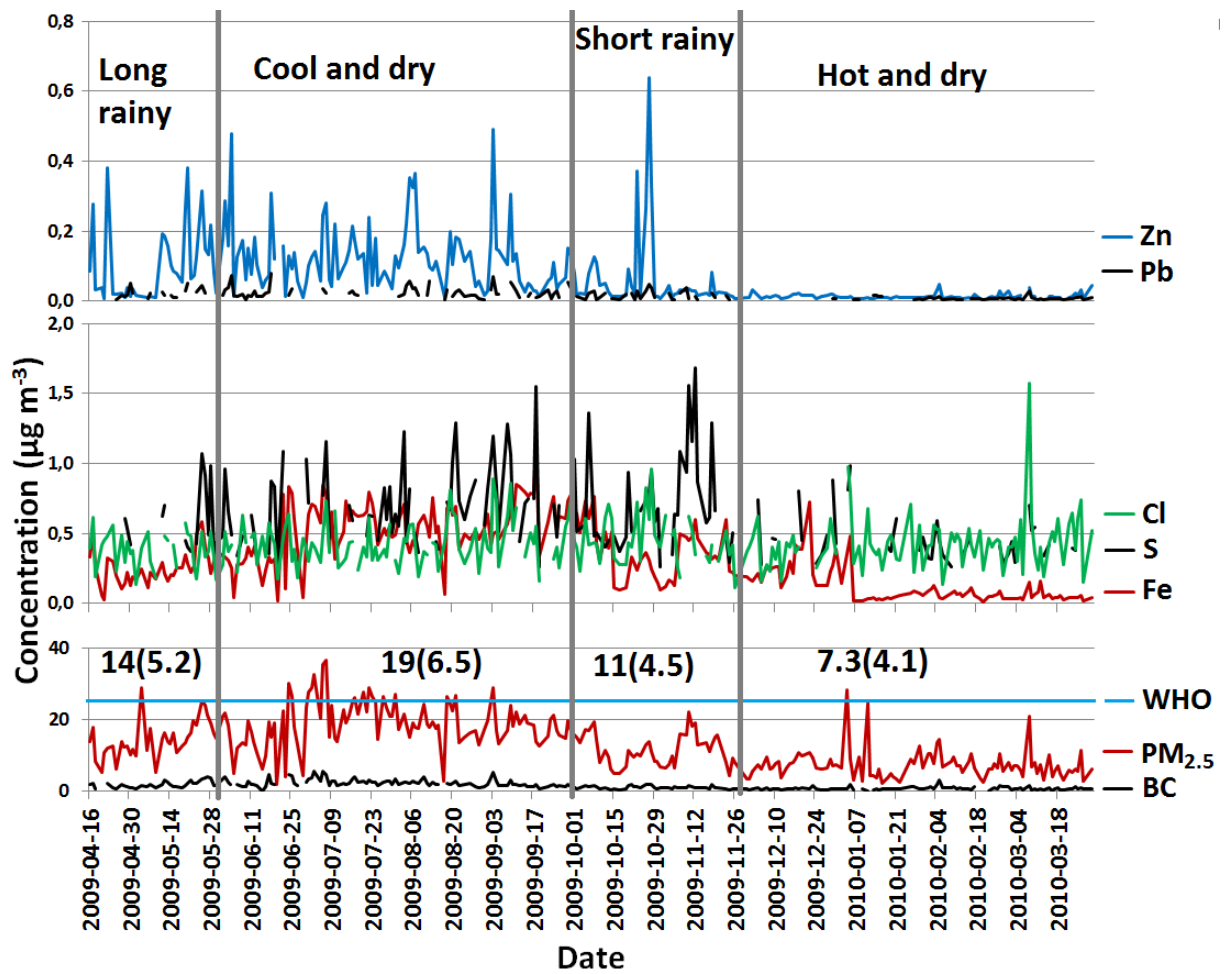


Fig. 5. Seasonal variation of PM_{2.5} and some elements sampled at the UNEP site. Included in the figure are the seasonal averages and standard deviations (enclosed in brackets) as well as the World Health Organization air quality guideline for a 24 h period.

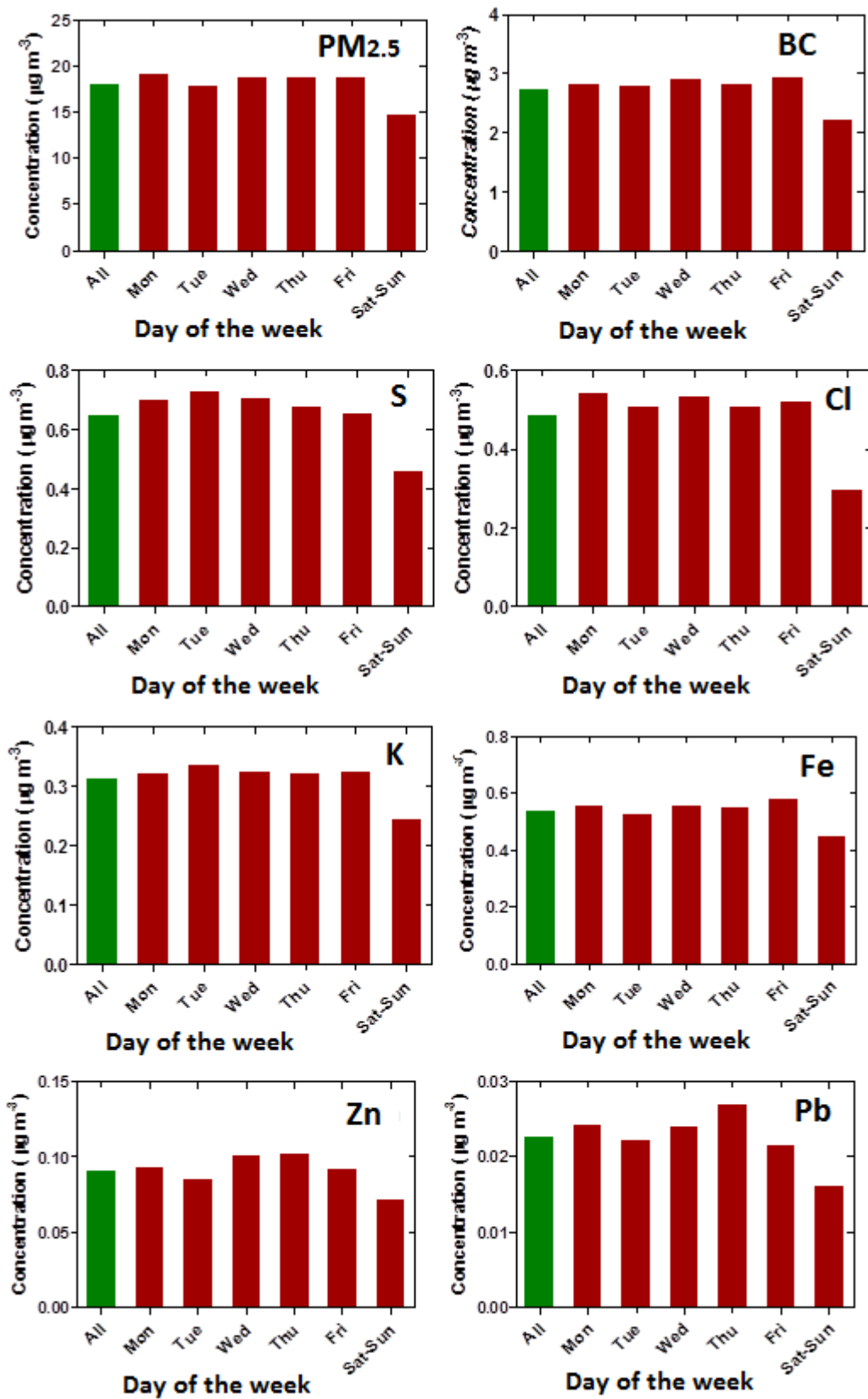


Fig. 6. Weekly variation of PM_{2.5} and some selected elements showing the trend based on calculated averages from respective days of the week.

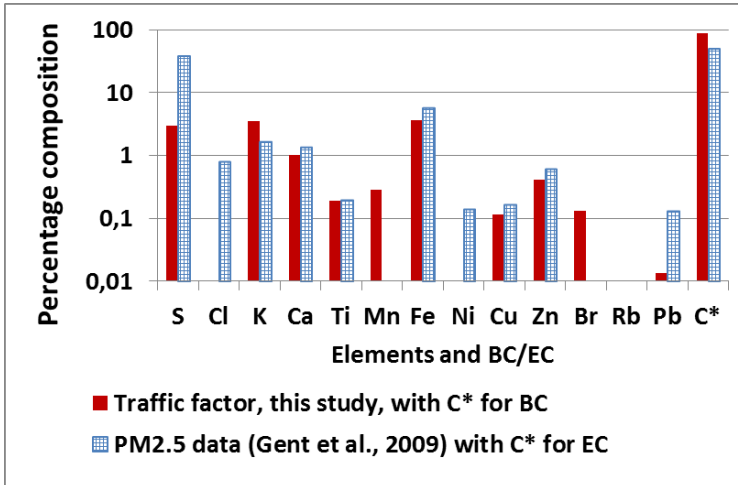


Fig. 7. Traffic factor from PMF analysis of PM_{2.5} from this study compared with PM_{2.5} from a traffic polluted site in Connecticut, USA (Gent et al., 2009).

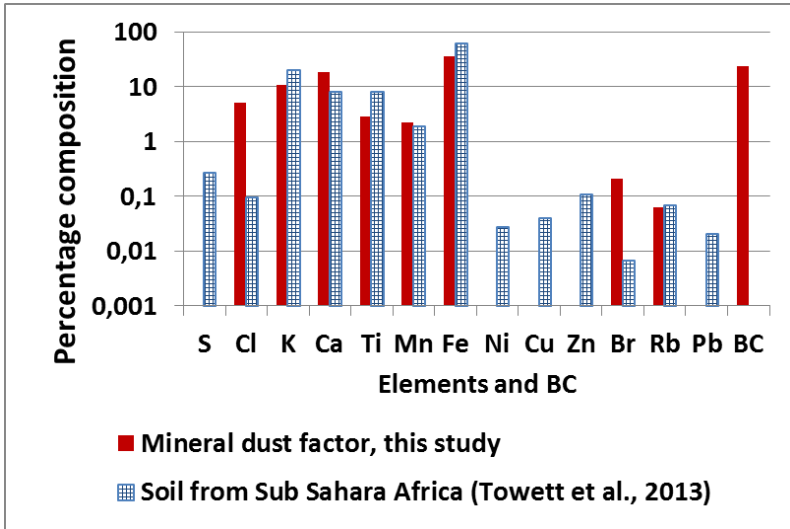


Fig. 8. Mineral dust factor from the PMF analysis of PM_{2.5} from this study compared with elements from soil samples from SSA countries (Towett et al., 2013).

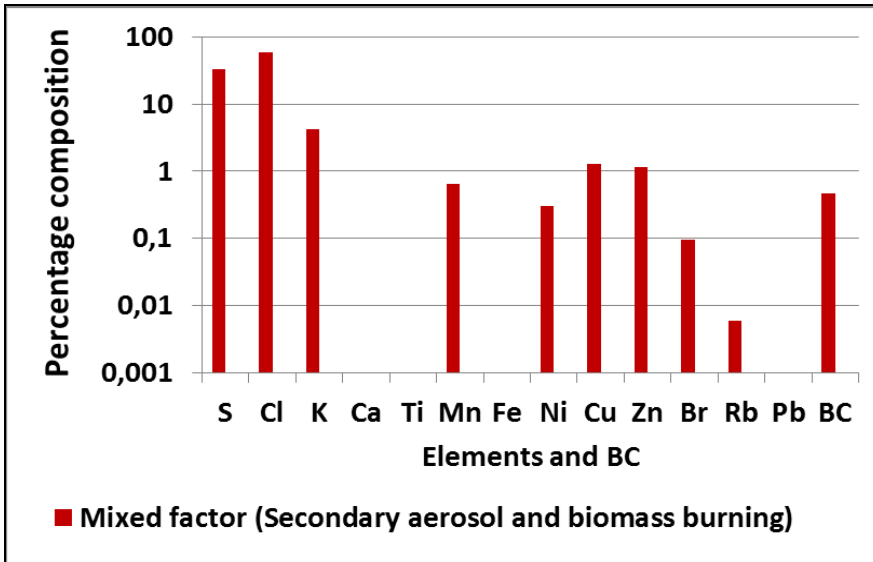


Fig. 9. Mixed factor (secondary aerosol and biomass burning) from the analysis of sampled PM_{2.5} marked by high concentration of S and Cl as well as substantial concentration of K.

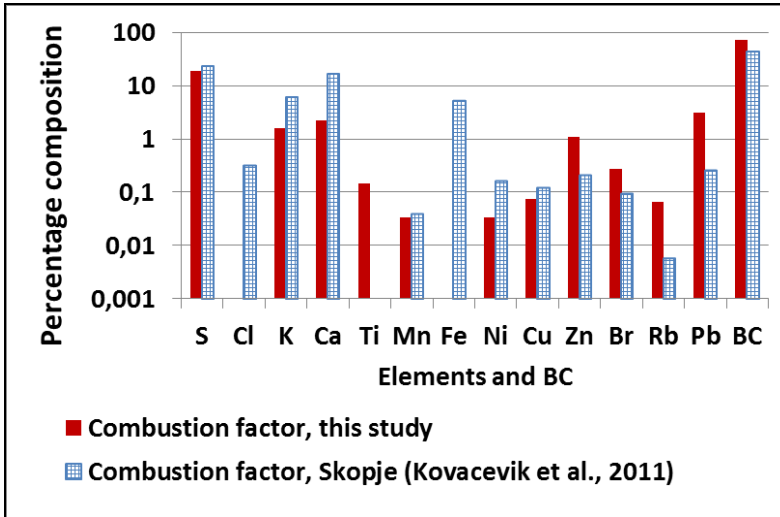


Fig. 10. Combustion factor from the PMF analysis of PM_{2.5} from this study compared with combustion factor from Skopje, Macedonia (Kovacevik et al., 2011).

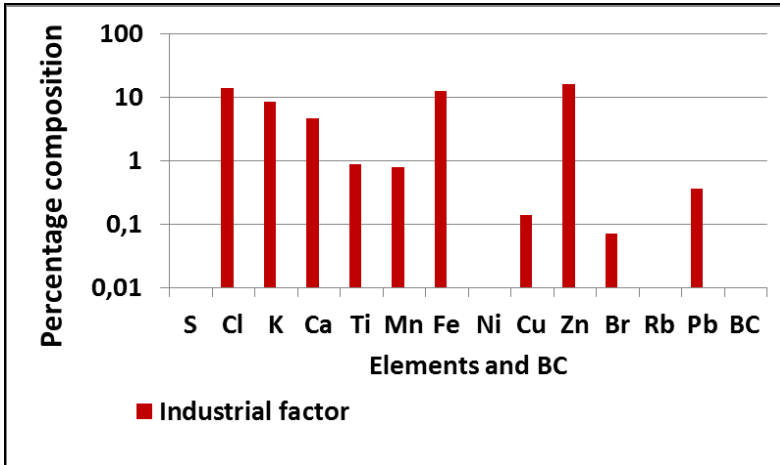


Fig. 11. Industrial factor from analysis of sampled PM_{2.5} showing the contribution of metallurgy industries (Fe and Zn) to aerosol in Nairobi.

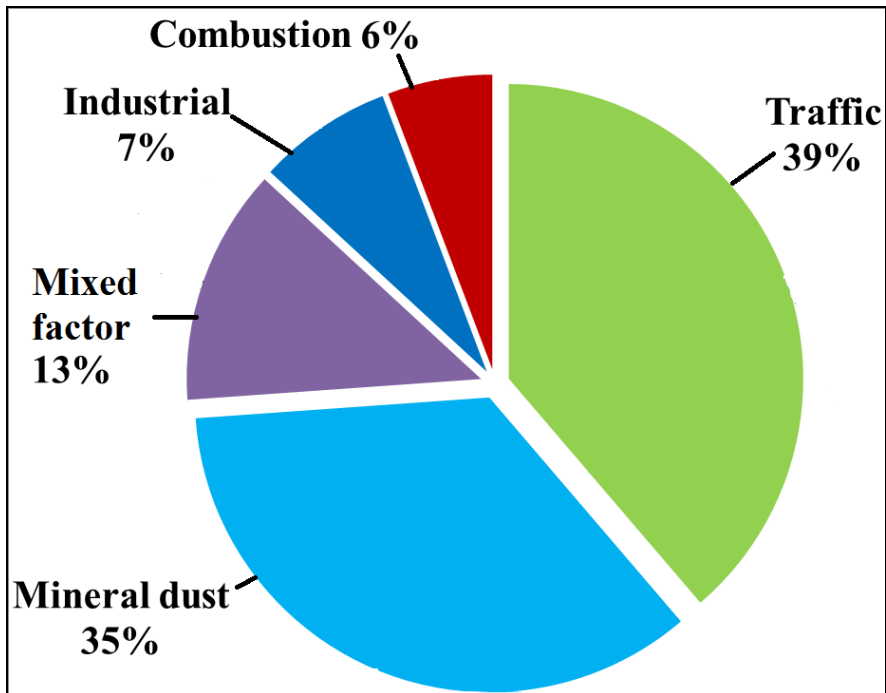


Fig. 12. Percentage composition of source factors from PMF analysis to PM_{2.5} collected in Nairobi, Kenya. Traffic and mineral dust factors have major contribution to airborne particulate pollutants.

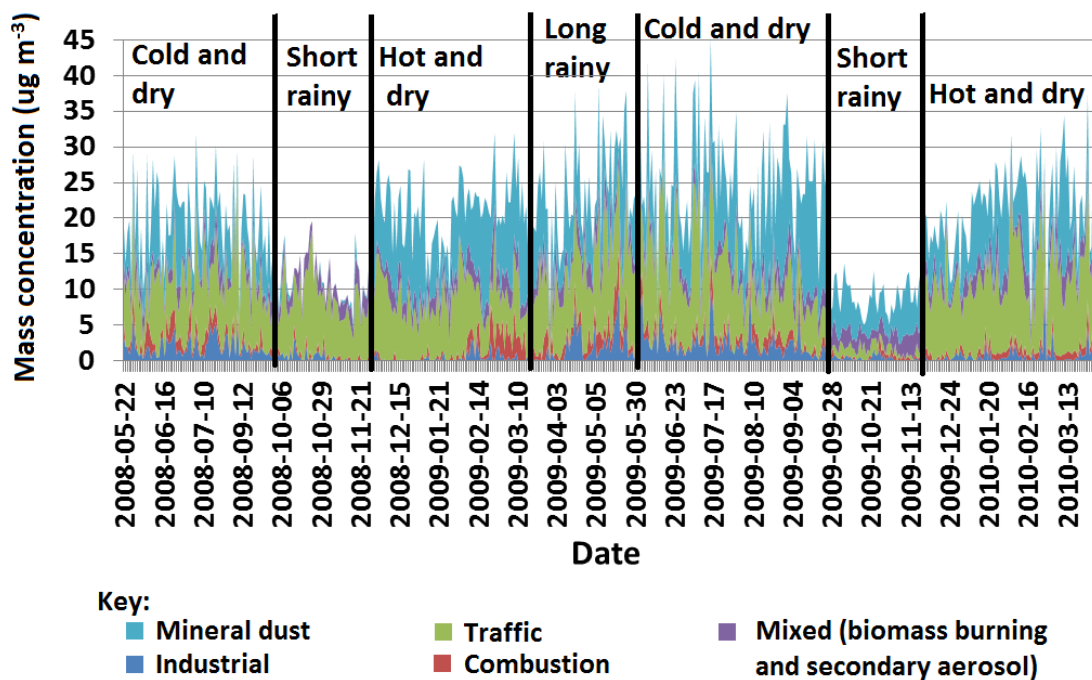


Fig. 13. Seasonal variation of the five factors obtained from the PMF analysis of the $\text{PM}_{2.5}$ composition at the university site. Traffic factor shows consistency throughout the sampling period highlighting the significance of vehicular emissions to urban air pollution. Seasons have been demarcated for clarity.

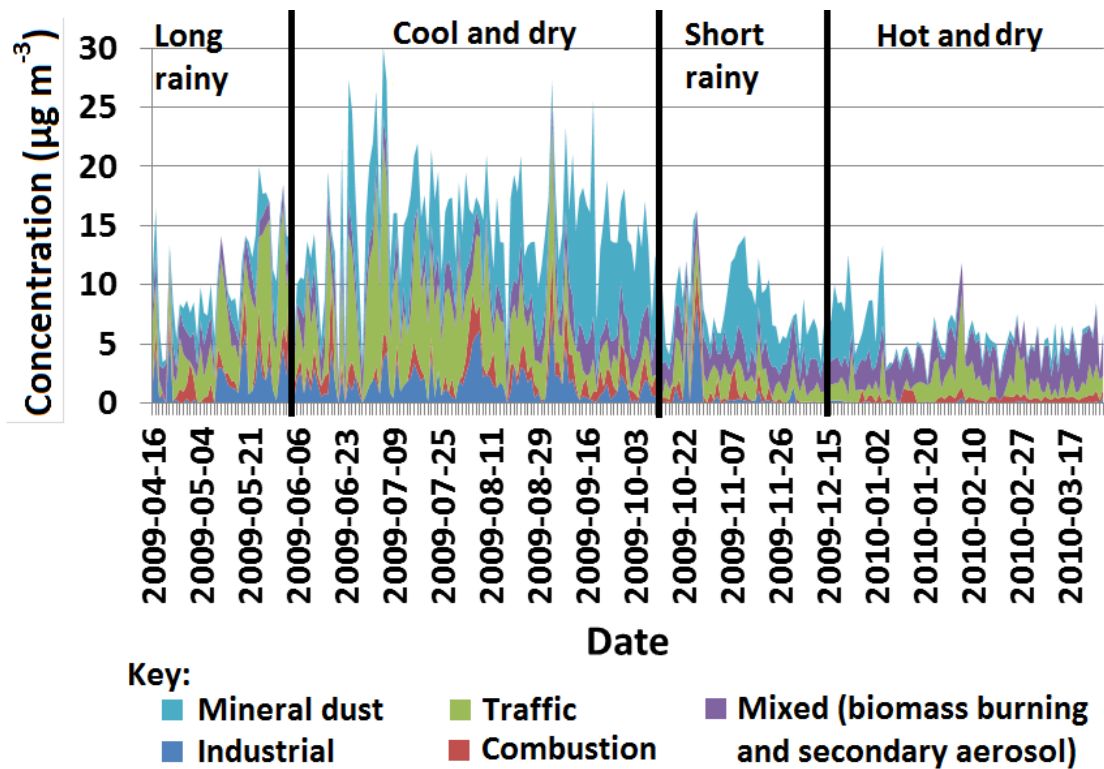


Fig. 14. Seasonal variation of the five factors obtained from the PMF analysis of the $\text{PM}_{2.5}$ composition at the UNEP site. The mixed factor constitute of contribution from biomass burning and secondary aerosol. The effect of erratic weather pattern is evident from the dampened contribution of mineral dust factor in 2010. Seasons have been demarcated for clarity.

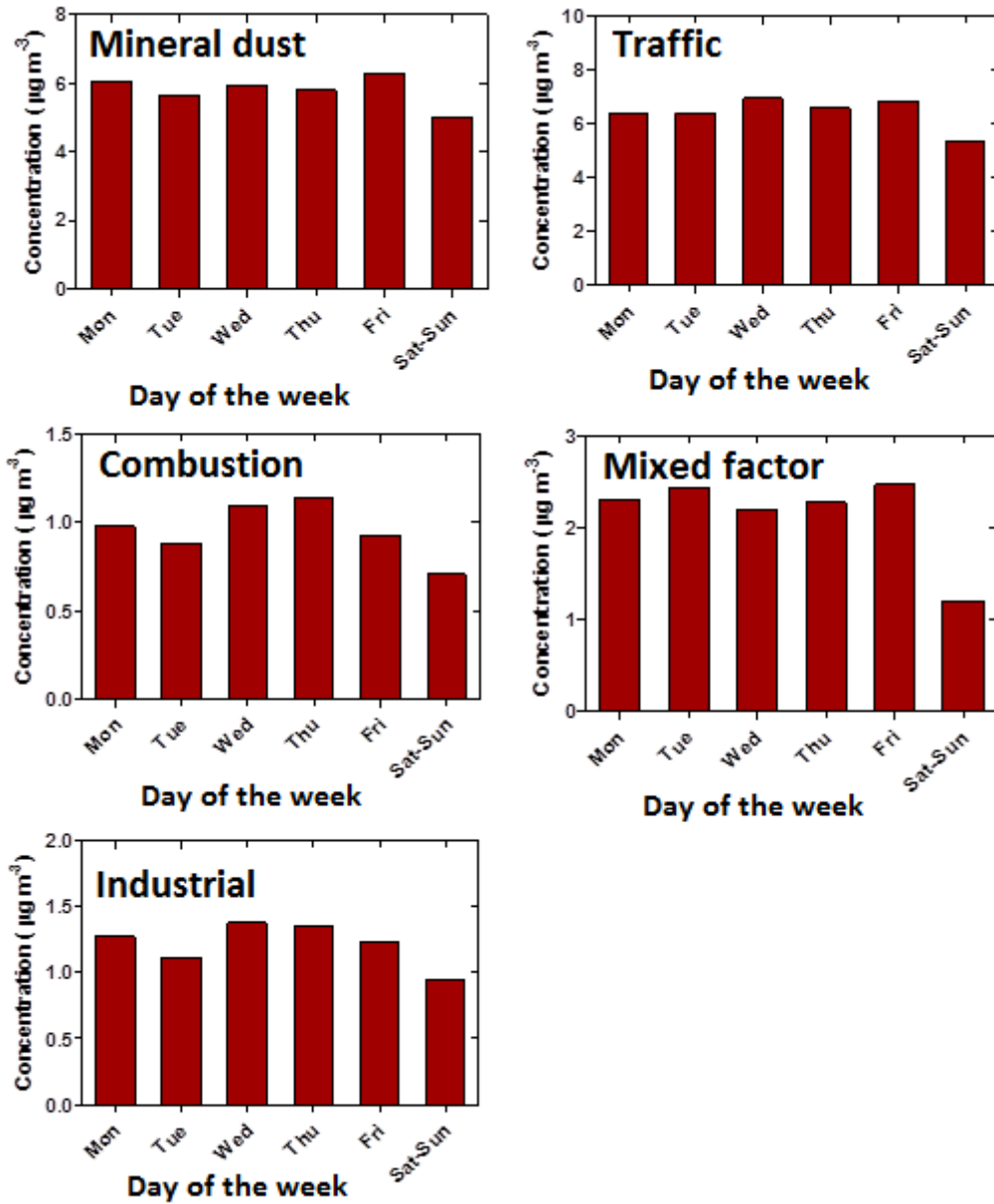


Fig. 15. Weekly series of the five factors obtained from the PMF analysis of sampled PM_{2.5}. The difference between weekdays and weekends highlights the anthropogenic contribution to air pollution in Nairobi. The mixed factor is attributed to contribution from biomass burning and secondary aerosol.