



## Characterization of fine particulate sources at Ashaiman in Greater Accra, Ghana

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### ABSTRACT

The sources of airborne fine particles in PM<sub>2.5</sub> range influencing air quality at Ashaiman, a semi-urban town north of Tema in Ghana had been investigated. Nuclepore and quartz fiber filters were used for the air particulate loadings and analyzed for elemental and carbonaceous compound (EC and OC) concentrations in the 8 carbon fractions using X-Ray spectrometry system and IMPROVE/Thermal Optical Reflectance method respectively. Positive matrix factorization (PMF) was utilized to identify the following eight sources; industrial emissions (11.4%), fresh sea salt (15.5%), diesel emissions (18.4%), biomass burning (9.5%), two stroke engines (5.1%), gasoline emissions (15.8%), aged sea salt (6.2%), and soil dust (17.7%). Source locations were verified by means of Conditional Probability Function (CPF) plots that utilize wind directions. The source contributions revealed the high influence of fossil fuel and biomass combustion on the air quality in Ashaiman. The presence of the harbor and the industries located at Tema were seen to have substantial impacts on respirable air particulate matter (APM) concentrations in Ashaiman.

### Keywords:

Fine particulate matter  
Positive matrix factorization (PMF)  
Conditional probability function (CPF)  
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### 1. Introduction

The positive links existing between airborne particulate matter concentrations and a wide range of adverse health effects have been of growing concern in recent years. Both long and short-term exposures influence population health issues and hence the need for more concerted effort to improve on air quality (WHO, 2000). Emissions from a variety of sources have resulted in atmospheric pollution that, in turn, has produced serious problems, such as visibility degradation and acidic deposition on local and regional scales and climate change on a global scale (Chan et al., 1999; Cheung et al., 2005; Sanderson et al., 2006). Because particulate matter (PM) has adverse effects on human health and welfare (Harrison and Yin, 2000; Calcabrini et al., 2004), many countries are developing and implementing environmental policies to control PM by establishing ambient air quality standards. Urban climate and air pollution are very well connected in several ways (Chimidza and Moloi, 2000) since climate parameters such as stability, wind direction, and wind speed govern the dispersion of air pollutants. In areas of rapid urbanization, such as in Asia and Africa, understanding of the interaction between these two can be a valuable tool to urban planners to mitigate the potential negative effects. Fine particle atmospheric pollution is thus of interest to environmental scientists.

To manage ambient air quality and establish effective emissions reduction strategies, it is necessary to identify sources and to apportion the ambient PM mass. To do so, receptor models

have been developed that analyze various measured properties of the pollutants at the receptor site, identify the possible sources, and estimate their contributions. Many studies have applied these methods to assess the contribution of sources to enable reasonable ambient aerosol control (Chow et al., 1992; Zelenka et al., 1994; Vega et al., 1997; Castanho and Artaxo, 2001; Ramadan et al., 2003). Among the multivariate receptor models used for PM source identification and apportionment is the positive matrix factorization (PMF) which has been developed (Paatero, 1997) to provide an explicit least-squares technique. PMF has been proven to be a powerful and very reliable technique relative to the traditional multivariate receptor models. It has successfully been used to assess ambient particulate matter source contributions in several locations globally. (e.g., Lee et al., 2002; Maykut et al., 2003; Begum et al., 2004; Kim et al., 2004; Zhou et al., 2004).

The objective of this study was to estimate the chemical (elemental and carbonaceous) composition of sources of fine particulate matter (PM<sub>2.5</sub>) and their mass contributions at Ashaiman considering the airborne industrial particulate emissions from Tema and biomass burning within the vicinity. PMF was applied to identify the sources and apportion the PM<sub>2.5</sub> particulate mass to each source. In addition, the conditional probability function (CPF) was applied to identify the predominant directions of local sources relative to surface wind directions.

## 2. Methods

### 2.1. Sampling

PM<sub>2.5</sub> were sampled on the Ashaiman Senior High School campus within Ashaiman Township. The Ashaiman Township, classified as semi-urban area is located at about 8 kilometers to the north of the Tema commercial center and about 30 kilometers from central Accra (Figure 1). It is on the north eastern part of Tema industrial area and about 10 km from the Tema harbor. The geographical location of the sampling site is on Latitude 5° 41' 42", Longitude 0° 01' 07", and an altitude of 60 m above sea level (Figure 1). The town has a population of about 220 000 and identified as the area with the highest population growth rate in Ghana of about 4.6%. The major anthropogenic sources of particulate pollution in Ashaiman are fuel wood combustion, biomass burning from bushfire and open refuse dumps (open burning), fossil fuel combustion from motor vehicle exhaust, dust from construction and re-suspension and particulate emissions from the Tema industrial area. Natural sources include sea spray, windblown dust, and Harmattan dust. These sources produce both fine particles (PM<sub>2.5</sub>, i.e. particulate matter of aerodynamic diameter less than 2.5 μm) and coarse particles (PM<sub>10-2.5</sub>, i.e.

particulate matter of aerodynamic diameter between 2.5 μm and 10 μm).

The sampling equipment was placed about 2.0 m above the ground level. The sampling was conducted using a Gent Stacked Filter Unit (SFU) system that collects two size (course and fine) fractions (Hopke et al., 1997; Begum, et al., 2011). The sampler operates at a flow rate of 16–17 L/min. Two samplers were co-located with about 1.5 m separation from each other. The fine particulate samples were collected on nuclepore polycarbonate and quartz fiber filters. The quartz fiber filters were pre-fired for at least 3 hours to remove background carbonaceous compounds before the sampling (Chow et al., 1993; Yang et al., 2005). The sampling duration was 24 hours on every other day from February 2008 to August 2008. However, the sampling period was changed to 16 hours or 12 hours distributed uniformly over the 24 hour period depending on prevailing ambient particulate levels. These shortened sampling periods were necessary because during the Harmattan period, ambient particulate matter concentrations gets sufficiently high that sampling continuously for 24 hours will overload the filters and reduce the flow rate below 15 L/min. Sampling with intermittent breaks was carried out from the month of February to the middle of March (Harmattan period).

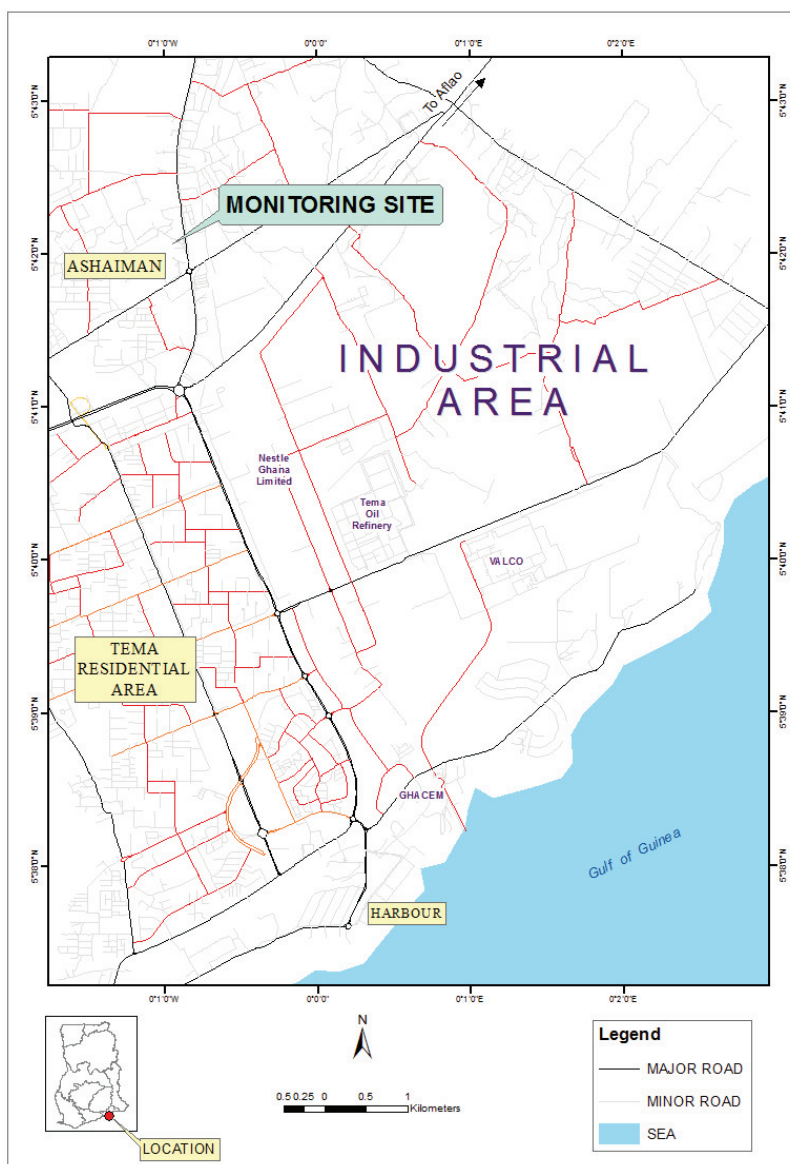


Figure 1. Map showing the monitoring site at Ashaiman and the locations of major source areas.

## 2.2. Analysis

The sample filters were conditioned in desiccators for at least 24 hours and each weighed before and after sampling to obtain the net weight (mass) of the collected sample. Filters (including field blanks) were weighed at least thrice using a Sartorius microbalance. The measured mass concentrations expressed in  $\mu\text{g}/\text{m}^3$  were obtained using the following equation;

$$C = \frac{M_i - M_u}{F \times t} \quad (1)$$

where  $C$  is the concentration ( $\mu\text{g}/\text{m}^3$ ),  $M_i$  is the loaded filter mass ( $\mu\text{g}$ ),  $M_u$  is the unloaded filter mass ( $\mu\text{g}$ ),  $F$  is the volumetric flow rate ( $\text{m}^3/\text{h}$ ), and  $t$  is the sampling time (h).

The nuclepore polycarbonate filters were used for the elemental analysis by employing energy-dispersive X-ray fluorescence (EDXRF) technique at the Air Resources Center at Clarkson University USA. The samples were analyzed using the Spectro X-Lab 20000 EDXRF system. The tube has a maximum operating power output of 400 W with a Rhodium (Rh) target and a palladium (Pd) end window tube. A 25 mm<sup>2</sup> Si (Li) detector with a beryllium window thickness of 8  $\mu\text{m}$  and X-Ray energy resolution of less than 150 eV measured at the Mn K $\alpha$  line with a high entry count rate (~40 000 cps) was used for the detection of the characteristic X-Ray photons from target sample materials (filters). The primary fluorescence X-ray energies were chosen depending on the analyte element of interest. The following were chosen for the excitation energies; Mo-Compton/secondary target, Al<sub>2</sub>O<sub>3</sub>-Polarization target, Highly Oriented Pyrolytic Graphite (HOPG)-crystal, Co-secondary target, Ti-Secondary target and Al-Secondary Target. The data analysis for elemental concentrations was carried out using the fundamental parameters approach. The following were the elements identified; Na, Mg, Al, Si, P, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Mo, Ag, Cd, Sn, Sb, Te, I, Cs, Ba, La, Ce, Sm, W, Hg, Pb.

The quartz filters were used for the analysis of the carbonaceous compounds [i.e. organic carbon (OC) and elemental carbon (EC)] using the Interagency Monitoring of PROtected Visual Environments/Thermal Optical Reflectance (IMPROVE/TOR) method for eight carbon fractions (Chow et al., 1993; Chow et al., 2004; Chow et al., 2008). Organic carbon (OC) fractions were volatilized by four temperature steps (OC1 at 120 °C, OC2 at 250 °C, OC3 at 450 °C, and OC4 at 550 °C) in a helium environment. Pyrolyzed OC (OP) was oxidized at 550 °C in a mixture of 2% oxygen and 98% helium environment until the original intensity of the reflectance is attained. This is followed by elemental carbon (EC) fractions measured in the oxidizing environment (EC1 at 550 °C, EC2 at 700 °C, and EC3 at 850 °C). OP was subtracted from EC1 and utilized as an independent variable in this study since the reported EC1 concentrations in IMPROVE/TOR method include OP concentrations. Thus, EC1 in this study did not include OP.

## 2.3. Source apportionment

Positive Matrix Factorization (PMF) (Paatero et al., 1997) has been widely applied to particulate matter composition data to provide source apportionments (Hopke, 2010). PMF was implemented using the EPA PMF version 3 in this work. PMF depends on error estimates for each measured data value, and the approach of Polissar et al. (1998) was used for estimating the concentration values and their associated error estimates including below detection limit values and missing data. The concentrations below the method detection limit (MDL) values were replaced by half of the MDL values, and their uncertainties were set at five-sixths of the MDL values (Kim et al., 2005). Missing concentrations were replaced by the geometric mean of the concentrations, and their accompanying uncertainties were set at four times the

geometric mean concentration. In this study, a third of the MDL was added to the analytical uncertainty for each value above the MDL (Polissar et al., 1998). Uncertainties in the OC and EC data were calculated by error propagation in the volume of air sampled and the variations in the replicate analyses of collected samples.

For the selection of the input variables, the signal-to-noise (S/N) ratios were calculated (Paatero and Hopke, 2003). Variables were defined to be good, weak, or bad depending on S/N ratio values. Species with S/N ratios less than 0.2 were considered bad and therefore rejected. Species that have signal/noise (S/N) ratios (Table 1) between 0.2 and 2 were considered weak variables and their estimated uncertainties were increased by a factor of 2 or 3 to reduce their weight in the solution as recommended by Paatero and Hopke (2003). Although species with S/N above 2 could be considered as good, the percentage of data above detection limit was used as a complimentary criterion for the choice of strong variables since S/N is very sensitive to sporadic values much higher than the level of noise (Amato et al., 2009). The species identified as bad and rejected based on their S/N values were EC3, Sc, Ge, Ag, Te, Cs, La, Ce, Sm, Bi, and I. The identified weak variables, OC1, EC2, Co, Se and Rb were down-weighted by a factor of 3.

## 2.4. Conditional Probability Function Analysis (CPF)

To analyze the impact of local source from various wind directions, the CPF values were calculated using source contribution estimates from PMF coupled with the wind direction values measured at the site (Kim and Hopke, 2004). The sources are likely to be located in the directions that have high conditional probability values. The CPF estimates the probability that a given source contribution from a given wind direction will exceed a predetermined criterion.

CPF is defined as:

$$\text{CPF} = \frac{m_{\Delta\theta}}{n_{\Delta\theta}} \quad (2)$$

where  $m_{\Delta\theta}$  is the number of occurrence from wind sector  $\Delta\theta$  that exceeded the criterion, and  $n_{\Delta\theta}$  is the total number of data from the same wind sector.

Daily fractional mass contribution from each source relative to the total of all sources was used rather than the absolute source contribution. This consideration was necessary to ensure minimizing the effect of atmospheric dilution. The threshold value was set at the upper 25<sup>th</sup> percentile of the fractional contribution from each source. The same daily fractional contribution was assigned to each hour of a given day to match the hourly wind data (Kim et al., 2003). The CPF was described in detail by Kim and Hopke (2004). In this study, 24 sectors were used ( $\Delta\theta=15^\circ$ ), and wind speeds of less than 1 m/s were considered to be calm and therefore excluded from the analysis.

## 3. Results and Discussion

The average PM<sub>2.5</sub> mass concentration and that of the identified species can be seen in Table 1. The average PM<sub>2.5</sub> obtained for the sampling period was 21.6  $\mu\text{g}/\text{m}^3$  which is higher than the WHO annual mean value of 10  $\mu\text{g}/\text{m}^3$  but less than that of 24-hour mean of 25  $\mu\text{g}/\text{m}^3$ . Table 2 compares the results in this work and that observed in other African studies (Kwabenya in Accra-Ghana and Al Zamalek in Cairo-Egypt). The concentration values of Cr, Mn, Fe, Ni, Cu, Zn, and Pb are seen to be significantly higher at Ashaiman than Kwabenya. This result shows the influence of industrial emissions on the ambient air quality at Ashaiman since Kwabenya is not close to heavy industrial areas.

**Table 1.** Summary statistics for the species measured at Ashaiman

Species <sup>a</sup>	Arithmetic Mean <sup>b</sup>	Standard Deviation	Minimum	Maximum	MDL	% BDL Values	% Missing Values	S/N Ratio
PM <sub>2.5</sub> (µg/m <sup>3</sup> )	21.6	12.93	5.6	73	1.32	0	0	32.7
OC1 (µg/m <sup>3</sup> )	0.14	0.09	0.01	0.5	0.42	20.8	2.1	0.8
OC2 (µg/m <sup>3</sup> )	2.6	1.01	0.37	5.8	0.42	0	0	8
OC3 (µg/m <sup>3</sup> )	2.74	1.12	0.37	6.1	0.42	0	0	11
OC4 (µg/m <sup>3</sup> )	0.91	0.52	0.02	2.9	0.42	4.2	2.1	2.1
EC1 (µg/m <sup>3</sup> )	1.88	1.26	0.01	5.8	0.06	6.2	2	26
EC2 (µg/m <sup>3</sup> )	0.19	0.14	0.01	0.8	0.06	25	2.1	0.9
OP (µg/m <sup>3</sup> )	1.12	0.68	0.01	3.9	0.06	6.3	2.1	2.2
Na	743	292	274	1 791	152	0	0	6.7
Mg	94.4	74.3	39.0	473	8	0	0	13
Al	806	592	313	3 607	94	0	0	122
Si	1 159	1 532	290	8 883	16	0	0	153
S	391	208	55.7	930	54	0	0	130
Cl	145	88.9	29.9	549	30	0	0	94
K	487	230	27.8	1 032	22	0	0	77
Ca	287	260	106	1 656	15	0	0	90
Ti	59.0	46.5	19.2	277	3.7	0	0	46
V	2.9	1.3	1.8	8.2	0.8	0	0	2.7
Cr	17.3	5.0	11.1	32.1	6	0	0	24
Mn	27.4	12.4	13.4	77.3	1.4	0	0	40
Fe	987	467	441	3 015	52	0	0	73
Co	7.7	3.5	1.4	19.6	1.6	0	0	1.2
Ni	54.4	14.6	35.2	96	14	0	0	18
Cu	180	48	115	331	6	0	0	34
Zn	164	109	77.3	617	25	0	0	43
Se	2.1	1.6	1.8	9.6	2	43.8	0	1.1
Br	32.4	20.7	6.9	153	4	0	0	22
Rb	2.1	1.3	1.5	5.6	0.6	10.4	0	1.2
Sr	7.2	4.0	1.8	19.7	1.5	12.5	12.5	3.4
Pb	43.9	28.0	17.9	149	8.9	0	0	14

<sup>a</sup> All values in ng/m<sup>3</sup> except as noted for specific species.

<sup>b</sup> Blank values were deducted from the initial concentration values.

The mean, maximum, and minimum of the ratios of carbon fractions (EC and OC) to total carbon (TC) and particulate mass are shown in Table 3. On average, EC and OC components in TC were found to be 20.5% and 78.4% respectively. The average amount of TC in PM<sub>2.5</sub> particulate mass was also found to be 40.3%.

An eight-source model and a value of FPEAK = 0.1 provided the most physically reasonable source profiles in a variety of source number solutions and FPEAK values and also on examination of the scaled residuals and the Q value (Song et al., 2001). The values of the scaled residuals (Paatero and Hopke, 2003) were symmetrically distributed and with the exception of a few cases were between ±3 for all the species (Amato et al., 2009).

Figures 2 and 3 show the source profiles obtained for the eight-factor PMF solution and the time series of contributions from each source respectively. The factors (Figure 2) were identified as industrial process, fresh sea salt, diesel emissions, biomass emissions, two stroke engines, gasoline emissions, aged sea salt, and soil dust.

The first profile has relatively high levels of OC2 OC3, EC1, EC2, K, Cr, Fe, Cu, and Zn. This source is attributed to the industrial activities. In this industrial area, there is a refinery and other petroleum industries, metal industries (aluminum and zinc industry producing roofing sheets, two steel industries), food processing, garment production, and chemical industries like paint. Cr, Fe, Cu, Zn are typical indicators of industrial emissions such as those from metal operations (Cohen et al., 2000; Cohen et al., 2010). The

highest contributions occurred at the end of the months of April and May. This source did not show distinct periodic variations in contribution (Figure 3).

**Table 2.**  $PM_{2.5}$  mass concentration values and the composition of the identified species at Ashaiman compared with that of other studies ( $ng/m^3$ )

Species	This Study	Kwabenya (Accra, Ghana) <sup>a</sup>	Al Zamalek (Egypt) <sup>b</sup>
$PM_{2.5}$ ( $\mu g/m^3$ )	21.6	40.8	61.9
OC1 ( $\mu g/m^3$ )	0.14		
OC2 ( $\mu g/m^3$ )	2.6		
OC3 ( $\mu g/m^3$ )	2.74		
OC4 ( $\mu g/m^3$ )	0.91		
EC1 ( $\mu g/m^3$ )	1.88		
EC2 ( $\mu g/m^3$ )	0.19		
OP ( $\mu g/m^3$ )	1.12		
Na	743		
Mg	94.4		
Al	806	833	120
Si	1 159	169	300
S	391	462	
Cl	145	123	
K	487	377	500
Ca	287	144	200
Ti	59.0	37.5	
V	2.9	1.9	
Cr	17.3	2.7	
Mn	27.4	7.6	
Fe	987	289	200
Co	7.7		
Ni	54.4	3.2	
Cu	180	4.1	
Zn	164	6.5	
Se	2.1	0.5	
Br	32.4	5.9	
Rb	2.1	1.4	
Sr	7.2	2.9	
Pb	43.9	2.5	700

<sup>a</sup> Aboh et al. (2009)

<sup>b</sup> Abu-Allaban et al. (2002)

**Table 3.** Ratio of carbon fractions to total carbon and  $PM_{2.5}$  particulate mass

Species Fractions (%)	Mean	Min	Max
OC/TC	78.4	63.9	87.2
EC/TC	20.5	3.3	36.1
OC/Mass	31.8	4.1	65.5
EC/Mass	8.5	2.2	19.9
TC/Mass	40.6	5.3	79.7

The second profile includes many of the species found in the first profile, but contains OC2, OC3, Na, Mg and relatively high Cl and S. This source can be seen to be a contribution from fresh sea salt with small additions from the industrial emissions. The Cl/Na ratio in this profile was found to be 1.6 which compares well with the ratio of 1.54 for the dry weight of sea salt [Salt = 2.54 Na] (Cohen et al., 1996; Cohen et al., 2010). The Tema harbor and industrial area are located to the south of Ashaiman, and fresh sea salt can be intermixed with the industrial emissions. As shown in Figure 3, the source contributions showed relatively high values from March to May. During this period of year in West Africa, the Intertropical Convergence Zone (ITCZ) moves further inland (from the Atlantic Ocean, close to the coast of the Gulf of Guinea) increasing the flow of moisture from sea to land (He et al., 2007). The low contributions in June are likely due to high humidity levels and rainfall that cause rapid downwash (wet deposition) and removal of the fresh sea salt particles.

The third profile is identified to be diesel emissions. Diesel emissions are characterized by organic and elemental Carbon (OC, EC) and traces of Na, Ca, S, Zn, Cu, Fe and Ni. EC is the primary pollutant emitted by diesel combustion (Gray and Cass, 1998). The EC1 and EC2 values in this profile are greater than that of gasoline and it serves as the basis for the identification of this source. The Zn and Ca are normally additives in motor oil (Hopke 1985; Alander et al., 2005) while Fe can also be coming from brake wear and muffler ablation. Figure 3 shows that the contribution of diesel emissions is highest in June. This observation could not be explained.

Biomass is identified by OC, EC, K. There are traces of Na, Cl, Zn, Cu, Br present in the fourth profile because of intermixing of other emissions. The source contributions were found to be high in February, April, and May as seen in Figure 3. The relatively high contribution of this source found in February is due to bush fires that commonly occur during the dry season (November to March). The observed rise in contribution in the months of April and May are mainly due to the slash and burn method to prepare the lands for farming in forest areas and most of the southern sector of Ghana.

The fifth profile has high OC, EC, and Zn concentrations with traces of Ca, Fe, Cu, Ni, Mn, Al and Pb. This source is attributed to two-stroke engines that are used in the large number of motorbikes and small motorcycles. Zn is a major species used to identify two-stroke engine emissions (Chueinta et al., 2000; Begum et al., 2004) and is seen to be high in this profile. Zn and Ca are additives in motor oil that is mixed with the gasoline in two-stroke engines. High contributions occurred in the months of April and May.

The sixth profile represents gasoline vehicular emission sources. It mainly includes OC, with EC, K, Ca, Fe and Zn. The EC and sulfur in the gasoline source are relatively lower than that of diesel. The manganese level obtained in this source is also low. The manganese mass concentration in air was on the average  $27 ng/m^3$  with a maximum of  $77 ng/m^3$  and a minimum of  $13 ng/m^3$ . This value is within the acceptable limits as set by Agency for Toxic Substance and Disease Registry (ATSR) (Blumberg and Walsh, 2004). This shows that the use of Methylcyclopentadienyl manganese tricarbonyl (MMT), a manganese based additive in gasoline in Ghana has not yet contributed much manganese to the ambient air. Manganese is known to be an essential element for human survival, but it is also toxic when too high concentrations are present in the body (Santos-Burgoa et al., 2001). This source did not show significant variations in mass contribution over the survey period (Figure 3).

The seventh profile consists Na, S, K Ca, Fe with very little Cl. This source is assigned to aged sea salt. This source contributes the most S of all the eight sources. The high levels of Na with low Cl serves as the basis for the identification of this source. The low Cl is due to the reaction of NaCl with  $H_2SO_4$  and gaseous  $HNO_3$ , respectively, into  $Na_2SO_4$  and  $NaNO_3$  (Dzubay et al., 1979; Harrison and Sturges, 1983; Seinfeld and Pandis, 1998; Qin et al., 2002).  $SO_2$  can also react directly with sea salt to displace the chlorine and produce sodium sulfate (Sievering et al., 1991; Luria and Sievering, 1991). Slightly high contributions of this source were observed in July and August but this observation could not be explained.

The major species contributing to the eighth source include Si, Fe, Ca, Al, K, Mg and Na, and this factor is assigned to soil dust. The source contribution plot shows high contributions in February and March. This observation is attributed to Harmattan dust that blows across West Africa from the end of November to the middle of March. The Intertropical Convergence Zone (ITCZ) in December to February is located in the Atlantic Ocean but close to the coast of the Gulf of Guinea (He et al., 2007), the Harmattan wind stops there and most of the dust settles over the land.

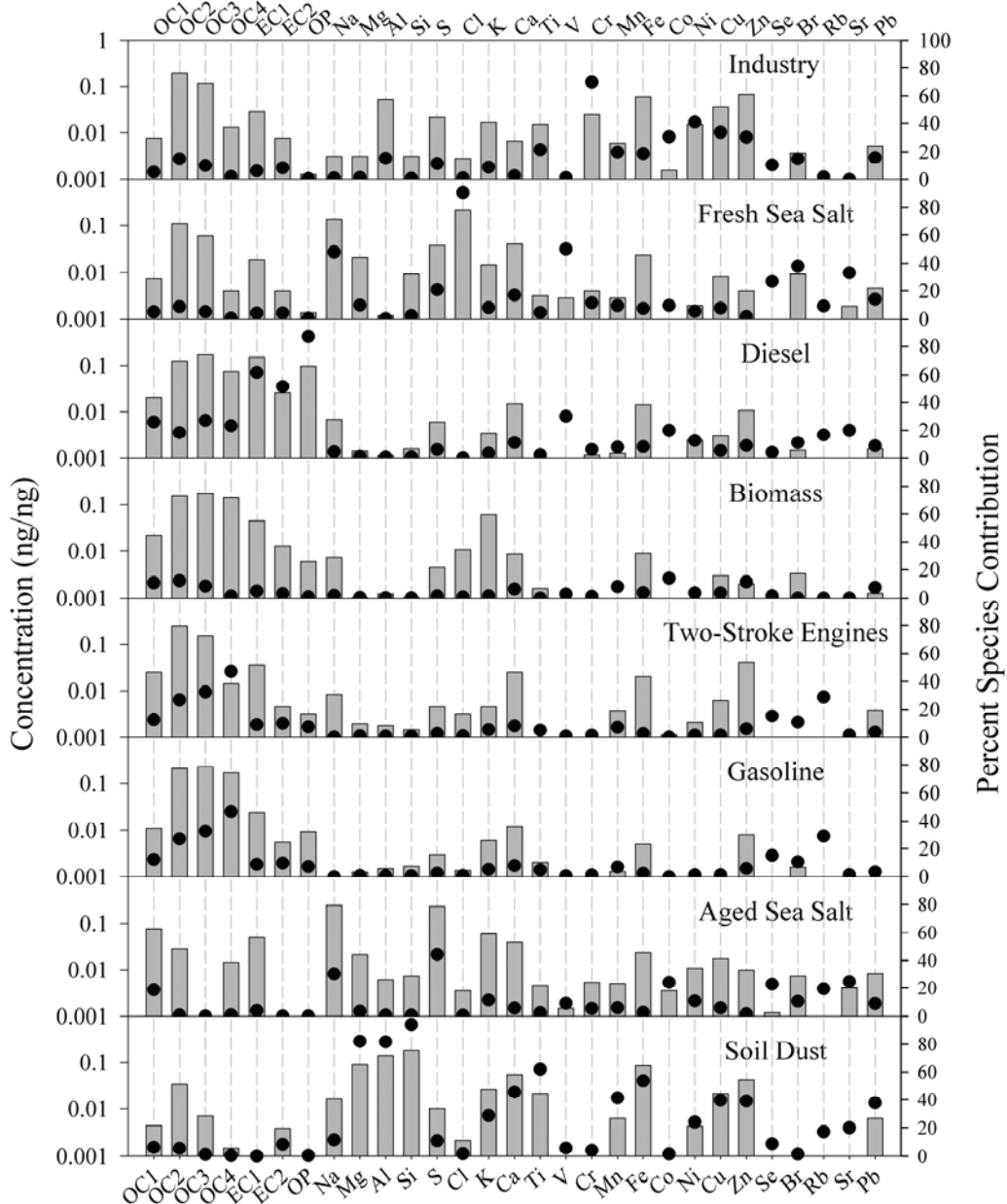


Figure 2. Source profiles deduced from the PMF analysis of data.

The average contributions of each source to the PM<sub>2.5</sub> mass concentrations are summarized in Table 4. It can be seen from this table that combustion processes from industry, vehicles, and biomass burning contributed the greater part of PM<sub>2.5</sub> mass in the study area (60.1%). Vehicular emissions alone contributed 39% of the ambient air fine particulates. Diesel emissions are seen to have contributed more than gasoline. Tema is a harbor town with many heavy-duty, diesel-powered trucks carrying goods for export and goods being imported into the country. As an industrial town, local raw materials are needed to feed the industries and the finished (factory) products are conveyed by the diesel powered (articulated) trucks. The oil refinery in Ghana is located at Tema and all of the refined products (gasoline, diesel and LPG) are transported and distributed throughout the country using diesel powered engine vehicles. The concrete road (Motoway) linking Tema and Accra which also forms part of the Trans-West Africa highway lies about 1.5 km south of Ashaiman Township. As Ashaiman is located downwind of Tema and the highway, it serves as a receptor for the emitted particles.

It can be observed that there are significant levels of Ca and Zn in all the vehicular emissions at Ashaiman. This can be due the use of old vehicles with engines that have not been well maintained. The Zn and Ca are additives in motor oil (Hopke 1985; Alander et al., 2005). Poorly functioning engines particularly those with leaky piston rings burn more lubricating oil releasing Zn and Ca as visible white clouds in many cases. The relatively high levels of Fe in vehicular emissions can partly be due to brake wear and muffler ablations.

The reconstructed PM<sub>2.5</sub> mass concentrations were estimated by the sum of the contributions from PMF resolved sources. The comparisons between the predicted and measured PM<sub>2.5</sub> mass concentrations show that the resolved sources effectively reproduced the measured values ( $R^2 = 0.922$ ) shown in Figure 4.

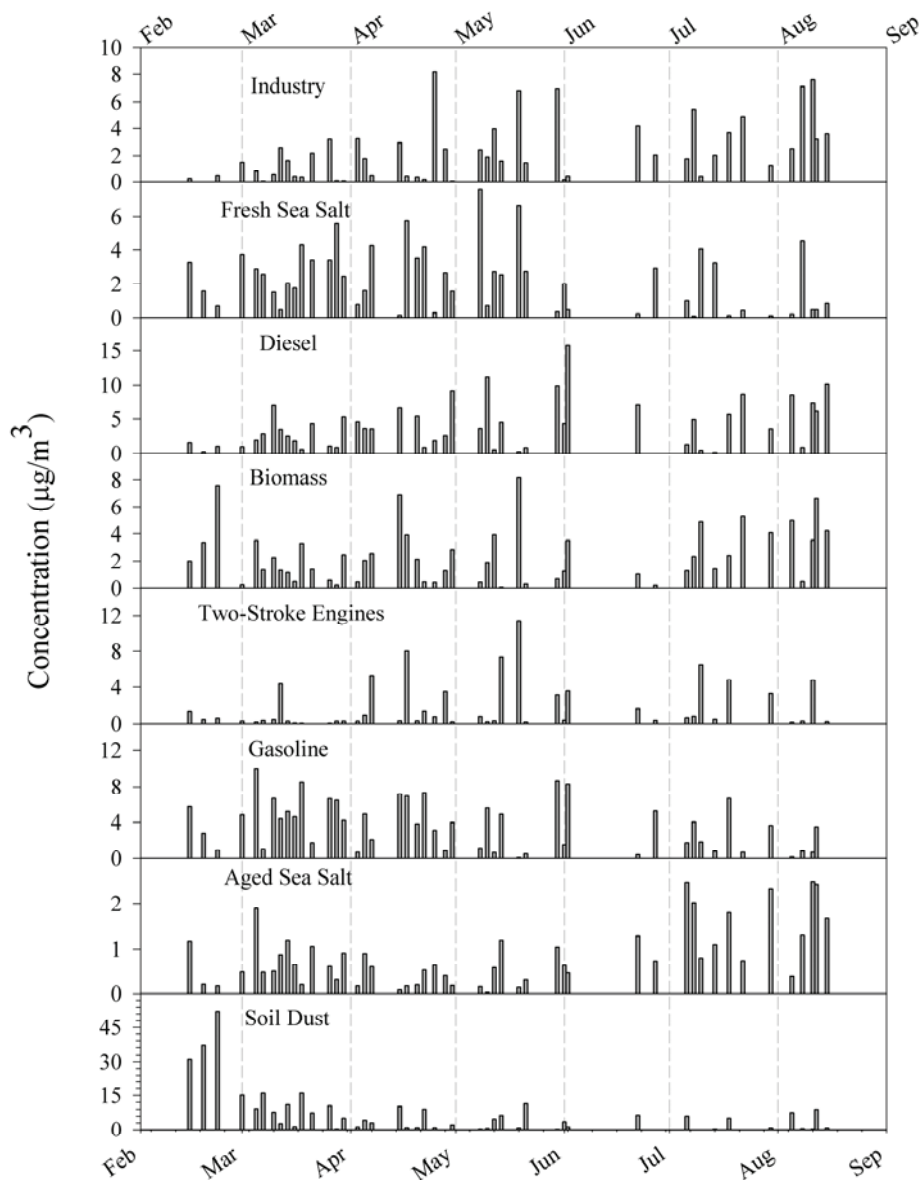


Figure 3. Source contributions deduced from the PMF analysis of data.

Table 4. Average source contributions (%) to PM<sub>2.5</sub> mass concentrations

Average Source Contribution (%)		
1	Industry	11
2	Fresh Sea Salt	16
3	Diesel	18
4	Biomass	9.5
5	Two stroke engines	5.1
6	Gasoline	16
7	Aged Sea salt	6.2
8	Soil Dust	18

The CPF values for gasoline and diesel vehicle emissions presented in polar plots shown in Figure 5 do not show much variation from each other. These two sources did not show specific source directionality but generally the contributions from the southern sector dominated. Similarly, soil dust did not show specific directionality but showed slightly more contribution from the northern sector. The Harmattan dust blows southwardly and can be considered as a significant factor to the dominance from the north. Biomass comes from all sectors but largely from the northwest. Ashaiman Township lies mostly to the west of the monitoring station suggesting that for the most part, the biomass emissions are coming from this area.

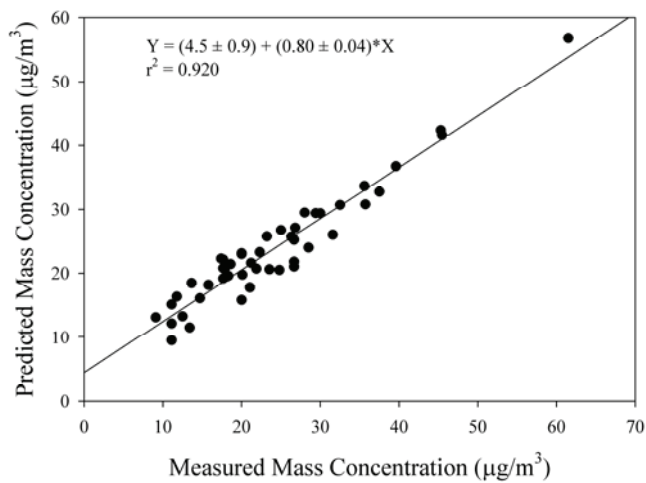


Figure 4. Comparison of the predicted PM<sub>2.5</sub> mass concentrations with measured PM<sub>2.5</sub> mass concentrations.

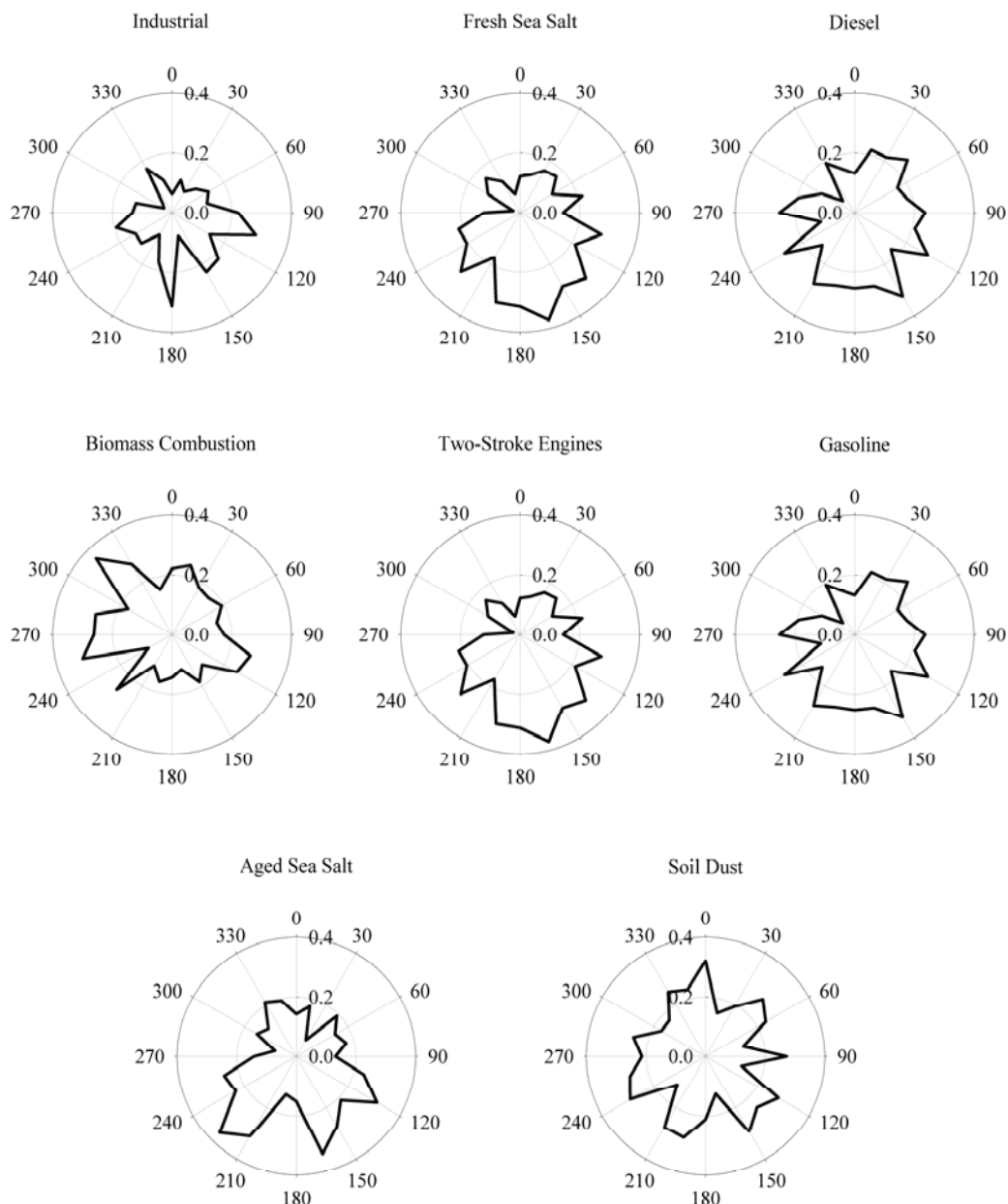


Figure 5. CPF plots for the source contributions from PMF results.

Aged and fresh sea salt intermixed with some industrial emissions are shown to come from the south since the sea and the industrial area lies to the south of Ashaiman (Figure 1). The aged sea salt is seen to be almost equally emanating from southeast and southwest. The contribution of the fresh sea salt from the southeast is slightly more than that from the southwest (Figure 5). The main industrial area at Tema lies mostly to the southeast of the monitoring location. This positioning may account for some industrial emission seen to be mixed up with the fresh sea salt. The CPF plot of industrial emissions shows that they are predominantly coming from the southeastern sector in the direction of the industrial complex.

#### 4. Conclusions

This study used the chemical composition (elemental and carbonaceous) to estimate the mass contributions of sources of fine particulates ( $PM_{2.5}$ ) at Ashaiman and its environs. Eight sources were resolved from the results of the aerosol samples collected. These sources are identified as: industrial emissions (11.4%), fresh sea salt (15.5%), diesel emissions (18.4%), biomass

burning (9.5%), two stroke engines (5.1%), gasoline emissions (15.8%), aged sea salt (6.2%), and soil dust (17.7%). Combustion sources contributed the majority of the ambient  $PM_{2.5}$  mass concentrations. Diesel emissions provided the largest single source contributions to ambient air PM values among the eight identified sources. Industrial emissions contributed significantly to air pollution in Ashaiman from the industrial area that lies to the southeast of the sampling location. Biomass burning contributed 9.5% of the average  $PM_{2.5}$  mass concentrations and was significant in a suburban community with the ambient air quality primarily influenced by urban heavy vehicular, industrial, and other commercial activities. The soil dust contribution to  $PM_{2.5}$  was 18% arising from transported dust as well as re-suspended road and other fugitive dusts. The sea spray contribution was significant as expected for a site located about 10 km from the sea. The relatively high levels of Ca and Zn observed in vehicular emissions have shown the high use of old and less efficient vehicular engines. The CPF plots for the source contributions give a good indication of the specific source locations.



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