SOURCE APPORTIONMENT OF PM_{10} IN BOGOTÁ, COLOMBIA

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1. INTRODUCTION

Bogota, Colombia's capital, is the largest city in the country. Bogota has 7 million inhabitants, comprises 17% of the total population, and generates 23% of the national Gross Domestic Product (GDP). As a result of its economic growth, Bogota's air is among the most polluted in Latin America. Analysis of monitoring network data shows that PM_{10} is the contaminant of most concern in the city with values near 55 $\mu g/m^3$ annual average, with some areas of the city experiencing higher values[1;2]. Previous work regarding PM_{10} in Bogotá partially addressed characterization of air quality samples; especially Pachón et al[7] who analyzed samples for carbonaceous material, organic carbon (OC) and elemental carbon (EC), and water soluble ions (SO_4^{2-}, NO_3^-, NO_2^-, $HCOO^-$, Cl^-, NH_4^+, $Ca2^{2+}$, K^+, Na^+). They concluded that the carbonaceous fraction was about 60% of total PM_{10}, and identified that secondary aerosol significantly contributed to PM_{10}. However, recent work disagrees with this result[8]. Metals have been analyzed[9] and Ag, Cu, Zn, Fe, and Pb were identified. Rivera and Behrentz[8] ran a Principal Component Analysis (PCA) source apportionment for three sites in Bogotá, based on characterization of PM_{10} and $PM_{2.5}$ samples. They analyzed samples for ions (Cl^-, NO_3^-, $SO_4^=$ and PO_4^{-3}; Na^+, NH_4^+, K^+, Mg^{+2} and Ca^{+2}) and metals (Fe, Al, Mg, Ca, K, Mn, Ga, Ba, Na, Cr, Ni, Zn, Cu), but not for carbonaceous material so the contribution of carbon to PM_{10} in the city could not be assessed.

In order to better understand the origin of PM_{10} in Bogotá, this study shows the results of characterization and source apportionment of air quality measurements at two different sites. The work focuses on PM10 because this is the size fraction for which the Colombian PM standard for air quality is regulated.

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2. EXPERIMENTAL

Two sites were chosen in different zones of the city. A total of 110 daily samples were collected, 55 at every site 1 (Suba) and 2 (Carvajal. Sites 1 is mostly residential, while site 2 has apartments and medium-size industries nearby.

Sampling site selection addressed neighborhood-scale EPA criteria. Harvard impactors for PM_{10} were used with a flow between 9.5 and 10.5 L/min at Bogota's environmental conditions (15ºC, 560 mmHg). Quartz and PTFE 37 mm filters were used at every site. Filters were conditioned for 24 hours at 15 ºC and 45±5% RH prior to gravimetric analysis before and after the sampling period. After gravimetric analysis, the filters were kept refrigerated (-5ºC) to avoid volatilization of some components.

The samples were analyzed at the Georgia Institute of Technology for organic carbon (OC) and elemental carbon (EC) using Thermal Optical Transmittance (Sunset Labs TOT), and water soluble ions (SO_4^{2-}, NO_3^-, NO_2^-, Oxalate$^=$, Cl^-, NH_4^+, Ca^+, K^+, Na^+) using ion chromatography IC (Dionex300DX). Energy Dispersive – X-Ray Fluorescence (ED-XRF) was performed in the Alpha 1 Lab in Bogotá, following EPA Method IO3.3.

Based on characterization data PMF software was used. The uncertainties were calculated for every characterization method and species. The numbers of factors tested were between 3 and 7 until the best adjustment to data results was achieved.

3. RESULTS AND DISCUSSION

The PM10 concentrations found were lower than the expected; the box plots are shown in figure 1.

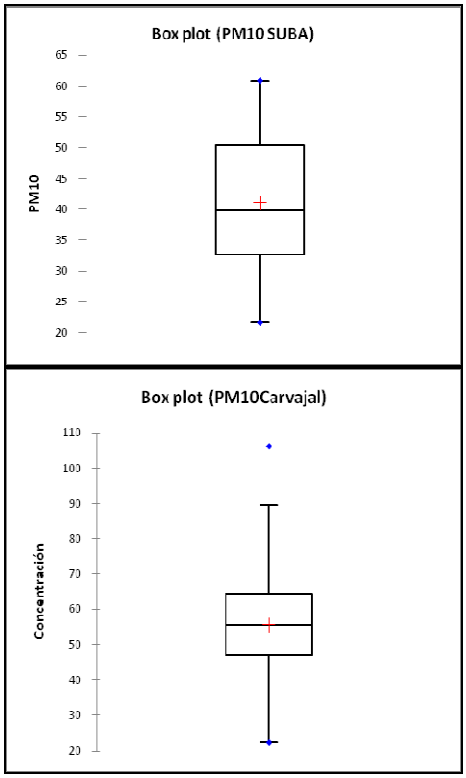
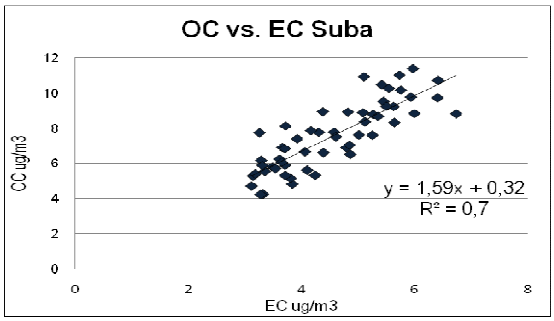


Fig. 1. Box plots PM10 concentration

The largest component of PM10 is, by far, the carbonaceous fraction accounting for 50 to 65 % of the mass. Figure 2 shows the relationship between OC and EC. This relationship is related to the diesel sulfur content. Diesel sulfur was 1200 ppm during the sampling period; however, currently diesel sulfur is 300 ppm due to reduction of sulfur by the Colombian oil company in second quarter 2009[15]. The relationship between OC and EC is also a function of the use of aged buses in the traditional transportation system and of the driving patterns in Bogotá[8].



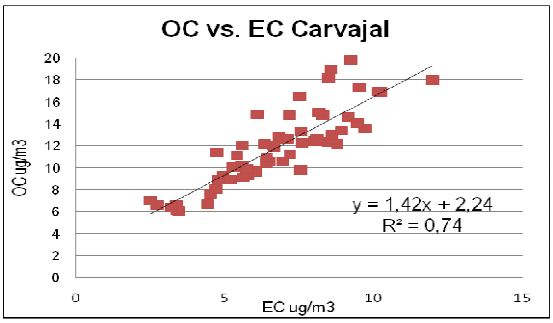
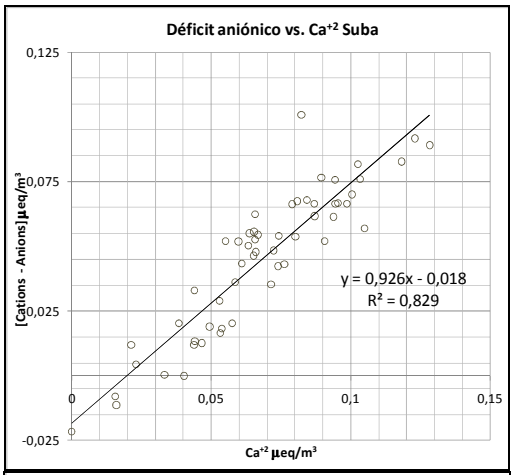


Fig. 2. Elemental Carbon vs. Organic Carbon

The sampling points have different OC vs. EC relationships; this may be due to different sources near the sites or to differing meteorological conditions[14]. . Based on characterization data, a mass closure was calculated following Lewis et al[12]. From ionic analysis, carbonate ion was identified and taken into account for mass closure as calcium carbonate.



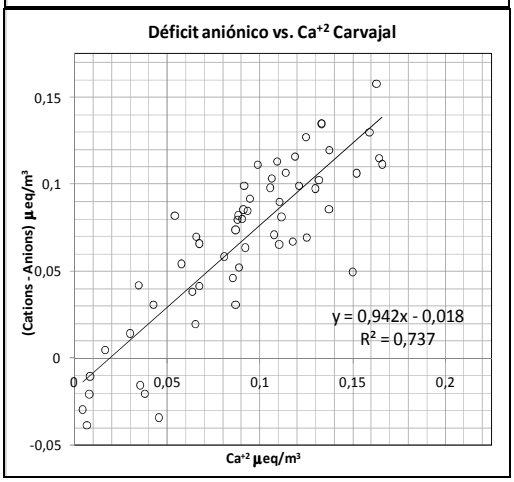


Fig. 3. Calculated calcium carbonate vs. calcium ion

Organic matter was calculated as 1.6*OC[13]. The PM_{10} mass closure is shown in Figure 3 (unidentified mass is between 5 to 10%, not shown).

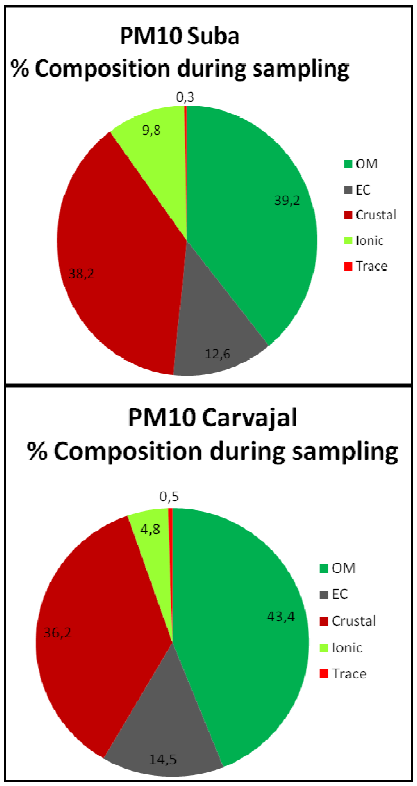
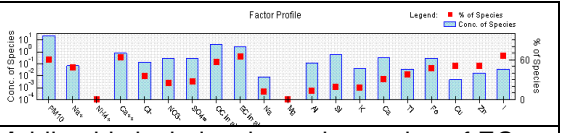
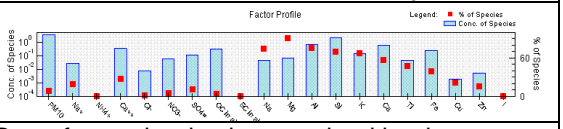


Fig. 3. Mass closure

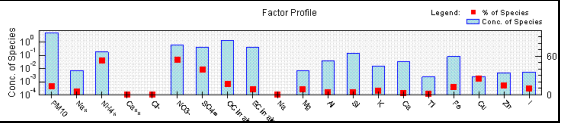
The PMF model was run independently for every site. Our preliminary finding is that factors identified are similar with a huge portion of PM10 associated with mobile sources. The Factors identified are shown in the next figures:



Mobile: this includes the major portion of EC, OC and some Ca^{+2}, associate to $CaCO_3$.



Dust: factor that is characterized by the content of Al, Si, K, Fe and Ti. There are OC and EC too.



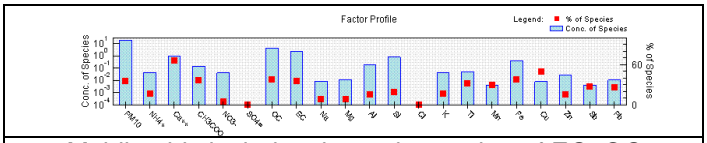
Secondary pollutants: this factor shows nitrate and sulfate together
Ionic long range transportation: Presence of ammonium, chloride and sodium ion.

Table. 1. Factors Resolved for Suba.

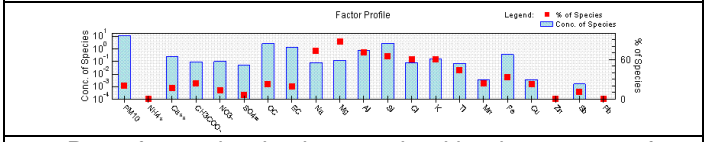
The apportionment of each factor are shown in

Factor	% Apport
Mobile	60
Dust	9
Secondary pollutants	13
Ionic	18

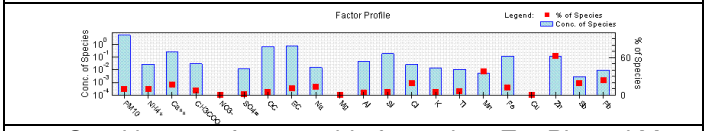
Table. 2. Factor Apportionment in Suba



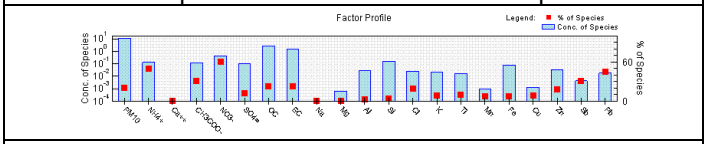
Mobile: this includes the major portion of EC, OC and some Ca^{+2}, associate to $CaCO_3$.



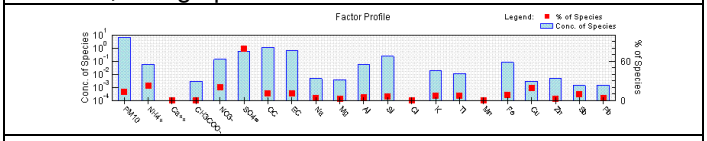
Dust: factor that is characterized by the content of Al, Si, K, Fe and Ti. There are OC and EC too.



Smelting non ferrous: this factor has Zn, Pb and Mn. Near the receptor site there is and semelter process



Nitrate rich/movil: high content of nitrate, 20% Ec and OC, a huge portion of Pb and Sb.



Sulfate rich: There is the highest content of sulfate.

Tabla 3. Factors Resolved for Carvajal.

The apportionment of each factor are shown in Table 4.

Factor	% Apport
Mobile	35.3
Dust	20.8
Nitrate rich/mobile	20.7
Sulfate rich	13
Smelting non ferrous	10.2

Table. 4. Factor Apportionment in Carvajal

As shown, the main factor is mobile, composed of mobile sources and associated dust. The dust factor is associated with fugitive windblown dust. In Carvajal dust is 20.8% of total PM10 and to Suba where dust is 9%, this difference among sites is mainly due is the proximity of the sites to unpaved roads. Industrial factors are higher in Carvajal, which may be due to the medium size industries in the sector. This site also shows higher concentrations of Pb, Cd, and Zn. The percentage of secondary pollutants is higher in the factor apportionment than in the chemical analysis; the additional mass is related to the EC, OC, and some crustal material related to these factors.

4. CONCLUSIONS

The major apportion to PM_{10} in Bogotá are associated to carbonaceous fractions which are mainly produced by combustion process. These fractions are more than 50% of PM10.

Crustal fractions, associated to resuspended matter and fugitive dust are a great part of PM_{10} and it is between 36 y un 38%. The ionic fraction was found between 5 and 8 %.

These results show that the composition and levels of PM_{10} in Bogotá varied significantly among sites, however systematic sampling and characterization of PM_{10} and $PM_{2.5}$ is needed in order to increase the samples numbers and improve PMF results. Further research is needed for $PM_{2.5}$ composition and source apportionment as well as additional monitoring should be conducted at different sites in the city to better understand the spatial variability in PM composition.

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