Title

Characterization and aerosol mass balance of PM$_{2.5}$ and PM$_{10}$ collected in Conakry, Guinea during the 2004 Harmattan period

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Abstract

Background PM$_{2.5}$ and PM$_{10}$ levels were determined during Harmattan (West African wind blown dust) at a background site in Conakry, Guinea. The study was conducted from January to February, 2004 when Harmattan dust appeared to be most pronounced. PM$_{2.5}$ concentrations at the Nongo American housing compound ranged from 38 $\mu$g m$^{-3}$ to 177 $\mu$g m$^{-3}$, and PM$_{10}$ ranged from 80 $\mu$g m$^{-3}$ to 358 $\mu$g m$^{-3}$, exceeding standards set by EPA and European Commission Environment Directorate-General. PTFE filter samples were analyzed for insoluble and soluble inorganic constituents by XRF and IC,
respectively. Sulfur and associated SO$_4^{2-}$ concentrations were notably consistent among PM$_{2.5}$ and PM$_{10}$ samples which marked a relatively stable S background signal from anthropogenic sources. Enrichment factor (EF) analysis and aerosol mass reconstruction (AMR) techniques were used to isolate potential PM source contributors. The EF’s for SiO$_2$, TiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$, and MnO were near unity which suggests a crustal origin for these elements. EF’s for Na$_2$O and K$_2$O were above unity and highly variable, these elements were elevated due to widespread mangrove wood combustion as a fuel source in Conakry. The EF’s for Cr were notably high with a median of 7 and interquartile range from 5 to 16, the elevated levels were attributed to unregulated point source and mobile source emitters in and around Conakry.

Keywords
Conakry, Guinea, Harmattan, Particulate matter, Enrichment factor, Mass reconstruction

1. Introduction
The United States EPA conducted a six week air quality screening survey of the city of Conakry, Guinea, West Africa in 2004 at the request of the U.S. Embassy in Conakry. The study was conducted to assess the background levels of anthropogenic and natural particulate matter (PM) and to investigate the local and regional sources of those pollutants. This paper presents the first reported concentrations of airborne particulate from one of the world’s dirtiest cities (Luck, 2008).

The air quality survey was conducted from January 11 through February 22, 2004. This period was selected because Conakry was in the middle of the dry season when visible air pollution appears to be most pronounced. The survey period overlaps with the
Harmattan dust season where cool, dry trade winds blow from the Sahara Desert toward the southwest from November to March every year (Breuning-Madsen and Awadzi, 2005).

Conakry has a wide range of environmental and public health problems including respiratory illnesses due to elevated levels of air pollution (World Health Organization, 2006a). Local pollution sources include: unregulated combustion and processing emissions from industrial point sources, unregulated emissions from leaded gasoline vehicles, widespread open pit burning of household and vegetative waste, and residential wood burning cooking ovens. The local industrial point source emitters include: an asphalt manufacturing plant, cement manufacturing plant, diesel and fuel oil combustion electric power plants, brick manufacturing operation, fish processing and smoking facilities, brewery, soft drink bottling plant, soap manufacturing facility, plastic injection molding facility, steel smelter, paint formulation plant, medical waste incinerator, and major bauxite, alumina, and cement operations (Fig. 1; Bermudez-Lugo, 2006).

This paper presents concentrations of PM$_{2.5}$ integrated and real-time samples and PM$_{10}$ integrated samples. The integrated samples were chemically characterized by XRF for inorganic constituents, ion chromatography (IC) for soluble species, and a limited number of elemental carbon (EC) and organic carbon (OC) measurements using a thermo-optical method. The paper explores the relative contributions of local pollution sources, the influence of Harmattan dust influx, and the possible sea salt aerosol contribution.

2. Methods

2.1. Study Area
Guinea is located on the Atlantic coast of West Africa and is bordered by Guinea-Bissau, Senegal, Mali, Cote d’Ivoire, Liberia, and Sierra Leone. The country is divided into four geographic regions: a narrow coastal belt (Lower Guinea), the pastoral Fouta Djallon highlands (Middle Guinea), the northern savannah (Upper Guinea), and a southeastern rain forest region (Forest Guinea). Lower Guinea has a tropical climate with a rainy season lasting from April to November, relatively high and uniform temperatures, and high humidity. The dry season spans November to March and features a cool, dry, dust-laden trade wind originating from the Sahara Desert, termed Harmattan wind (Adepetu et al., 1988).

The capital of Guinea, Conakry, is located on the west coast of the country on a peninsula extending into the Atlantic Ocean. Conakry has a population of approximately 2 million people located on the peninsula and partially on the mainland toward the east with a total area of approximately 135 km² (The World Bank Sub-Saharan Africa Transport Policy Program, 2004). Conakry’s year round average high temperature is 29 °C and the low is 23 °C with an average annual rainfall of 430 cm. During Harmattan, Conakry is uniquely situated on the Inclined Meteorological Equator (IME) which forms the west-east boundary between the northeast trade winds and the southwest monsoon in the West African region (Giresse, 2008). The IME migrates seasonally which establishes the wet and dry seasons in West Africa; the northerly migration establishes the rainy season and southerly migration establishes the dry season (Dupont et al., 1996).

2.2. Sampling and analysis

The bulk of the air quality monitoring was conducted at a secure background site located at the northeast corner of the Nongo American housing compound. The background site was located north of the geographic center of Conakry and had no major
emission sources within 100 m, as such, it meteorologically and geographically represented typical ambient PM in the Conakry area. The PM sampling devices were located on scaffolding 4.3 m above the ground per the U.S. Code of Federal Regulations 40 CFR 58, Appendix E for ambient air quality monitoring (U.S. Code of Federal Regulations, 2002).

Point source air quality monitoring was conducted at fifteen sites in addition to the background PM sampling effort at Nongo. A variety of sampling technologies and techniques were employed during the air quality survey. This paper presents the quantitative results from the most robust sampling techniques, namely, the 24 h PM filter samples. One 24 h filter sample was collected at a home in the Sangoyah district of Conakry to measure PM from prolific residential outdoor cooking. Another 24 h filter sample was collected at the Guinean government’s Presidential Palace site which is in strikingly close proximity to the alumina, bauxite, and cement ship loading operations (Fig. 1).

Two MiniVol (Airmetrics) portable, battery-powered samplers were used to collect 24 h PM$_{2.5}$ and PM$_{10}$ (particle equivalent aerodynamic diameter less than or equal to 2.5µm and 10µm, respectively) on 47 mm polytetrafluoroethylene (PTFE) and quartz filters at the Nongo background site (Hill et al., 1999). The MiniVol samplers were subject to the following field QC procedures: leak and zero flow check, rotameter adjustment to 5 L min$^{-1}$, and flow rate recording before and after each run. Field and transportation blank filters were collected for contamination assessment. An EPAM-5000 (Environmental Devices Corporation) real-time aerosol nephelometer provided 10 s continuous PM$_{2.5}$ measurement data in conjunction with a 47 mm backup PTFE filter at three sampling sites. EPAM-5000 measurements were scaled to the corresponding gravimetric mass results from the MiniVol filter samples. Gravimetric results from the
MiniVol filters were considered more representative of the actual PM levels than those measured by nephelometry. The field sampling matrix is described in Table 1.

PTFE filter (Whatman 2 µm pore size) samples were pre- and post-weighed in a temperature and humidity controlled chamber using a Mettler ME22 balance with a BE22 control unit and BA25 electronic display. 47 mm quartz fiber filters were punched from 20 cm x 25.4 cm sheets of Pallflex Tissuquartz sheet, heated overnight at 500 °C, and sealed in Petri dishes for transport to the field.

The inorganic constituents of the PTFE filters were determined by energy-dispersive X-ray fluorescence (XRF) using a Kevex EDX-771 spectrometer. The instrument sample chamber maintained a positive flow of helium gas to minimize the loss of volatile species. The XRF procedures are listed in the EPA Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air Method IO-3.3 (U.S. Environmental Protection Agency, 1999). NIST SRM 1833 and SRM 1832 standards were analyzed immediately before and after the unknown filter samples and the QC results were within the NIST certified value range. PTFE filter samples were subsequently extracted in deionized water using a heated ultrasonic bath for 15 min and analyzed for major ions using a Dionex DX-500 IC. The IC procedures are listed in Method A of the EPA Method 300.0 Determination of Inorganic Anions by Ion Chromatography (Pfaff, 1993).

Elemental carbon (EC) and organic carbon (OC) analyses were performed on five PM$_{2.5}$ quartz filters collected with the MiniVol sampler at the Nongo background site. One quartz filter was analyzed in duplicate with two 1.45 cm$^2$ punch samples and the resulting analytical precision was 0.25%. The EC/OC analysis was performed with a custom made thermo-optical transmission instrument by Sunset Laboratory Inc. per the NIOSH Standard Method 5040 (Birch, 1999).
The sampling equipment and filter samples were transported from the U.S. to Conakry and back to the U.S. via standard passenger airline transport methods. The filter samples were individually labeled and sealed in sterilized 49mm molded polystyrene petri dishes (Millipore Corp., product number: PD1004700).

3. Results and discussion

3.1. Particulate mass concentration

Table 1 gives a summary of the concentrations of PM$_{2.5}$ and PM$_{10}$ collected with the MiniVol and EPAM-5000 samplers. PM$_{2.5}$ concentrations at the Nongo site ranged from 38 µg m$^{-3}$ to 177 µg m$^{-3}$, and PM$_{10}$ ranged from 80 µg m$^{-3}$ to 358 µg m$^{-3}$. Concentrations of PM$_{2.5}$ and PM$_{10}$ increased markedly on February 6 through February 13 which coincided with field observations of unusually strong Harmattan winds during that period. As shown in Fig. 2, real-time measurements of PM$_{2.5}$ at the Nongo background site indicate baseline levels of approximately 20 µg m$^{-3}$ to 40 µg m$^{-3}$ with pronounced spikes into the mg m$^{-3}$ range from 0200 to 0600 Coordinated Universal Time (UTC±0).

On February 6, the baseline concentrations of PM$_{2.5}$ began to rise at approximately 1400 UTC±0 which corresponded with the onset of a strong Harmattan wind event that lasted several days. The origin of the pronounced PM$_{2.5}$ concentration spikes is unknown, one plausible explanation is the initiation of a major industrial activity or set of activities from the port of Conakry or land-based point source polluters (Fig. 1).

The PM$_{2.5}$ filter sample collected at the Sangoyah residential cooking site had an integrated concentration of 187 µg m$^{-3}$. The real-time analysis at that location marked a PM$_{2.5}$ baseline of approximately 200 µg m$^{-3}$ with substantial spikes during the majority of the daylight hours (Fig. 2). The PM$_{2.5}$ filter sample collected at the Presidential Palace site had an integrated concentration of 76 µg m$^{-3}$. The real-time analysis showed a
jagged PM$_{2.5}$ baseline centered on 30 µg m$^{-3}$ and there were pronounced PM$_{2.5}$
concentration spikes at several times throughout the day and night with a sustained PM
spike at approximately 1300 UTC±0 (Fig. 2).
Overall, sustained PM$_{2.5}$ and PM$_{10}$ levels were high and spike levels were extremely
high in comparison to PM regulations promulgated by the U.S. EPA, the European Union
Directorate-General (DG Environment), and guidelines adopted by the World Health
Organization (WHO). The EPA National Ambient Air Quality Standards (NAAQS)
established a 24 h average concentration of 35 µg m$^{-3}$ for PM$_{2.5}$ and 150 µg m$^{-3}$ for PM$_{10}$
established a 24 h average concentration of 25 µg m$^{-3}$ for PM$_{2.5}$ and 50 µg m$^{-3}$ for PM$_{10}$
(World Health Organization, 2006; European Parliament and the Council of the European
Union, 2008). Further, the EPA and DG Environment set the annual arithmetic mean for
PM$_{2.5}$ at 15 µg m$^{-3}$ and 25 µg m$^{-3}$, respectively. DG Environment specifies a 40 µg m$^{-3}$
annual arithmetic mean for PM$_{10}$. Every PM$_{2.5}$ filter sample collected during the study
period exceeded the standards set by EPA and DG Environment; every PM$_{10}$ filter
sample exceeded 24 h and annual mean standards set by DG Environment.

3.2. Elemental concentrations
The average concentrations of inorganic chemical species at three sampling sites are
given in Table 2. Elemental concentrations at the Nongo background site were highly
variable for most major elements (Cl$^-$, NO$_3^-$, Na, Mg, Al, Si, K, Ca, and Fe) in both the
PM$_{2.5}$ and PM$_{10}$ modes. The sulfur and associated sulfate concentrations are notably
consistent among all sample modes and sampling locations. The source for ambient
sulfur was likely the unregulated combustion of fossil fuels in motor vehicles and
industrial point sources. The Conakry area contained over 90% of the vehicles on the road in the entire country and field observations during the sampling period indicated that a vast majority of motor vehicles had visible smoke emanating from the tailpipe (The World Bank Sub-Saharan Africa Transport Policy Program, 2004). Industrial point sources including electric power generation, public works, and the mining industry generated unregulated emissions from the combustion of diesel and fuel oil (International Monetary Fund, 2008). Lead was detected in PM$_{2.5}$ and PM$_{10}$ at the Nongo background site and the Presidential Palace site which was likely due to the use of leaded gasoline in motor vehicles. All filter samples had Pb levels below ambient exposure regulatory standards set by the EPA (U.S. Code of Federal Regulations, 2008).

Significant elemental concentration differences were observed between the Nongo background site, the Sangoyah residential cooking site, and the Presidential Palace site. The Sangoyah residential cooking site was an effective source marker for the combustion of mangrove wood and charcoal in outdoor residential cooking. Field observations indicated that residential cooking fires are routinely ignited with plastic. Mangrove wood is an abundant and easily obtained fuel source in Conakry as it grows in the estuarine environments surrounding the city. Mangrove wood combustion emissions are relatively enriched in K, Na, Ca, Mg, Cl, and SO$_4^{2-}$ (Loto and Fakankun, 1989). The ambient concentrations of K, Na, and Cl at Sangoyah were 2 to 10 times higher than those at the Nongo background site due to the combustion of mangrove wood. The Presidential Palace site was an effective source marker for the aerosolization of alumina (Al$_2$O$_3$) and Portland cement (65% CaO, 20% SiO$_2$) dust due to the short distance and geographic proximity to major ship loading operations handling those materials (Ilyasov et al., 2008). The Presidential Palace PM$_{2.5}$ Al concentration was 1.8 times higher than the median
PM$_{2.5}$ background concentration measured at Nongo, Si was 1.63 times higher, and Ca was over 12 times higher. The relatively high Ca signal was due to the widespread cement dust fallout from the port operations. Ground observations noted that a white dust perpetually covered grass, plants, vehicles, roads, and buildings near the port and surrounding neighborhoods.

3.3. IC versus XRF

IC results were compared with XRF results as a QC check between the analytical methods and to assess the soluble components of PM. Sulfate, as measured by IC, was converted to sulfur ($S_{ic} = \frac{[SO_4^{2-}]_{ic}}{2.995}$) in order to compare with elemental S by XRF. Good inter-method agreement was observed for S ($r = 0.91$), Na ($r = 0.95$), Cl ($r = 0.95$), and K ($r = 0.90$). The recovery rate, PM$_r$, for each soluble species was estimated using Eq. (1),

$$PM_r = \sum E_i \left( \frac{IC_{Ei}}{XRF_{Ei}} \right)$$

where $E_i$ is the element of interest, $IC_{Ei}$ is the individual elemental concentration as measured by IC, and $XRF_{Ei}$ is the individual elemental concentration as measured by XRF. Eq. (1) includes both PM$_{2.5}$ and PM$_{10}$ samples and PM$_r$ showed a mean and standard deviation as follows: $S_{mean}$ 0.823 ± 0.114, $Na_{mean}$ 0.816 ± 0.364, $Cl_{mean}$ 0.667 ± 0.324, and $K_{mean}$ 0.785 ± 0.201. The high recovery rates suggest that these elements are largely unassociated with the local or regional deposition of insoluble Harmattan dust; rather, they are associated with anthropogenic emissions, aerosolized sea salt, or both. In this study, the sea salt component in measured PM could not be estimated due to the pervasive open vegetative burning for residential cooking and waste disposal in Conakry;
these burning activities contributed substantially to the overall soluble Na and Cl signature as seen in the Sangoyah residential cooking site PM$_{2.5}$ sample (Table 2). In contrast to other well known air sheds characterized in the literature, it cannot be assumed that the soluble Na and Cl are solely due to sea salt (Cheng et al., 2005).

3.4. Enrichment factor analysis

The enrichment factor (EF) for each measured element was calculated to understand the relative contribution of Harmattan dust and anthropogenic emissions in the Conakry air shed. Typically, Al is used as a reference element because it has no significant anthropogenic source (Petaloti et al., 2006). However, Conakry had many potential sources of anthropogenic Al from the mining and refinement of bauxite ore. Further, Guinea featured the world’s largest bauxite reserves which comprised the bulk of exposed soil in Lowland-Guinea (Boulange et al., 1996; Plunkert, 2002). Titanium was used a reference element for Saharan-blown desert sand comprising the Harmattan dust (El Tayeb et al., 2001). The EF for each elemental component in PM was calculated using Eq. (2),

\[
EF = \frac{[E]_{PM}/[Ti]_{PM}}{[E]_{soil}/[Ti]_{soil}}
\]

(2)

where $[E]_{PM}$ and $[Ti]_{PM}$ are normalized XRF concentrations, in $\mu$g g$^{-1}$, of the elemental component of interest and Ti in the PM sample; $[E]_{soil}$ and $[Ti]_{soil}$ are the average concentrations of the elemental component and Ti in Harmattan dust.

The PM airborne concentration data were converted to $\mu$g g$^{-1}$ according to Eq. (3),

\[
[E]_{PM} = \sum \frac{E_i \times 10^{-3} DF}{M}
\]

(3)
where $E_i$ is the element of interest in ng m$^{-3}$, $D$ is the sampling duration in min, $F$ is the sampler flow rate in L min$^{-1}$, and $M$ is the total measured PM mass on the filter in mg. Eq. (3) values were converted to their corresponding element oxide forms for the most abundant elements: SiO$_2$, TiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$, MnO, MgO, CaO, Na$_2$O, and K$_2$O. The trace elements Cr and Zn were left in their elemental form. The summation of the 11 elements of interest for each sample was normalized to 100% to facilitate the EF calculation for each element.

A composite Harmattan dust profile was created using instrumental neutron activation analysis (INAA) data from Adepetu et al. (1988), and XRF data from Eltayeb et al. (2001). The INAA method does not routinely include Si and Ca; the absolute concentrations of these elements were estimated from the 2.6 μm tick line in Figure 2 from Eltayeb et al. (2001). The major elements Si, Ti, Al, Fe, Mn, Mg, Ca, Na, and K were converted to their crustal oxide forms and the results added to the reported concentrations of the trace elements As, Au, Ba, Br, Ce, Co, Cr, Cs, Eu, Ga, Hf, La, Rb, Sb, Sc, Se, Sm, Th, U, V, and Zn. The resulting summation of absolute concentrations was normalized to 100%, and the results of the Harmattan dust profile are given in Table 3.

The PM$_{2.5}$ and PM$_{10}$ elemental concentrations were first converted to μg per filter, then converted to weight percent (wt%) for major element oxides and μg g$^{-1}$ for trace elements, and finally converted to the crustal oxide forms for major elements. The EF analysis results are presented in Fig. 3. The TiO$_2$ EF median and interquartile range is close to unity which suggests the valid application of this element as a reference. EF’s for SiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$, and MnO are also close to unity which suggests a crustal origin for these elements. The EF’s for Na$_2$O, and K$_2$O show a wide range which suggests variable sources for these elements. Calcium oxide is relatively depleted compared to the
Harmattan dust profile for PM$_{2.5}$ presented in Eltayeb et al. (2001), this relationship is likely the result of a poor estimate of the Ca concentration in the composite profile due to widely variable levels of Ca as a function of PM cut point in the original measurements. The relatively large range observed between the 5$^{th}$ and 95$^{th}$ percentile box plot whiskers for Zn suggests a widely variable source in Conakry (Fig. 3). The median Zn EF value is significantly below unity which indicates a weakness in the EF analysis for Zn. The original Harmattan dust profile data sources reported unusually high Zn concentrations which they attributed to possible anthropogenic contributions for Zn. The Harmattan PM concentration data obtained from the literature for Si, Al, Fe, Mn, Na, K, and Cr were reported as representative values for wind blown dust originating from the Saharan region of Nigeria and Sudan (Adepetu et al., 1988; Eltayeb et al., 2001).

The EF for Cr is notably high with a median greater than 7 and an interquartile range from 5 to 16. All PM$_{2.5}$ and PM$_{10}$ samples have Cr EF values that are moderately to significantly higher than the Harmattan dust profile which suggests an anthropogenic source influence for Cr (Sutherland, 2000). Anthropogenic emissions of Cr are well documented in the combustion of fuel oil and coal for power generation, cement production, refractory brick production, and refuse incineration (Nriagu and Nieboer, 1988). All of these known Cr emitting point source types were present in the greater Conakry area. Additionally, the point source and mobile source emitters in and around Conakry had no emission control devices to reduce probable emissions of Cr and other toxic metals.

3.5. Mass reconstruction

An aerosol mass reconstruction (AMR) analysis was conducted to explore the relative contributions of the measured inorganic and organic chemical species and their
relationship to the total measured gravimetric mass. On five sampling days the two MiniVol samplers were collocated at the Nongo background site and PM$_{2.5}$ was collected on both PTFE and quartz filters for inorganic and organic analysis, respectively (Table 1).

The AMR was performed using the method from Edgerton et al. (2005). The calculation differed slightly in that no nylon filters were collected during this study. The volatilized component of NO$_3^-$ and NH$_4^+$ on the PTFE filters was therefore not quantified. The mass reconstruction for the sample collected on February 7, 2004 was omitted from further discussion due to a malfunction detected on the MiniVol sampler with the PTFE filter, the AMR recovery rate was erroneously calculated at 152% of measured mass.

The total recovery rate, $R_\%$, is calculated according to Eq. (4),

$$R_\% = \left( \sum \frac{E_i}{M_{grav}} \right) \times 100$$

where $\sum E_i$ is the sum of the mass concentrations of the individual species and $M_{grav}$ is the measured gravimetric mass on the PTFE filter. Overall, the recover rates were very good with values of 92%, 71%, 92%, and 95% (Fig. 4).

The AMR analysis shows that the organic matter and metal oxide components comprise the vast majority of the sample, yet these components vary significantly among the samples. In contrast, the EC, sulfate, nitrate, and ammonium values represent a consistently small portion of each sample (Fig. 4). The relatively large organic matter values, low EC/Total carbon ratios, and low sulfate values strongly suggest a significant wood burning source contribution in the PM$_{2.5}$ samples (Hays et al., 2002). Further, the relatively high EF’s for K in the Nongo background site samples coupled with the high
concentrations of K, Cl, and Na measured at the Sangoyah residential cooking site and the results of the AMR analysis indicate wood burning was a significant source of air pollution in Conakry (Khalil et al., 2003). The significant wood burning contribution to the local pollution inventory is consistent with the $2 \times 10^6$ kg of mangrove wood that is burned in Conakry per year, based on conservative estimates (International Monetary Fund, 2008). The local meteorological conditions during the study period support the assertion that wood burning was partly responsible for elevated PM$_{2.5}$ concentrations in Conakry. The 24 h mean wind speed for all sampling days, as measured at Gbessia international airport, was relatively calm with a range from 7.96 km h$^{-1}$ to 13.15 km h$^{-1}$ (National Weather Service AWIPS NDW, 2009).

4. Conclusions

A unique air quality study was conducted during Harmattan in Conakry, Guinea in 2004. A combination of integrated and real-time PM sampling instruments collected samples over a one month period. Real-time PM$_{2.5}$ measurements indicated high baseline levels of PM coupled with markedly high PM spikes from 0200 to 0600 UTC±0. The origin of the PM$_{2.5}$ spikes is uncertain; however, the source was likely a local or regional industrial point source emitter with substantial stack emissions. Every integrated PM$_{2.5}$ filter sample exceeded ambient air quality standards set by EPA and DG Environment and every PM$_{10}$ filter sample exceeded 24 h and annual mean standards set by DG Environment.

A series of mass balance calculations were used to assess the relative contributions of unregulated industrial point source and mobile source emissions, widespread municipal and industrial burning emissions, and the Harmattan dust influx. Results suggest that the majority of the background PM$_{2.5}$ and PM$_{10}$ originated from a
combination of pervasive open vegetative burning and Harmattan dust influx with a smaller contribution from fossil fuel combustion sources. The contribution from the wide variety of unregulated fossil fuel combustion sources was not insignificant. The majority of filter samples contained Pb in both the PM$_{2.5}$ and PM$_{10}$ mode. Chromium in all filter samples substantially exceeded levels seen in wind blown dust from the Sahara desert region. Overall, this study highlighted the composite effects of an expansive, diverse, and largely unregulated emissions suite coupled with the seasonal Harmattan dust events and Conakry’s geographic position on the IME.

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### Table 1

Description of sampling matrix and gravimetric analysis

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<th>Sample type</th>
<th>Filter type</th>
<th>Instrument</th>
<th>Location</th>
<th>Sampler flow rate (L m⁻¹)</th>
<th>PM concentration (μg m⁻³)</th>
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<td>Presidential palace</td>
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Table 2
Concentrations\(^{a,b,c}\) of PM and associated elemental compositions at three sampling sites in Conakry

<table>
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<tr>
<th>Species</th>
<th>Nongo (N=18)</th>
<th>Nongo (N=10)</th>
<th>Sangoyah (N=1)</th>
<th>Palace (N=1)</th>
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<tr>
<td>Type</td>
<td>PM(_{2.5})</td>
<td>PM(_{10})</td>
<td>PM(_{2.5})</td>
<td>PM(_{2.5})</td>
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<td>Mass</td>
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<td>145256 ± 109194</td>
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<td>F(^+)</td>
<td>16 ± 17</td>
<td>100 ± 118</td>
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<tr>
<td>Cl(^-)</td>
<td>545 ± 536</td>
<td>1455 ± 996</td>
<td>5198</td>
<td>462</td>
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<tr>
<td>Br(^-)</td>
<td>27 ± 21</td>
<td>10 ± 2</td>
<td>12</td>
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<tr>
<td>NO(_3^-)</td>
<td>955 ± 710</td>
<td>3412 ± 1605</td>
<td>1425</td>
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<tr>
<td>PO(_4^{3-})</td>
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<td>2209 ± 421</td>
<td>1599</td>
<td>2140</td>
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<tr>
<td>SO(_4^{2-})</td>
<td>1470 ± 459</td>
<td>2209 ± 421</td>
<td>1599</td>
<td>2140</td>
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<tr>
<td>Na(^+)</td>
<td>258 ± 182</td>
<td>780 ± 377</td>
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<td>NH(_4^+)</td>
<td>527 ± 193</td>
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<td>K(^+)</td>
<td>931 ± 527</td>
<td>1406 ± 661</td>
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<td>Na</td>
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<td>Mg</td>
<td>405 ± 350</td>
<td>1252 ± 1046</td>
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<td>Al</td>
<td>3062 ± 3102</td>
<td>12613 ± 12355</td>
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<tr>
<td>Si</td>
<td>6537 ± 6980</td>
<td>24971 ± 27848</td>
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<td>P</td>
<td>131 ± 1</td>
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<td>S</td>
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<td>V</td>
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<td>Cr</td>
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<td>Mn</td>
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<td>Pb</td>
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\(^a\) Concentrations in ng m\(^{-3}\).
\(^b\) Mean ± standard deviation.
\(^c\) Data were filtered to include individual elemental concentrations > 2σ uncertainty to minimize type I errors.
Table 3
Average concentration of chemical species in the composite Harmattan dust profile (Adepetu et al., 1988; Eltayeb et al., 2001)

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$^a$ Concentrations of element oxides in wt% and trace elements in µg g$^{-1}$. 
Figure
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Figure captions

Fig. 1. Map of Conakry, Guinea, West Africa with monitoring sites and local points of interest.

Fig. 2. Concentrations of PM\textsubscript{2.5} at the Nongo background site measured with the EPAM-5000 nephelometer. Sample times are presented in coordinated universal time UST±0.

Fig. 3. Average enrichment factor (EF) results for PM\textsubscript{2.5} and PM\textsubscript{10} samples collected at the Nongo background site.

Fig. 4. Aerosol mass reconstruction (AMR) results for four PM\textsubscript{2.5} samples collected at the Nongo background site.