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The Impact of Sugar Cane Burning Emissions on the Respiratory System of Children and Elderly

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Abbreviations:

Al – Aluminum

BC – Black Carbon.

Br – Bromine

Ca – Calcium

Cl – Chlorine

Cr – Chromium

Cu – Copper

Fe – Iron

ICD – International Code of Diseases

K – Potassium

Mn – Manganese

Ni – Nickel

P – Phosphorus

Pb – Lead

PIXE – Particle Induced X- ray Emissions

$PM_{10}$ – particles with aerodiameter equal to or smaller than 10 micrograms per cubic meters.

$PM_{2.5}$ - particles with aerodiameter equal to or smaller than 10 micrograms per cubic meters.

S – Sulfur

SFU – Stacked Filter Units

Si – Silicon

Tg – teragram (one million metric tons)

Ti – Titanium

V – Vanadium

Zn – Zinc

**ABSTRACT**

The influence of sugar cane burning emissions on the respiratory system was analyzed during almost one year in the city of Piracicaba, in southeast Brazil. From April 1997 through March 1998, samples of inhalable particles were collected, separated into fine and coarse particulate mode and analyzed for black carbon and tracer elements. At the same time, daily records of children (under 13 years of age) and elderly people (older than 64 years of age) hospital admissions due to respiratory diseases were examined. Generalized linear models with natural cubic splines to control for season and linear terms to control for weather were adopted. Analyses were carried out for the entire period as well as for burning and non-burning periods. Additional models using three factors obtained from factor analysis instead of particles or tracer elements were built. Increases of 10.2 $\mu g/m^3$ in $PM_{2.5}$ and 42.9 $\mu g/m^3$ in $PM_{10}$ were associated with increases of 21.4% (95% CI 4.3;38.5) and 31.03 % (95% CI 1.25 - 60.21) in child and elderly respiratory hospital admissions, respectively. When we compared periods, the effects during the burning period were much higher than the effects during non-burning period. Elements generated from sugar cane burning (Factor 1) were those most associated with both children and elderly respiratory admissions. Our results show the adverse impact of sugar cane burning emissions on the health of the population reinforcing the need for public efforts to reduce and eventually eliminate this source of air pollution.

## INTRODUCTION

The impact of biomass and fossil fuel burning is felt throughout the world. While studies have documented the impact of fossil fuel air pollution on health (Braga et al. 2001; Hoek and Brunekreef 1994; Hoek et al. 1997; Laden et al. 2000; Lin et al. 1999; Pope et al. 1995; Saldiva et al. 1994; Schwartz and Dockery 1992; Schwartz et al. 2001) there is a scarcity of information on biomass burning (Arbex et al. 2000; Brauer and Hisham-hashim 1998; Long et al. 1998; Phonboon et al.1999; WHO 1998). Most biomass burning is carried out in developing countries and is done to clear land for shifting cultivation, to convert forests to agricultural or pastoral lands, and to remove dry vegetation in order to promote agricultural productivity. Burning of agricultural wastes in the field, such as sugar cane and stalks from grain crops is another important type of biomass burning (Artaxo et al. 1999; Crutzen and Andrea 1990).

Biomass burning emissions represent an important global source of particles and gases to the atmosphere, especially in the tropics where biomass burning is widespread. Annually, 7,500 to 8,600 Tg of dry material is emitted to the atmosphere around the world through the process of burning. About 43% of this dry material is derived from savannah burning, 23% from the burning of agricultural waste, 18% from rainforest burning and 16% from wood burning used to produce fuel (Levine et al. 1995). Biomass burning emits large amounts of carbon and particulate matter. Estimates show that the annual carbon and particulate matter released to the atmosphere due to biomass fires in the tropics is around 2,000 to 4,500 Tg and 36 to 154 Tg, respectively (Crutzen and Andrea 1990).

Brazil plays an important role in biomass burning emissions. Most of the fires in Brazil occur during the dry season, from May to October. An especially critical area in the country is the Amazon region, where every year approximately 17,000 km$^2$ of tropical forests are cut down and most of them burned. Until now, of the total Amazon area (5.5 million of $Km^2$) 14% has been deforested (INPE 2002).

In Sao Paulo State, located in the southeastern region of Brazil, most of the fires are generated in agricultural fields, especially sugar cane crops, in which 20 tons per hectare are burned every year to facilitate harvesting. Sugar cane fires also have significant effects on the composition and acidity of rainwater over large areas of southeastern Brazil due to the emissions of aerosol and trace gases (Lara et al. 2001). Aerosols can also cause injury to human health. Small particles, particularly those less than 2.5 µm in diameter ($PM_{2.5}$), appear to have the greatest potential for damaging health because they can penetrate deep into the lungs and reach the lower respiratory system (Committee of Environmental and Occupational Health of the American Thoracic Society 1996). Despite its importance, little information about the aerosol particles emitted from sugar cane burning is available (Lara et al. 2005; Martinelli et al. 2002;).

Within this scenario, the Piracicaba region, located in Sao Paulo State, is especially interesting because the atmosphere of this region receives emissions not only from industrial and urban sources, but also and primarily from sugar cane burning (Lara et al. 2001). In this study, we investigated the influences of particulate matter generated from sugar cane burning on child and elderly respiratory hospital admissions.

## DATA AND METHODS

*Study Area and Sampling*

The city of Piracicaba is located in the western part of the Piracicaba River basin, in Sao Paulo State and has a population of approximately 320,000 inhabitants, and a population density of 242 inhabitants/km$^2$ (Figure 1). The land use in this area is dominated by sugar cane plantations (80%), followed by pastures (11%), urban areas (6%) and finally forests (3%) (CENA 1997). Sugar cane is burned every year from May to October, during the dry season, while the wet season extends from November to April.

From April 1997 through March 1998 samples of inhalable particles ($PM_{10}$) were taken from 4 Stacked Filter Units (SFU) in two separated size fractions: fine particulate mode, PM2.5 ($dp<2.5$ µm) and coarse mode, CPM ($2.5<dp<10$µm). Each filter unit was 47 mm diameter nuclepore polycarbonate filters and was taken every 72 hours. Samplings were obtained at the meteorological station of the "Escola Superior de Agricultura Luiz de Queiroz – ESALQ", wich is located about 4 km from downtown Piracicaba and less than 1 km from the nearest sugar-cane plantation. The SFU inlets were located 3 meters above the ground to minimize direct the influences of local resuspended soil dust. The dominant wind direction was from the sugar-cane plantations to the sampling station. Gravimetric mass and black carbon were measured in the Nuclepore filters. Black carbon (BC) was measured by a reflectance technique according to the method developed by Reid et al. (1998).

Elemental composition was measured by PIXE (Particle Induced X-ray Emission) (Johansson and Campbell 1998), a multi elemental technique that allows the identification of about 21 elements (Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, Se, Br, Rb, Sr, Zr, Pb). PIXE detection limits are about 1 ng.m$^{-3}$ for elements with $Z > 20$, and about 10 ng.m$^{-3}$ for elements from Na to K. More details about PIXE technique and aerosol sampling can be obtained from Artaxo et al. (1999) and Yamasoe et al. (2000).

In order to investigate the respiratory health effects on the Piracicaba population, daily records of child (under 13 years of age) and elderly (older than 64 years of age) hospital admissions due to respiratory diseases were obtained (ICD $9^{th}$ revision: 460-519; and ICD $10^{th}$ revision: J00-J99) from the Government Health Agency (DATASUS) from April 1997 to March 1998. The Agricultural School of São Paulo University (ESALQ) located in Piracicaba provided daily records of minimum temperature and relative humidity.

*Statistical analysis of air pollutant health effects*

Counts of daily respiratory hospital admissions for children and elderly were modeled separately for the entire period in Poisson regressions. The generalized linear model (McCullagh and Nelder 1989) with natural cubic splines (Green and Silverman 1994) was adopted to control for season. Splines were used to account for the non-linear dependence of the hospital admissions on that covariate.

The purpose of the function of time is to remove the basic seasonal pattern (and long term trend) from the data. If each admission were an independent event, we would expect no serial correlation in the data. Seasonal patterns for each endpoint (child and elderly respiratory hospital admissions) were modeled. Because we assumed that seasonal patterns would vary according to the adopted endpoint, endpoint-specific time smoothing parameters were used.

It was not necessary to incorporate autoregressive terms (Brumback et al. 2000) in the models because autocorrelation plots showed there were no remaining serial correlations in the residual.

Indicators for day of the week were included in order to control for short-term trends.

Respiratory diseases present an almost linear relationship with weather. Therefore, linear terms for temperature and relative humidity were adopted. In order to reduce sensitivity to outliers in the dependent variable robust regression (M-estimation) was used.

Three day moving averages of black carbon, particulate matter and their main tracer elements to estimate the effects on respiratory morbidity.

For each age group, using the coefficients of the pollutants that presented adverse effects on respiratory hospital admissions for the entire period, the effects in two different periods were estimated: burning (May to October) and non–burning (November to April).

Additionally, due to the large number of elemental components, specific rotation factor analysis was performed to identify main factors that could represent the main sources of air pollution in Piracicaba (Weiss, 1971), reducing the analysis to a small number of factors. Factor analysis is a multivariate technique that allows for the combination of multiple variables into few factors based on their degree of correlation; thereby reducing the number of elements included in the analysis. Using Varimax rotation technique, 3 main factors were identified, from the 17 tracer elements mentioned above: biomass burning and soil dust (factor 1), industrial emissions (factor 2) and fuel or automotive emissions (factor 3) (Table 1). Additional models using the factors instead of tracer elements in single and three-factor models were built.

Results were expressed in terms of percentage increases in respiratory hospital admissions for interquartile range increases in air pollutant concentrations.

To carry out the statistical analyses S-Plus (version 4.536) was used.

## RESULTS

At the time of the study, 26% of the Piracicaba population were children and adolescents under 13 years of age while 7% were older than 64 years. There were 673 hospital admissions due to respiratory diseases among children and 275 among the elderly. Table 2 shows the daily descriptive analysis of child and elderly respiratory hospital admissions and temperature and humidity of the city of Piracicaba during the study period. The average number of child respiratory hospital admissions was more than twice that of the elderly. However, as presented above, the child population was almost four times the elderly population. The weather in Piracicaba is warm (climate characterized as sub-tropical C) and low temperatures are very rare.

Table 3 presents the descriptive analysis of the particulate matter and its main elements measured during the entire period of study, burning and non-burning periods. Concentrations of $PM_{10}$, $PM_{2.5}$, and black carbon presented large seasonal variability with higher concentrations during the burning period compared with non-burning period. The same behavior is observed in the elements generated mainly by biomass burning and soil dust. Their concentrations increased from two to four fold between non-burning and burning periods. During the entire period of study, the $PM_{10}$ concentration surpassed the standard limit adopted for this pollutant (50 $\mu g/m^3$).

Daily variations in $PM_{10}$ and $PM_{2.5}$, as well as in BC, Al, Si, and K, which are products of biomass burning and soil dust (Lara et al., 2005), were significantly associated with child respiratory hospital admissions even after controlling for season and weather (Figure 2). Manganese and sulphur, proxies of industrial and automotive emissions, respectively, also presented effects on respiratory hospital admissions.

Furthermore, was observed associations between daily variations in $PM_{10}$, BC, and K and elderly respiratory hospital admissions for the entire period (Table 4).

Figure 3 presents the estimated percentage increases in children respiratory hospital admissions divided by periods (burning and non-burning seasons). We observed that $PM_{2.5}$, $PM_{10}$, black carbon and those elements from fine particles generated from biomass burning and soil dust promoted higher effects during the burning period than during the non-burning period. Because the burning period is also the period with lower humidity and temperature, which impair air pollution dispersion, increases were observed in the elements generated from other sources and, consequently, higher respiratory effects resulted.

Among the elderly (Figure 4), we also observed significant increases in respiratory hospital admissions due to increases in $PM_{10}$, black carbon and K, a proxy of biomass burning, during the sugar cane burning period. Manganese, a proxy of industrial emissions, presented significant associations with elderly hospital admissions during the non-burning period, showing a different pattern of susceptibility than those observed among the children.

Models using factors (1-biomass burning and soil dust, 2-industrial emissions, and 3-automotive emissions) instead of pollutants and tracer elements were essential in specifying the source with the major impact on respiratory diseases among elderly and children. Factor 1 presented the highest effect on respiratory hospital admissions in both single and three-factor models for children (Table 5) and elderly (Table 6).

## DISCUSSION

Differently from large cities, such as Sao Paulo, Santiago del Chile, New York, Baltimore and cities of Pakistan and China, where the main sources of aerosol particles are emissions linked to fossil fuel combustion (Artaxo et al. 1999; Castanho and Artaxo 2001; Conner et al. 2001; Lena et al. 2002; Zhang et al. 2002), the main source of aerosol in the city of Piracicaba is biomass burning (Martinelli et al. 2002). In Piracicaba city, sugar cane burning contributed with 60% of the fine mode aerosol mass. The second major source was re-suspended soil dust representing 14% of the $PM_{2.5}$. Industry and oil combustion each contributed with 12% of the total fine particulate mass (Lara et al., 2005).

Studies have already shown that land use can influence the atmospheric composition in the Amazon Basin (Artaxo et al. 1999; Yamasoe et al. 2000) and in the State of Sao Paulo (Lara et al. 2001; Martinelli et al. 2002). Particularly, in the Piracicaba basin, the main land-use is sugar cane plantations covering almost 80% of the total area.

In the present study, increases in $PM_{10}$ and $PM_{2.5}$ were strongly associated with respiratory hospital admissions. The magnitudes of those effects were slightly higher than that found in the largest Brazilian city (Braga et al. 1999; Braga et al. 2001; Lin et al. 1999). It is important to observe that when the magnitude of the effects of $PM_{10}$ and $PM_{2.5}$ were assessed for the same endpoint there were no differences between them. It could be explained by the fact that we worked with total $PM_{10}$ measurements instead of just the coarse mode fraction. Hence, it is possible to assume that the effects observed for $PM_{10}$ include $PM_{2.5}$ effects.

However, in a region with at least three important sources of particulate air pollution, i.e. biomass burning and industrial and automotive emissions, it is necessary to identify the air pollution source responsible for most of the respiratory hospital admissions. In this context, the association of elemental components of fine particles that are generated mainly from biomass burning and soil dust (BC, Al, Si, and K) and the results of factor analysis showing that factor 1 (biomass burning) was the most associated with respiratory hospital admissions, reinforced the role of this source of air pollution on children and elderly respiratory diseases in this region, despite the contribution of industrial and automotive emissions.

The use of factor analysis to identify and apportion ambient concentrations to sources has been used in the past, and an EPA-sponsored workshop has explored the use of resolved source contributions in health effects models. For this workshop multiple groups of investigators have analyzed particulate composition data sets from 2 US cities, and, although different factor analysis methods were used, similar source profiles were extracted from these sets, with a good agreement among the major resolved source types. The same investigators found also similar health effects associations (Hopke et al. 2005; Ito et al. 2005; Laden et al. 2000; Mar et al. 2005). In our data set, we had one year of daily data, which is less than in the above studies; the factor analysis chose only some factors, and in the model we adjusted for all potential confounders, which have been shown to be the most relevant. The associations of health effects with the metals is still under investigations, and yes, some associations might be due to chance, but evidence has been found in the past and we believe that our results are not due by chance, even though other studies are needed to confirm these findings.

Studies have shown that population exposure to high levels of pollutants can increase the risk of acute respiratory infections, chronic obstructive pulmonary disease and lung cancer (Smith et al. 1999). Children are the most susceptible group. Studies performed in the city of São Paulo already showed adverse effects of particles on inflammatory and infectious diseases of both upper and lower respiratory tracts (Farhat et al., 2005; Lin et al., 1999). Indeed, acute lower respiratory infections are the single most important cause of mortality in children under 5 years of age (Bruce et al. 2000). Globally, about 43 % of the total burden of disease due to environmental risks falls on children under 5 years of age, although they make up only 12 % of the population (Smith et al. 1999).

This study adopted total respiratory hospital admissions of children and elderly instead of specific-respiratory disease diagnoses due to the small number of events observed in the city during the study period. Moreover, this approach avoid misclassification of disease-specific diagnose.

Around the city of Piracicaba the percentage increase in child respiratory hospital admissions in relation to the mean levels of $PM_{10}$, $PM_{2.5}$, BC, Al, Si, Mn, K, and S was higher (2 – 3 times) in the burning season than in the non-burning season, compromising the health of this population. Among the elderly, the same pattern of effects were observed between burning and non-burning periods. It undoubtedly shows that the months of the year when sugar cane is burned are the most dangerous for the inhabitants of the region.

In fact, the association between exposure to indoor and outdoor biomass smoke and health effects has already been reported in some areas of Asia and India (Behera et al. 1994; Phonboon et al., 1999). Deposition of carbon in the lungs occurred consistently in patients exposed to biomass burning (Bruce et al. 2000). However, differently from most of the mentioned regions where outdoor biomass burning events are episodic, in Piracicaba and other Brazilian sugar cane plantation areas biomass burning is a common usual and scheduled activity exposing the population on a regular basis.

The mechanisms whereby the particles cause airway diseases have been studied. It has been suggested that oxidative stress, caused by the release of oxidant radicals by inflammatory cells, may be an important component in promoting inflammation and respiratory cell damage, compromising pulmonary function, increasing susceptibilities to allergens and increasing the incidence of respiratory infections (Bernstein et al., 2004; Bruce et al. 2000).

It is important to remember that the population of these areas has been exposed to sugar cane burning for at least 6 months every year for the last 4 decades. The health effect is determined not just by acute exposures to high pollution levels but also, and more importantly, by the length of time that people spend breathing polluted air chronically. Similar to this study, the acute effect of sugar cane-generated air pollution was assessed previously in Sao Paulo State (Arbex et al., 2000). However, the magnitude of chronic effects is not known.

Alcohol produced from sugar cane is a renewable fuel and less pollutant than fossil fuel. Brazil is the largest producer of sugar and alcohol from sugar cane in the world. Plantations cover about 5 million hectares and surround a great number of cities, mainly in the southeastern region of the country. About 80% of the sugar cane crops are burned to facilitate harvesting every year (Brazilian Agriculture Ministry, 2005).

The addition of alcohol in gasoline and national policies to reduce automotive emissions contributed to a decrease in air pollution in Brazilian urban centers in the last 20 years. Nowadays, the use of alcohol as automotive fuel is under study or has already been partially adopted in many countries. Hence, it is clear that ethanol production will tends to grow in this century. To avoid secondary health damages the procedure of burning the crops before harvesting should be banished.

In summary, we showed that air pollution from biomass burning cause damage to the respiratory system leading to an increase in respiratory hospital admissions. This effect is higher for children and elderly and it is similar to that observed in urban areas due to exposure to industrial and vehicular-emitted air pollutants. Finally, it is necessary to keep in mind the close relation between health effects and air pollution. This concern should be included in public efforts for sustainability and improving environmental health conditions.

**Competing financial interest:**

There is no competing financial interest in this paper.

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Table 1. Factor Analysis using Varimax rotation for $PM_{2.5}$ tracer elements.

| Tracer elements of $PM_{2.5}$ | Factors (Main Sources) | | | Communalities |
|---|---|---|---|---|
| | Biomass Burning | Industrial | Automotive | |
| Si | .876 | .221 | .382 | .911 |
| S | .509 | .090 | .856 | .889 |
| Cl | .475 | .051 | .726 | .763 |
| K | .888 | -.045 | .385 | .898 |
| V | .295 | .288 | .665 | .973 |
| Fe | .619 | .671 | .377 | .874 |
| Ni | .283 | .317 | .686 | .982 |
| Cu | .256 | .678 | .200 | .910 |
| Zn | .039 | .836 | .086 | .879 |
| Br | .610 | .415 | .238 | .813 |
| Pb | -.089 | .640 | -.004 | .913 |
| % Variance | 59 | 21 | 10 | |

Table 2: Descriptive analyses of child and elderly respiratory hospital admissions, temperature and humidity of Piracicaba city during the study period

| | Daily Mean | SD[a] | MIN.[b] | IQR[c] | MAX[d]. | N[e] |
|---|---|---|---|---|---|---|
| **Hospital Admissions** | | | | | | |
| Children | 2.2 | 1.7 | 0.0 | 2.0 | 8.0 | 306 |
| Elderly | 0.9 | 1.0 | 0.0 | 1.0 | 5.0 | 306 |
| **Weather** | | | | | | |
| Minimum Temperature ($^{o}$C) | 15.8 | 4.1 | 5.5 | 6.5 | 23.2 | 298 |
| Relative Humidity (%) | 81.7 | 9.5 | 52.0 | 12.0 | 100.0 | 298 |

[a] standard deviation; [b] minimum; [c] interquartile range; [d] maximum; [e] number of days

Table 3. Descriptive analysis of $PM_{10}$, $PM_{2.5}$, BC (concentrations in μg/m$^3$), Al, Si, S, K, and Mn (concentrations in ng/m$^3$) in entire period of study, burning and non-burning seasons.

| | Entire Period | | | Burning Period | | | Non-Burning Period | | |
|---|---|---|---|---|---|---|---|---|---|
| Pollutant | Mean | SD[a] | IQR[b] | Mean | SD | IQR | Mean | SD | IQR |
| $PM_{10}$[c] | 56.1 | 49.8 | 42.9 | 87.7 | 57.9 | 89.5 | 28.9 | 12.8 | 15.0 |
| $PM_{2.5}$[c] | 16.1 | 12.4 | 10.2 | 22.8 | 14.7 | 17.3 | 10.0 | 4.6 | 5.5 |
| BC[c] | 2.1 | 2.0 | 1.9 | 4.2 | 2.3 | 2.9 | 1.8 | 0.7 | 1.0 |
| Al[d] | 166.3 | 260.7 | 193.7 | 370.8 | 317.5 | 480.1 | 157.9 | 149.7 | 124.9 |
| Si[d] | 404.5 | 369.1 | 275.7 | 545.3 | 462.9 | 669.2 | 283.9 | 201.8 | 234.6 |
| S[d] | 1362.1 | 1049.2 | 1009.6 | 1922.9 | 1237.5 | 1370.5 | 881.4 | 497.2 | 492.7 |
| K[d] | 380.2 | 359.0 | 383.5 | 626.6 | 390.4 | 539.1 | 168.9 | 113.4 | 114.2 |
| Mn[d] | 12.6 | 10.0 | 9.0 | 16.9 | 12.4 | 12.3 | 8.8 | 4.6 | 6.82 |

[a] standard deviation; [b] interquartile range; [c] concentrations are expressed in μg/m$^3$; [d] concentrations are expressed in ng/m$^3$

Table 4. Percentage increases and 95% confidence intervals in elderly respiratory hospital admissions due to interquartile range increases in $PM_{10}$, BC and K during the period of study.

| Pollutant | Percentage Increase (95% CI) |
|---|---|
| $PM_{10}$ | 31.03% (1.25 – 60.81) |
| BC | 36.41% (11.14 – 61.68) |
| K | 46.74% (11.67 – 81.82) |

Table 5. Regression coefficients, standard errors, and statistical significance of the models for children respiratory hospital admissions using single or three factors as independent variables.

| | Models | | | | | |
|---|---|---|---|---|---|---|
| | Single Factor | | | Three-Factor | | |
| | β[a] | SE[b] | p[c] | β | SE | p |
| Biomass Burning | 0.1996 | 0.1138 | 0.0867 | 0.2138 | 0.1180 | 0.0775 |
| Industrial | 0.0722 | 0.0922 | 0.4378 | 0.0559 | 0.0921 | 0.5470 |
| Automotive | 0.0426 | 0.0949 | 0.6559 | 0.0832 | 0.0935 | 0.3791 |

[a] regression coefficient; [b] standard error; [c] statistical significance

Table 6. Regression coefficients, standard errors, and statistical significance of the models for elderly respiratory hospital admissions using single or three factors as independent variables.

| | Models | | | | | |
|---|---|---|---|---|---|---|
| | Single Factor | | | Three-Factor | | |
| | β[a] | SE[b] | p[c] | β | SE | p |
| Biomass Burning | 0.4156 | 0.1522 | 0.0092 | 0.3527 | 0.1644 | 0.0380 |
| Industrial | -0.0990 | 0.1380 | 0.4771 | -0.0703 | 0.1356 | 0.6070 |
| Automotive | -0.3009 | 0.1767 | 0.0961 | -0.1753 | 0.1541 | 0.2622 |

[a] regression coefficient; [b] standard error; [c] statistical significance

Figure 1. Location of the city of Piracicaba (sampling site) in Sao Paulo State, southeastern Brazil.

Figure 2. Percentage increases and 95% confidence intervals in child respiratory hospital admissions due to interquartile range increases in $PM_{10}$, $PM_{2.5}$, BC, Al, Si, Mn, K and S during the period of study.

Figure 3. Percentage increases and 95% confidence intervals in child respiratory hospital admissions due to mean levels of $PM_{10}$, $PM_{2.5}$, BC, K, Si, Mn, Al and S during burning (solid symbols) and non-burning periods.

Figure 4. Percentage increases and 95% confidence intervals in elderly respiratory hospital admissions due to mean levels of $PM_{10}$, BC, K, and Mn during burning (solid symbols) and non-burning periods.

Figure 1

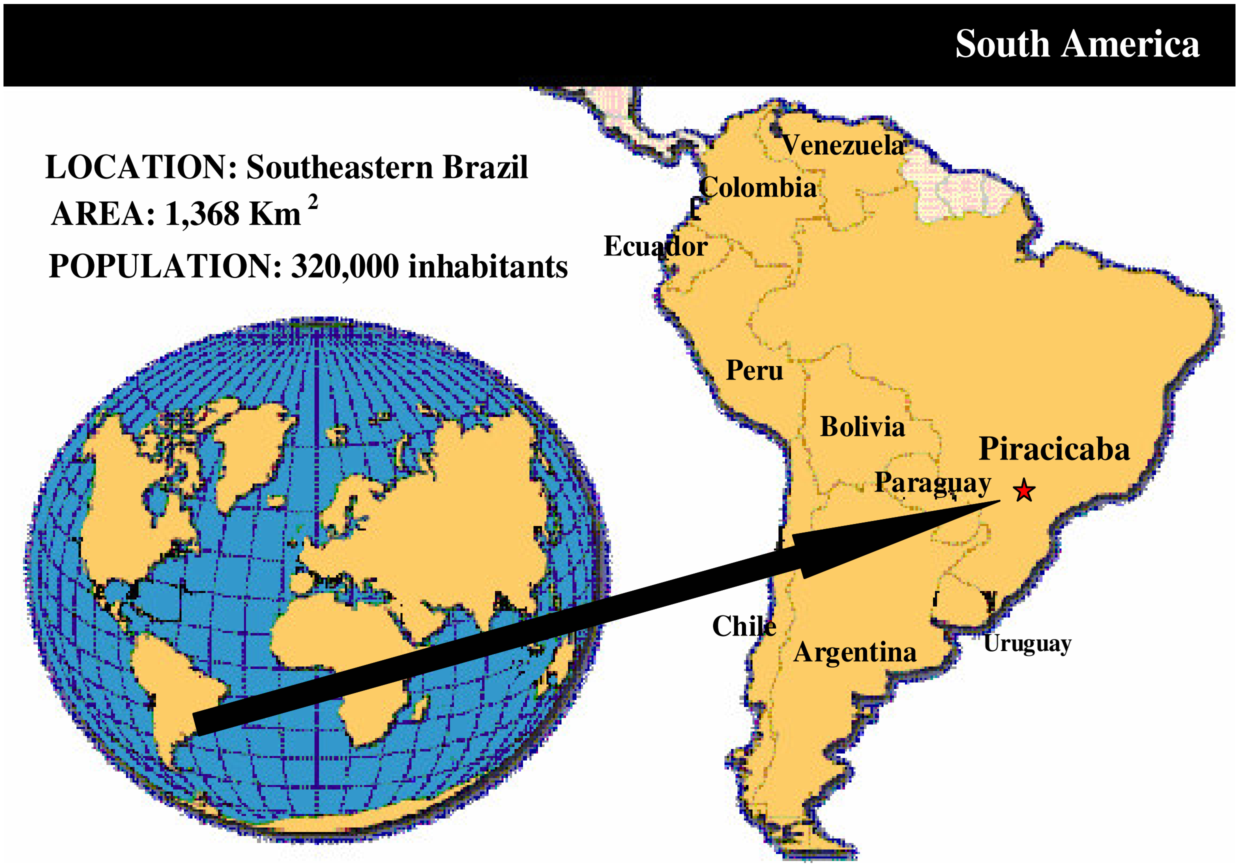

South America
LOCATION: Southeastern Brazil
AREA: 1,368 Km 2
POPULATION: 320,000 inhabitants
Venezuela
Colombia
Ecuador
Peru
Bolivia
Piracicaba
Paraguay
Chile
Argentina
Uruguay

Figure 2

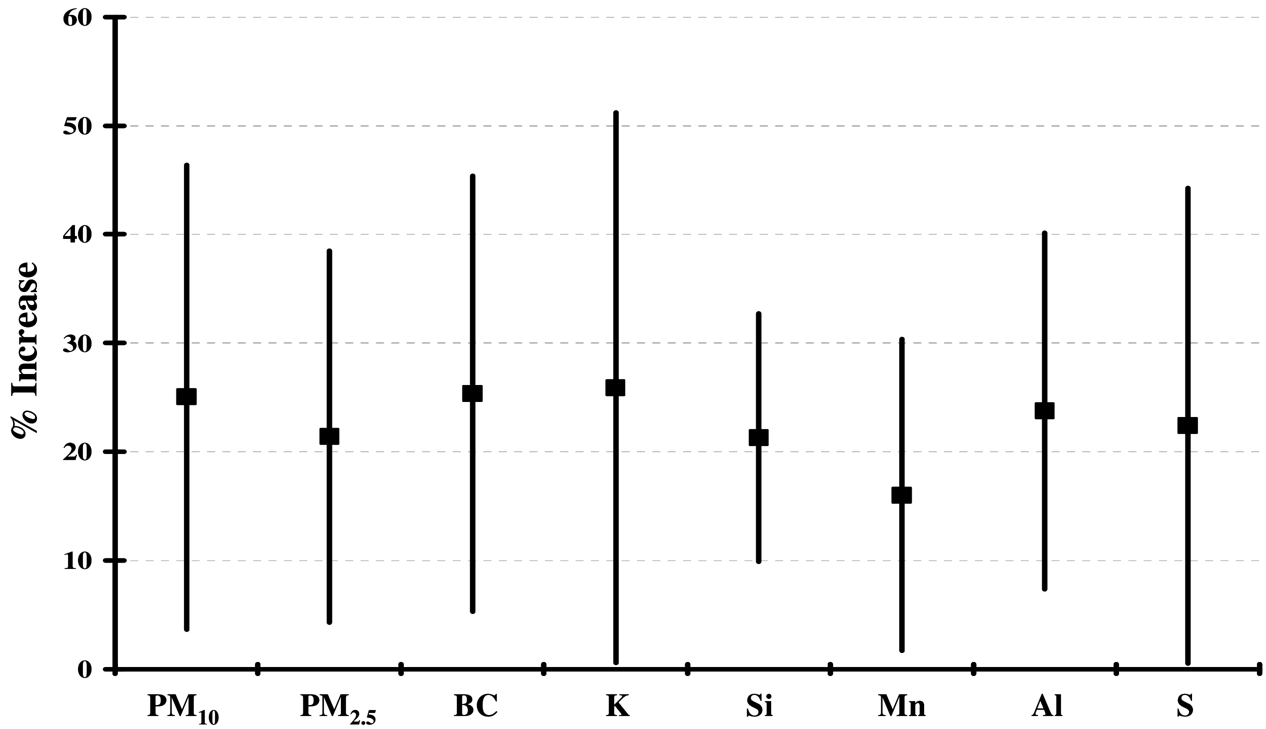
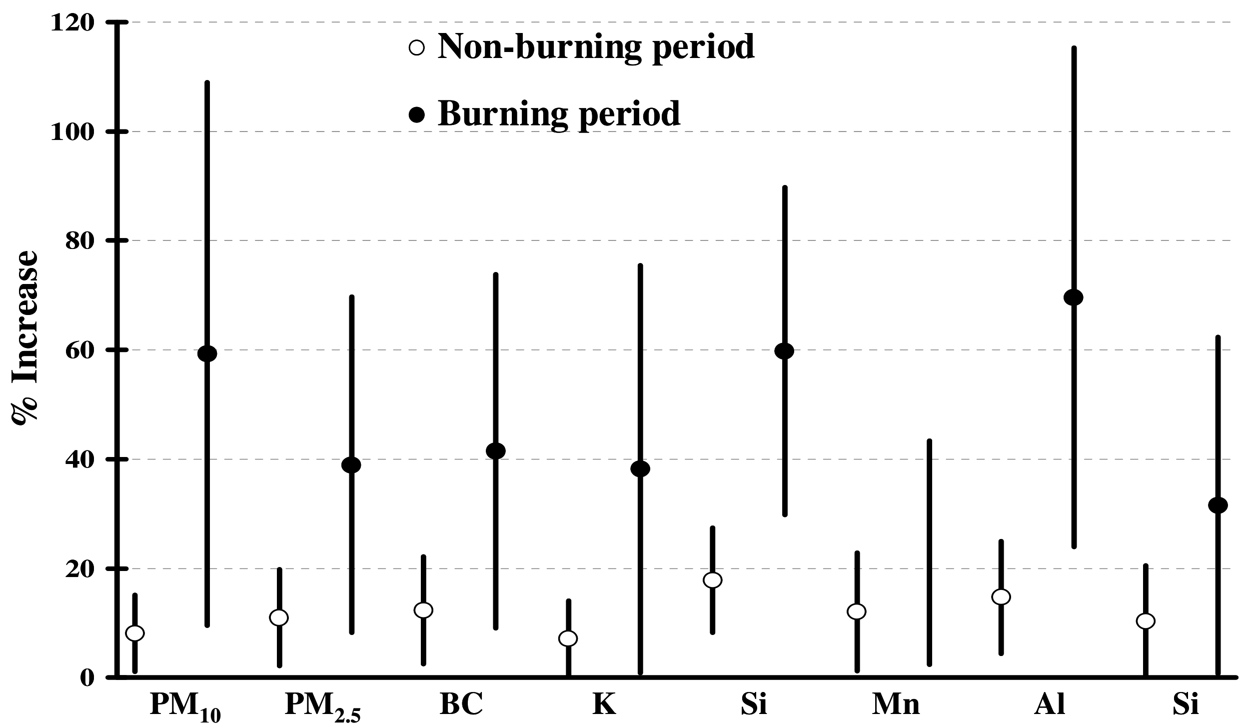
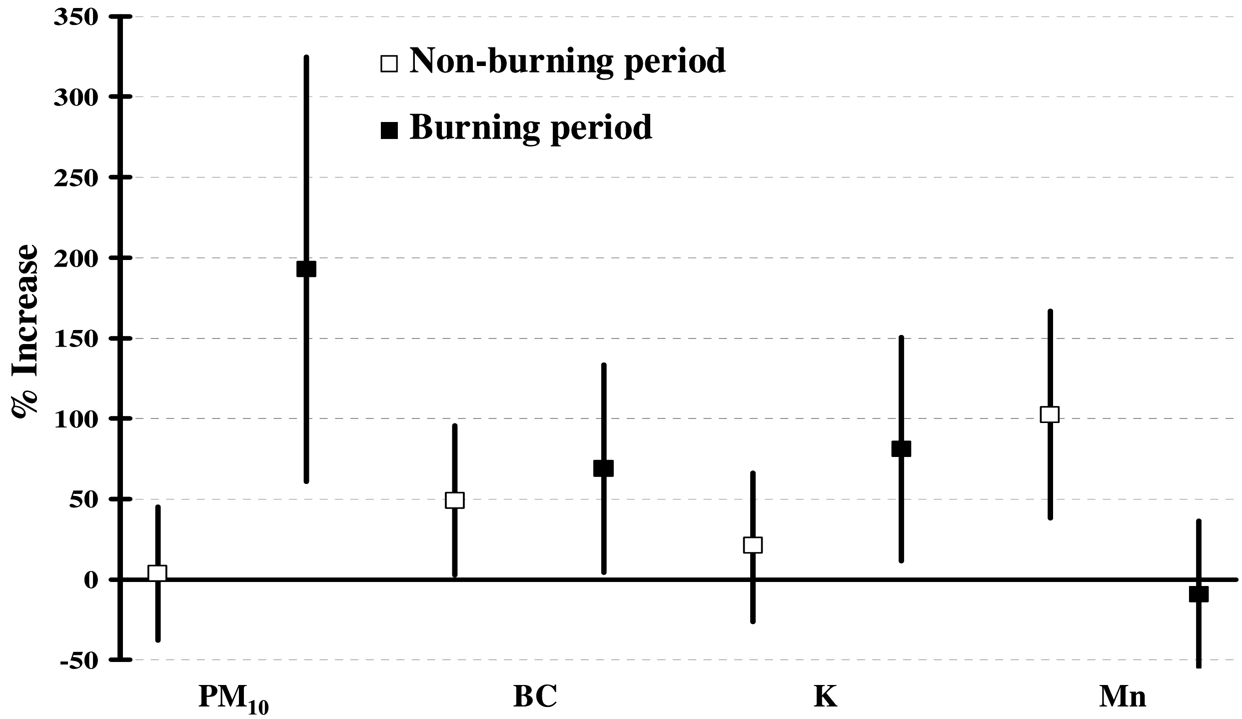


Figure 3



○ Non-burning period
● Burning period
% Increase
120
100
80
60
40
20
0
PM10
PM2.5
BC
K
Si
Mn
Al
Si

Figure 4



□ Non-burning period
■ Burning period
% Increase
350
300
250
200
150
100
50
0
-50
PM10
BC
K
Mn