Source identification and apportionment of particulate matter in Accra, Ghana

Zheng Zhou1, 2, Thiago G Verissimo3, Kathie L Dionisio1, 2, Americo S Kerr3, Brent Coull2,4, Raphael E Arku2, Allison F Hughes5, Jose Vallarino2, John D Spengler2, Petros Koutrakis2, Samuel Agyei-Mensah6,7, Majid Ezzati8

1Department of Global Health and Population, Harvard School of Public Health, Boston, MA, United States of America; 2Department of Environmental Health, Harvard School of Public Health, Boston, MA, United States of America; 3Institute of Physics, University of Sao Paulo, Sao Paulo, Brazil; 4Department of Biostatistics, Harvard School of Public Health, Boston, MA, United States of America; 5Department of Physics, University of Ghana, Legon, Ghana; 6Environmental Science Program, University of Ghana, Legon, Ghana; 7Department of Geography and Resource Development, University of Ghana, Legon, Ghana; 8MRC-HPA Center for Environment and Health, Department of Epidemiology and Biostatistics, Sch

BACKGROUND AND OBJECTIVES

Urban particulate matter (PM) pollution is a complex mixture of particulate emissions from industry, transportation, and domestic energy use. Previous studies have found that biomass burning, motor vehicles, road dust, and industrial pollution may be common anthropogenic sources for urban PM pollution in developing country cities. Little is known about PM pollution sources and their relative contributions in African cities. The objective of this study was to identify sources of ambient PM pollution in Accra, Ghana and to apportion the contribution of each source.

METHODS

Study location

Our study took place in four Accra neighborhoods: Jamestown/Ushertown (JT), Asylum Down (AD), Nima (NM) and East Legon (EL) (Figure 1).

- **JT & NM:** poor, densely populated neighborhoods; biomass fuels are common for own or small-scale commercial cooking
- **AD:** middle-class, mostly residential neighborhood; less biomass use than JT & NM
- **EL:** upper-class, sparsely populated neighborhood; most homes have modern indoor kitchens and use liquefied petroleum gas

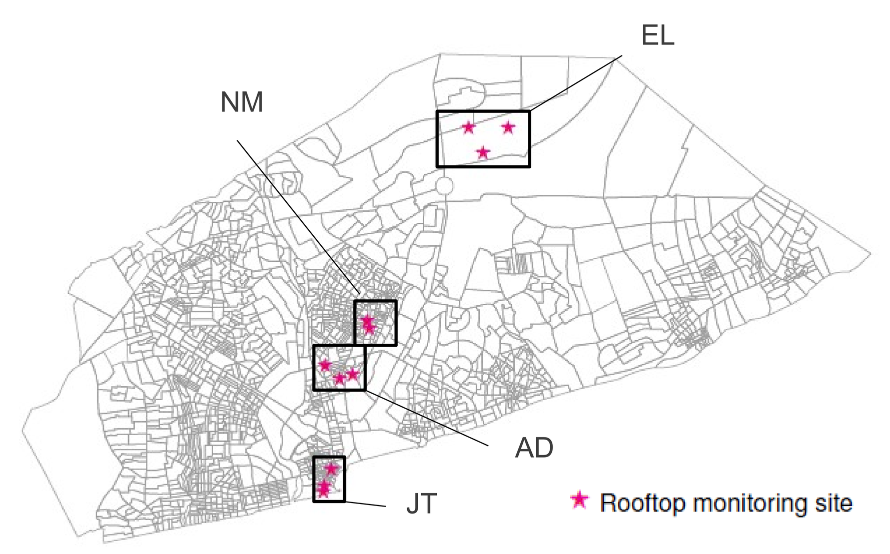


Figure 1. Map of Accra with measurement sites

Pollutant measurement

We measured PM2.5 and PM10 at 11 rooftop sites in the four neighborhoods (Figure 1) between November 2006 and August 2008. We used gravimetric measurement for 48 hours with 879 PM2.5 samples and 885 PM10 samples.

- **Integrated PM:** collected on PTFE filters using either a Personal Exposure Monitor (PEM) or a Harvard impactor (Dionisio et al. 2010).
- **Elemental concentration:** concentrations for sodium (Na) through lead (Pb) were analyzed at the Institute of Physics, University of Sao Paulo, Brazil by X-ray fluorescence (XRF).

Data analysis

Positive Matrix Factorization (PMF) was used to determine the number of PM sources, the chemical composition profile of each source, and the amount of PM that each source contributed to each sample. PMF model assumes that concentrations at a receptor are linear combinations of different sources and decomposes a matrix of speciation concentration data into two matrices, factor contributions and factor profiles.

$$X_{ij} = \sum_{k=1}^{p} g_{ik} * f_{kj} + e_{ij}$$

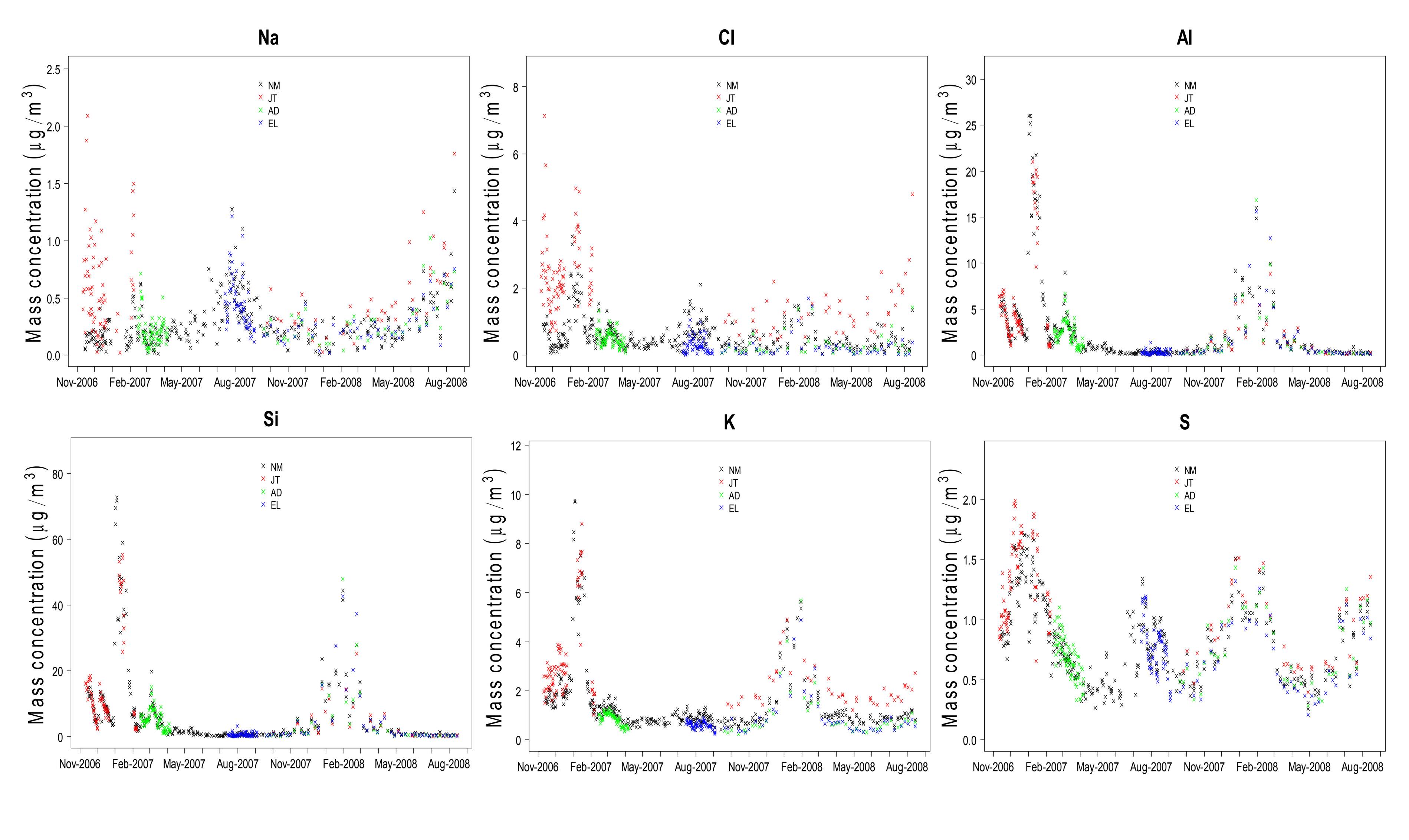
where xij is the observed concentration of species j at the ith observation; gik is the contribution of source k at the ith observation; fkj is the factor loading of species j in the source k; and eij is the residual.

In PMF, sources are constrained to have non-negative species concentration, as well as non-negative source contribution. PMF provides a solution that minimizes the sum of the squares of residuals weighted inversely by the uncertainty. The objective function to be minimized by PMF is:

$$Q = \sum_{i=1}^{n} \sum_{j=1}^{m} \left[\frac{e_{ij}}{u_{ij}}\right]^2$$

RESULTS

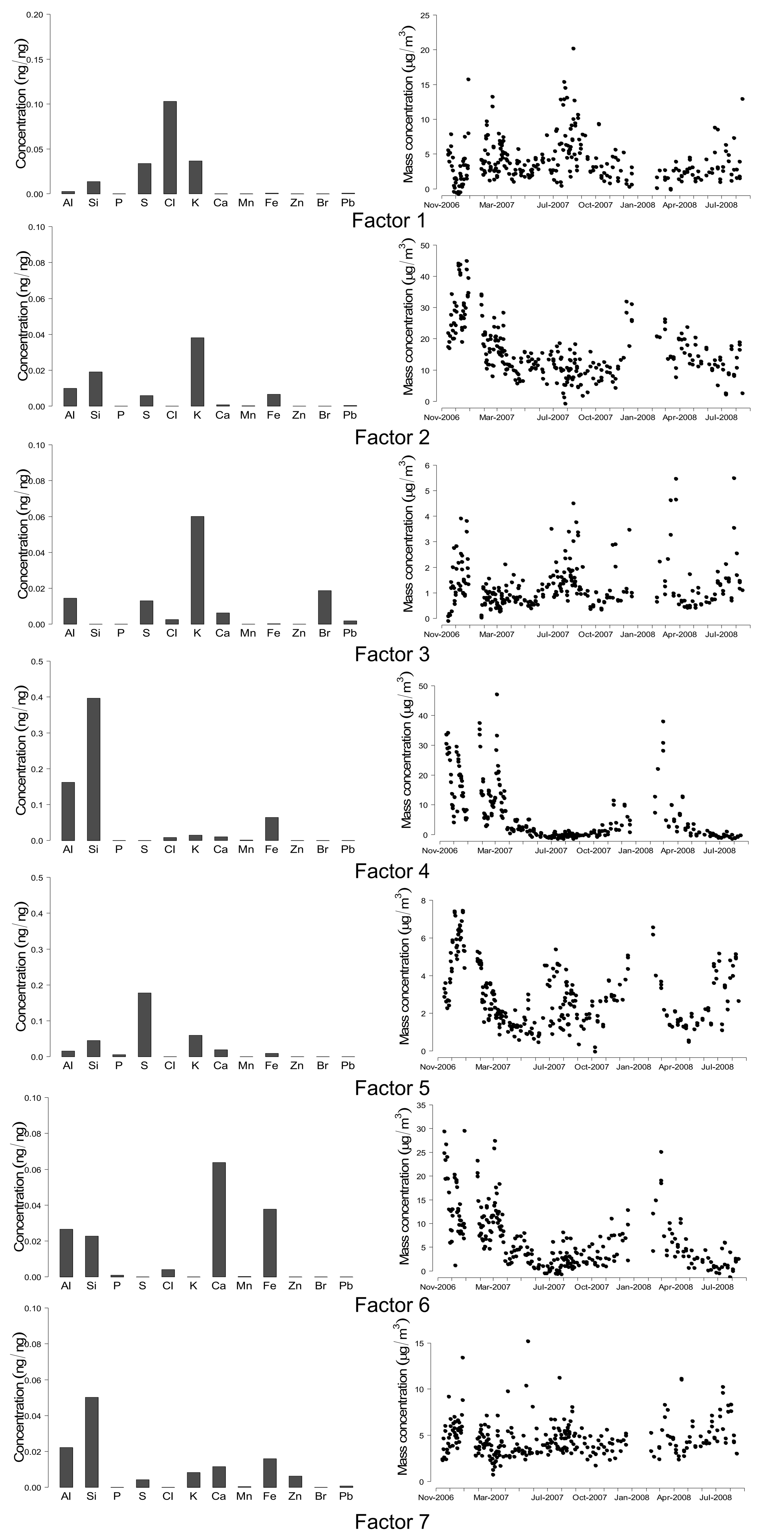
Figure 2: Selected elemental concentrations of fine PM (PM2.5) samples over two-year measurement period



- Sea salt is the predominant source of Na and Cl. Higher levels of Na and Cl were observed in JT, which is the closest neighborhood to the ocean.
- Al and Si are major crustal elements. The concentrations of Al and Si were extremely high during peak Harmattan period (December ~ January).
- The level of Sulfur shows a seasonal pattern, peaking in January and August and lowest in May and November. It may correspond to two rainy seasons in Accra: May to mid-July and mid-August to October.

RESULTS

Figure 3: Factor profiles (left) and factor contributions as a function of time (right) at Nima sites



- Factor 1 has high loading of Cl, representing sea salt source.
- K is the dominant element in Factor 2, suggesting that it may relate to biomass burning.
- Br is associated with Factor 3, suggesting Factor 3 is motor vehicle source.
- High concentrations of Al, Si, Fe, Ca, and K in Factor 4 identifies that it is crustal material. The temporal trend shows that it has higher contribution between November and March, corresponding to warm and dry season in Accra.
- Factor 5 is dominated by S, this source could be attributed to transported emissions from distant sources.
- The presence of Al, Si, Ca, Fe in Factor 6 is possibly the result of road dust.
- Factor 7 is associated with Zn. It may relate to industrial source.

CONCLUSIONS

- PMF identified 7 source factors for PM2.5 samples collected in Nima Sites. They are sea salt, biomass burning, motor vehicle, crustal material, sulfur source, road dust and industrial source.
- Biomass burning was found to be the most important contributor, accounting for 38% of total PM2.5 mass concentration on average.
- Crustal material was another major source of fine PM pollution, with significant contribution during dry season in Accra (November to March).

REFERENCES

Dionisio KL,et al.(2010) Air pollution in Accra neighborhoods: Spatial, socioeconomic, and temporal patterns. Environ Sci Technol 44:2270-2276.