CORRELATION BETWEEN POLLUTANTS EMISSION AND INHABITANT'S MORBIDITY: SÃO PAULO CITY STUDY CASE

Gheisa R. T. Esteves
Sonia R.C.S. Barbosa
Campinas, Brazil

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CORRELATION BETWEEN POLLUTANTS EMISSION AND INHABITANT'S MORBIDITY: SÃO PAULO CITY STUDY CASE[1]

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1. Introduction

The humanity lives a moment in its history where it is ascending the environmental concern. Not so long ago, the human kind believed that energy sources were inexhaustible and that it could be consumed without attempting for problems like scarcity and the harming effects of pollutants on human health and the environment. In the end of XX century, a number of episodes pointed out the actual development model have a extremely predatory character.

Air pollution is a growing problem in big urban centers. Cities like Los Angeles, Tokyo, Mexico City and São Paulo has a huge vehicle fleet, not just for having high concentration of population, but also due to the actual world socioeconomic conjuncture (Goldenberg, 1998). Its conjuncture tends to prioritize the individual transport when compared with the collective transports. When the focus is the developing countries, it is necessary to add that, the collective transport usually has really bad conditions and it ends up encouraging people to use individual transport.

In the beginning of the capitalism, during the industrial revolution, most of the air pollution came from industries. After the introduction of rigid control to industrial emission, the main source of emission became the vehicle fleet and therefore it is nowadays the most responsible for the deleterious effects that air pollution has human health.

The first episode of increase in the respiratory diseases morbidity and mortality in a region due to the unexpected increases of pollutants concentrations was notified in

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[2] PhD Student in Energy Planning - Mechanical Engineering Faculty – State University of Campinas (UNICAMP). Email: gheisa@fem.unicamp.br.
[3] Associate Researcher of Environmental Studies Center (NEPAM) at State University of Campinas (UNICAMP), Brazil.

1930, in an area between the cities of Huy and Liége (Belgium). The two cities are located in the Muse Valley, which is a region with high concentration of industries. In that occasion, the numbers of respiratory morbidity and mortality went up due to a junction of some factors: adverse meteorological conditions (among them the absence of wind flows), that made difficult for the pollutants to be dispersed. Other similar events occurred some years later, in Pennsylvania (1948) and the most notorious and serious one, in London (1952). In the "London Fog" episode, there was, approximately, 4.000 deaths and some thousands visits to the emergency rooms in just 3 days. Most of the hospitals visits and deaths were caused by thermal inversion that made difficult the dispersion of the pollutants emitted by the industries.

Due to the events listed above, it was created the "Clean Air Acts" in Europe and the establishment of air quality standards in the United States. In developing countries, especially in São Paulo city and Metropolitan area, not so serious episodes motivated the government to adopt control measures for air quality and pollutants emission both for transport and industrial sectors.

In São Paulo City, the LPAE (Atmospheric Pollution Laboratory) was the first to study the effects of air pollution on human health, animals and plants. According to LPAE, in São Paulo city, the risk of death by respiratory and cardiovascular diseases increases 12% in days with high levels of air pollution. The most susceptible part of the population is children and elderly people, besides from people with chronic respiratory diseases (Saldiva, Braga&Pereira, 2001).

It's well known the actual pollutants levels are bellow from the numbers registered some decades ago (CETESB, 2006). However, those levels still are harming to the population living in the area. It's out of question that there was a mitigation of those effects, but they remain causing problems on people's health. In fact, any pollutant level will have some adverse effects on the population.

Based on the problems remarked in the previous paragraphs, the objective of the study is to establish the relation between air pollutants concentration and the number of children visiting to hospitals in São Paulo. In the first part of the study, it will be established the spearman correlation between the number of people going to public health clinics monthly as well the monthly variation of each pollutant. The age groups will be divided as follow: less than 1 year old, between 1 and 4 years old, between 5 and 9 years old, between 10 and 14 years old, between 15 and 19 years old, between 20 and 59 years old, between 60 and 69 years old, between 70 and 79 years old and more than

80 years old. Then, it will be modeled the group of children under 1 year old and between 1 and 4 years old to using a generalized additive model, supposing that it follows a Poisson distribution. In the final part it will be presented conclusions taken from the results obtained.

2. Air Pollution and Impacts on Human Health: The Case of São Paulo City

The air quality in São Paulo city is determined not just by its topographic characteristics and meteorological conditions but also by the way the vehicles circulate in the city and the localization of industries (Cetesb, 2004). Also the urban development process occurred in the city after the fifties is responsible for the air quality problems, because it end up causing the creation of a heat island in the area (Carmo, 1995, Cetesb, 2005).

In 2004, São Paulo city had its vehicle fleet composition as it's shown on Figure 1. Most of the fleet is composed by vehicles and motorbikes. Even though, buses corresponds to just 3% and trucks to 8% of the fleet, it's necessary to take into consideration that its daily circulation is much higher than of the other vehicles.

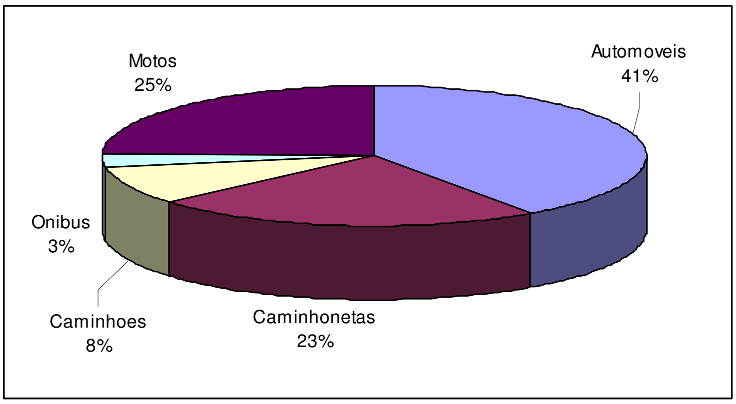

Figure 1 – Organization of São Paulo City Vehicle Fleet – 2004

Source: Prodesp/Detran (2006)

Concerning the fuels used by the fleet, 77% of the vehicles run with gasoline, 16% with alcohol and 6% with diesel. It is important to say that the vehicles which run with gasoline and alcohol follow the Otto cycle and the main pollutants emitted by them are carbon monoxide, nitrogen oxides, hydrocarbons and aldehydes. In the case of vehicles that run with gasoline, it also emits particulate matter and sulphur oxides. In the vehicles moved by diesel the main pollutants emitted are particulate matter, nitrogen oxides and sulphur oxides (Alvarez, 2002).

Facing the fact of the great gravity of the air pollution problem, it was created by the government in 1980 a program fixing limits of pollutants emission. PROCONVE – Programa de Controle da Poluição do Ar por Veículos Automotores (Vehicles Air Pollution Control Program) was created based on international experiences and determine maximum limits to vehicle and engines emissions. With the implementation of this program, in 2000, the pollutants emissions reduced in 90% when compared with 1986.

CETESB is the institution responsible for monitoring and controlling the air quality in São Paulo. According to the institution, air quality is measured by the quantification of the harmful substances presents in the air. The pollutants who integrate the air quality standard are total particles in suspension, inhale particles, smoke, sulphur dioxide, nitrogen dioxide, carbon monoxide and ozone. On Table 1 is listed the scales used for the air quality standard, and on Table 2 the effects that each scale has on human health.

Table 1 – Scale and Air Quality Standard

Quality	Index	PM_{10} - (µg /m³)	O_3 - Ozone (µg /m³)	CO - Carbon Monoxide (ppm)	NO_2 - Nitrogen Dioxide (µg /m³)	SO_2 - Sulphur Dioxide (µg /m³)
GOOD	0- 50	0-50	0-80	0-4,5	0-100	0-80
REGULAR	51 - 100	50-150	80-160	4,5-9	100-320	80-365
INADEQUATE	101 - 199	150-250	160-200	9'-15	320-1130	365-800
BAD	200 - 299	250-420	200-800	15-30	1130-2260	800-1600
REALLY BAD	300 - 399	>420	>800	>30	>2260	>1600

Source: CETESB, 2006.

Table 2 – Effects of Each Scale on Human Health

Quality	Effects on Human Health
Good	Almost no risk to human health.
Regular	Children, elderly and people with respiratory and/or cardiovascular diseases can present dry cough and fatigue. The rest of the population is not afected.
Inadequate	The whole population can present symptoms like dry cough, fatigue, pain in the eyes, nose and throat. Children, elderly and people with respiratory and/or cardiovascular diseases can present more intense adverse effects than the rest of the population.
Bad	The whole population can present an intensification of symptoms like dry cough, fatigue, pain in the eyes, nose and throat and still present lack of air and gasping breath. More serious effects to health will be presented by children, elderly and people with respiratory and/or cardiovascular diseases.
Really Bad	The whole population can present serious respiratory and cardiovascular diseases. Increase of premature deaths of children, elderly and people with respiratory and/or cardiovascular diseases.

Source: CETESB, 2006.

CETESB has a number of stations to measure the pollutants in different locations around the city. The stations cover the most critical points of the city. Figure 2 shows the monitoring stations around the city, and on Table 3 there is information about the variables measured in each one of the stations. It is important to say that just the particulate matter is measured in all the monitoring stations.

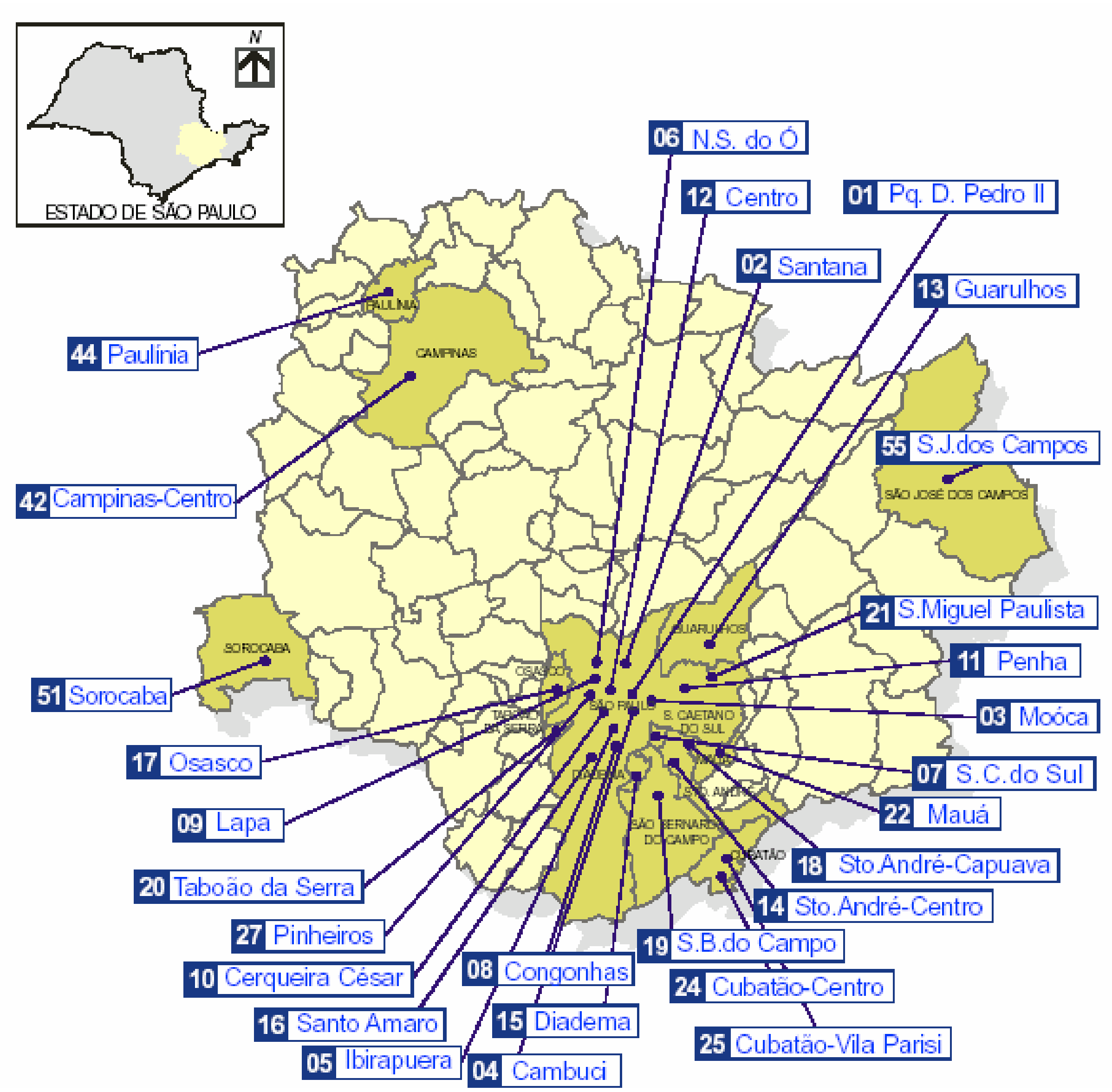

Figure 2 – Localization of the Monitoring Stations in São Paulo State

Source: CETESB, 2006

Table 2 – Location and Pollutants Monitored at the Stations in São Paulo City and Metropolitan Area

LOCATION	INFORMATION MONITORED														
CAPITAL	MP_{10}	SO_2	NO	NO_2	NO_X	CO	CH_4	HCNM	O_3	UR	TEMP	VV	DV	P	RAD
Cambuci - Av. D. Pedro I, 100	●	-	-	-	-	●	-	-	-	-	-	-	-	-	-
Centro[1] - A. São Luiz com R. da Consolação	●	●	●	●	●	●			-	-	-	-	-		
Cerqueira Cesar[2] - Av. Dr. Arnaldo, 725	●	●	●	●	●	●	-	-	-	-	-	-	-	-	-
Congonhas - Al. Dos Tupiniquins, 157	●	●	●	●	●	●	-	-	●	-	-	-	●	-	-
Ibirapuera[3] - Parque do Ibirapuera, setor 25	●	●	●	●	●	●	-	-	●	●	●	●	●	●	●
Santana[4] - Av. Santos Dumont, 1019	●	-	-	-	-	-	-	-	●	-	-	●	●	-	-
Lapa[1/5/6] - Av. Embaixador Macedo Soares, 7995	●	-	●	●	●	●	-	-	●	-	-	●	-	-	-
Moóca[2] - Rua Bresser, 2341	●	-	-	-	-	-	-	-	●	-	-	●	●	-	-
Nossa Senhora do Ó - R. Capitão José Aranha do Amaral, 80	●	-	-	-	-	-			-	-	-	-	-		
Parque D. Pedro - P. D. Pedro II, 319	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Penha[1] - Av. Amador Bueno da Veiga, 2932	●	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pinheiros[8] - Rua Frederico Hermann Jr, 245	●	●	●	●	●	●	-	-	●	-	-	-	-	-	-
Santo Amaro - Av. Padre José Maria, 355	●	-	-	-	-	●	-	-	●	-	-	●	●	-	-
São Miguel Paulista - Rua Diego Calado, 166	●	-	-	-	-	-	-	-	●	●	●	●	●	-	-
METROPOLITAN AREA															
Diadema - Rua Beijamin Constant, 3	●	-	-	-	-	-	-	-	●	-	-	-	-	-	-
Guarulhos - E. E. do Bairro de S. Roque - P. CECAP	●	-	-	-	-	-	-	-	-	-	-	●	●	-	-
Mauá - Rua Vitorino Del'Antonia, 150	●	-	●	●	●	-	-	-	●	-	-	-	-	-	-
Santo André - Centro, Rua das Caneleiras, 101-C	●	-	-	-	-	●	-	-	-	-	-	●	●	-	-
Santo André - Capuava, Rua Manágua, 2	●	-	-	-	-	-	-	-	●	-	-	●	●	-	-
São Bernardo do Campo - Rua Cásper Libero, 340	●	-	-	-	-	-	-	-	-	-	-	●	●	-	-
São Caetano do Sul - Rua Aurélia s/n (EMI F. Pessoa) V. Paula	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Osasco[5/6/7] - Av. dos Autonomistas c/ R. S. Maurício	●	●	●	●	●	●	-	-	●	-	-	●	●	-	-
Taboão da Serra - Praça Nicola Vivilechio, 99	●	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL RMSP MONITORS	23	7	9	9	9	11	2	2	12	4	4	13	13	2	1

Source: CETESB, 2006.

3. Impacts on Human Health – Previous Studies and Historical Information

There are a number of studies and ways to measure the impacts of air pollution on human health. The first studies started in the XX century as a consequence of the events listed at the introduction. A different number of statistical techniques were applied to establish this relation. The first studies (in the fifties) started using just simple descriptive analysis from the data to point out the effects of air pollution on morbidity and mortality. This study was done after the episode of the London fog. In the Sixties, more sophisticated techniques were used, as the scientists' analyzed daily number of deaths and air pollutants concentration with correlation analysis and simple linear regression. In both cases, the results obtained showed significant relationship between the two variables.

In the Seventies, there were some innovation on the statistical framework, as the scientists started to use multiple linear regression in the studies, as well as the addition of meteorological variables on the models, besides from the trend and seasonality. The use of multiple linear regression persisted until the Eighties when scientists started to look for non-linear regression methods whose could explain those relation.

But it was just in the second half of the nineties and in the year 2000 that big evolutions were made in the field. First it has begun to be used in the analysis auto-regressive Poisson models and distributions. The event of a hospital visit or death follows a Poisson distribution because the probability of a person to be admitted in a hospital (or die) in a certain day or month, due to respiratory diseases is quite low.

Then in the years 2000, linear and additive generalized models started to be applied to measure the relationship. The additive generalized models allow more flexibility to describe the standard of association between the variables through smooth functions. It gives the possibility of adjust the control variables (trend, seasonality and meteorological factors) through a non parametric process, meanwhile on the linear generalized models parametric process are used.

Most of the studies that deals with the effects of air pollution on human health had been carried out in the developed world but countries like Brazil, Mexico and Chile already have a significant number of studies in this matter (Cifuentes, 2001). Between them, it can be mentioned a relevant study done by Martins et al (2002) where it was analyzed the variation of the daily levels of carbon monoxide, sulphur dioxide, nitrogen dioxide, ozone, particulate matter and the daily number of hospital visits of people with 64 years old or more in São Paulo from 1996 until 1999. The analysis was done using additive generalized models. It was constructed individual models for each pollutant. Martins concluded that an increase to $15\,\mu g/m^3$ at the concentration of sulphur dioxide will add up 14,5% more hospital visits of elderly people with pneumonia or influenza. In the case of the ozone an increase of $38{,}8\,\mu g/m^3$ will cause 8,07% more hospital visits.

Studies conducted by Gouveia (2000) analyzed the relation between daily concentration of pollutants and hospital visits of children (below 5 years old) and elderly (65 years or more) in Rio de Janeiro and São Paulo. It was concluded that an increase of 10 $\mu g/m^3$ in particulate matter concentration would cause an increase in hospital visits by 1,9% in Rio de Janeiro and 3,5% in São Paulo. Those are just two between a numbers of studies done for São Paulo city related to the theme. Studies done by Azevedo (1999), Azuaga (2000), Pereira (1999), Miraglia (1997) and Saldiva also have given interesting contribution to the issues.

4. Methods

The methodology used to evaluate the impacts of air pollution on health of children of São Paulo city was divided into 3 phases. Initially, it was established the existing relation between the pollutants concentration and the child hospital visits with respiratory diseases. The next step was to develop a model to estimate the importance of this correlation. As already said before in this article, hospitals visits usually follows a Poisson distribution, so the present study will use additive generalized models (in a semi-parametric model) to relate the pollution with child hospitals visits. The model can be described as written bellow (Simas, 2003; Grant, 2001, Woolson, 1987).

$$Ln(E[Y_t]) = \alpha + \sum_{j=1}^{p} f_j(x_{tj}) \qquad \text{(Equation. 1)}$$

Where

Y : Number of hospital visits;

t : Month;

$E[Y_t]$: Expected number of hospital visits at month t;

α : trend;

$f_j(x_{tj})$: Group of arbitrary and non specified functions of the independent variables.

suposing that $Y_t \sim Poisson(\mu)$

The independent variables were smoothed with the splines technique. This technique consists of divide the variable that is supposed to be predicted into pre-defined intervals and then adjust a polynomial (usually a cubic one) to each one of these intervals, in a way that make them be grouped smoothly.

The association between air pollution and hospital visits can be influenced by other factors, known as confusion factors. Adding those factors into the modeling has the purpose of giving to each model component its exact contribution. So a model of this nature must contain as independent variables, not just the pollutants concentration, but also controls for seasonality (through month and year indexes), temperature, humidity and the series trend.

It is important to emphasize the existence of multicolinearity between the pollutants itself and with the meteorological variables. The correlation method used in the article is the Spearman correlation, as the modeling method applied is a non linear and semi-parametric one so it's necessary to use also a non linear correlation framework.

As the final models were obtained for the two groups studied (children bellow 1 year old and children between 1 and 4 years old), the relative risk were calculated for them. The relative risk is the percentage of hospitals visits occurred due to the concentration of certain pollutant. Its mathematical expression is presented bellow (Miraglia, 1997; Martins, 2002):

$$\left(e^{(\beta)\times P_t} - 1\right)\times 100 \qquad \text{(Equation 2)}$$

Where

β : pollutant or index coefficient;

P_t : pollutant or index average.

And the confidence interval where the relative risk is inserted is expressed with the following equation

$$IC_{95\%} = e^{[\beta \pm 1{,}96\,\mathrm{ep}(\beta)]} \qquad \text{(Equation.3)}$$

Where

$IC_{95\%}$: 95% confidence interval;

β : Pollutant or index coefficient;

$\mathrm{ep}(\beta)$: Pollutant or index standard error.

Based on the results from the relative risk, it's possible to determine the amount of children visiting hospitals due to air pollution.

4.1 Air Pollution Data

Monthly pollutants concentration data was obtained with CETESB for the period between January 1998 and March 2006. It was collected data for the following pollutants: PM_{10}, NO_2, CO and SO_2 for each monitoring station in São Paulo city.

Actually, there are 13 monitoring stations at São Paulo city. Only PM_{10} is monitored in all 13 stations; SO_2 is measured in 6 of them; 7 measure NO_2; and 9 of them CO. Data collected for PM_{10} and SO_2 are daily averages measured in $\mu g/m^3$; for CO, the data is measured in ppm and is the maximum of 8 hours; and finally NO_2 is measured in $\mu g/m^3$ and is the maximum of 1 hour.

It was calculated monthly averages for all pollutants on each monitoring station and them for the whole city.

4.2 Hospital Visits Data

Hospital visits monthly data was provided by DATASUS for January 1998 until March 2006. DATASUS is the SUS Hospital Information System, administered by the Ministry of Health. At this system, the hospital units who belongs to SUS (both public and private ones), provide information about the number hospital visits by nature of the disease occurred in each month of the year. This information is grouped in accordance with the International Diseases Classification.

It was collected data for children bellow 1 year old and children between 1 and 4 year old. It's important to say that the SUS (Integrated Health System) is only responsible for 50% of all the hospitals attendances in Brazil and most of the population covered by it belong to the lowest income classes (Freitas, s/d)

4.3 Meteorological Data

Monthly minimum temperature and relative humidity data were provided by the Astronomy, Geophysics and Atmospheric Sciences Institute (IAG/USP). The data obtained from IAG/USP was considered representative of the city as a whole.

5. Results

This topic will present the variables analyzed as well as the results obtained from the modeling. As already said before, the association between child visits and pollutants concentration will be done through an additive generalized model.

To create a model, the variables listed bellow was used:

Monthly Hospital Visits due to Respiratory Diseases

- Children under 1 year old;
- Children between 1 and 4 years old;
-

Monthly data for Average Pollutants Concentration

- Particulate Matter of size less than 10 $\mu g/m^3$;
- Carbon Monoxide;
- Nitrogen Dioxide;
- Sulphur Dioxide;

Monthly data for Meteorological Factors

- Minimum Temperature
- Humidity.

Figure 3 show the hospitals visits evolution from January 1998 until March 2006. It can be noticed the existence of a cycle in the series, because on winter's month the number of hospitals visits goes up meanwhile during the summertime it goes down.

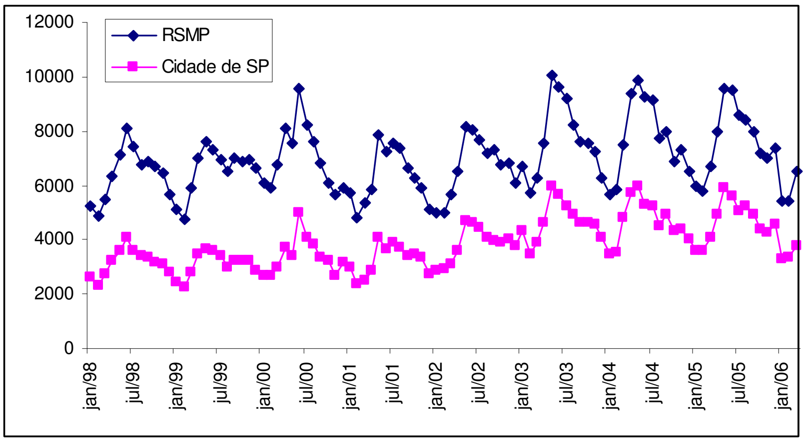

Figure 2 – Total Hospital Visits due to Respiratory Diseases in São Paulo and Metropolitan Area (number of people)

Source: DATASUS (2006)

The age groups were divided as children, teenagers, adults and elderly. It was considered children people with less than 9 years old; teenagers people from 10 to 19 years old, adults people from 20 to 59 years old and elderly people with more than 60 years old. This classification has the intent of separating the active economic population and point out that children are the ones with more susceptibility to respiratory diseases.

In 2005, 53% of all hospitals visit due to respiratory diseases were done by children and elderly were responsible for 20,4% of it. In other words, the most susceptible groups had been the cause of more than 70% of its hospitals visits.

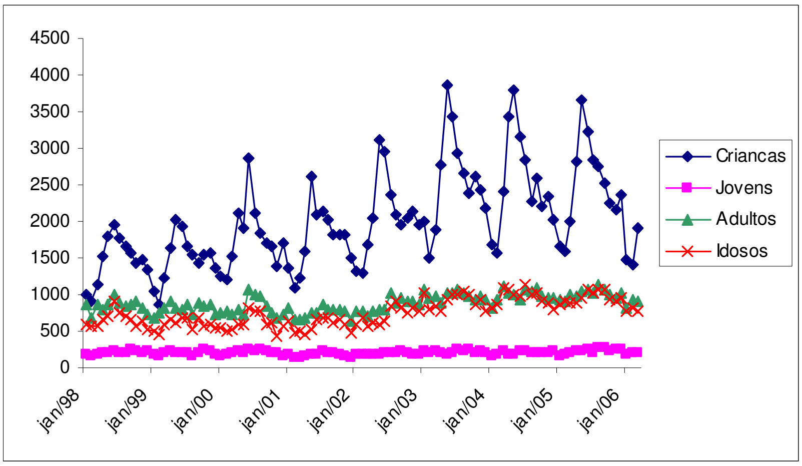

Figure 3– Hospital Visits due to Respiratory Diseases by Age Groups in São Paulo (number of people)

Source: DATASUS (2006)

Of all the respiratory disease hospital visits, children between 1 and 4 years old had 21,6% of its responsibility, and the children with less than 1 year old 21%. In Figure 3 and Figure 4 can be visualized the seasonal cycle, especially for children (Figure 3).

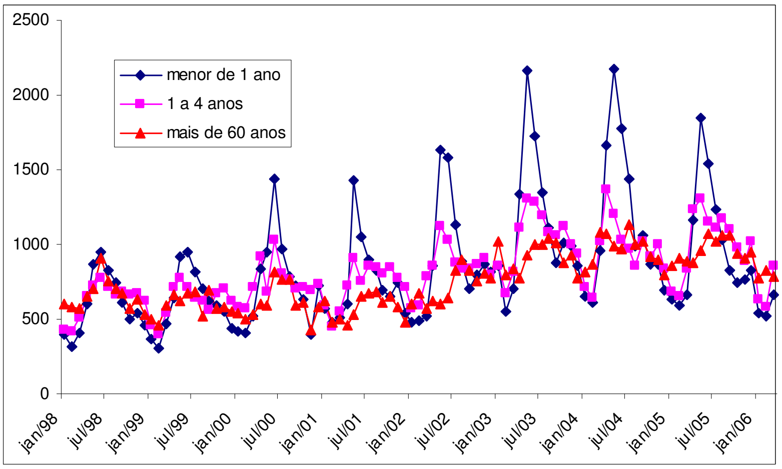

Figure 5 – Hospital Visits due to Respiratory Diseases in Children and Elderly People – São Paulo

Source: DATASUS (2006)

From Figure 6 to Figure 9, are presented the pollutants concentration evolution. At São Paulo, SO_2 concentration decreased 46%, NO_2 reduced 11%, CO had a 65% reduction and PM_{10} a 32% decrease. Especially for PM_{10} and CO is possible to capture, just by a glance in the figures, the seasonal component of the two series. The number of studies in the literature has already mentioned the existence of this event in São Paulo city (CETESB, 2006; Miraglia, 2002). All the pollutants concentrations are bellow the annual averages limits determined by CONAMA Resolution no. 03 from 28/06/90 (CETESB, 2006).

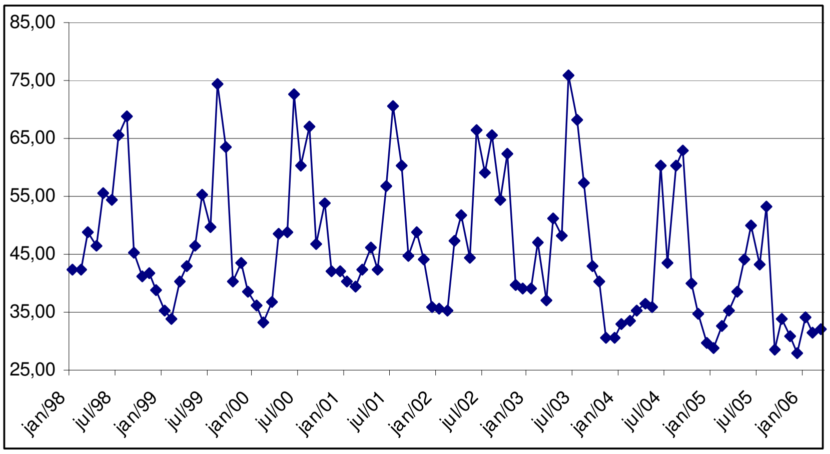

Figure 6 – Particulate Matter (PM_{10}) Concentration

Source: CETESB (2006)

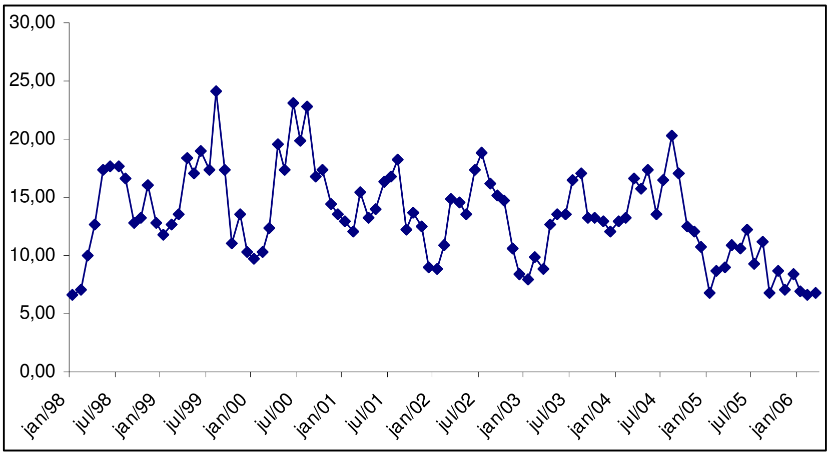

Figure 7 – Sulphur Dioxide (SO_2) Concentration

Source: CETESB (2006)

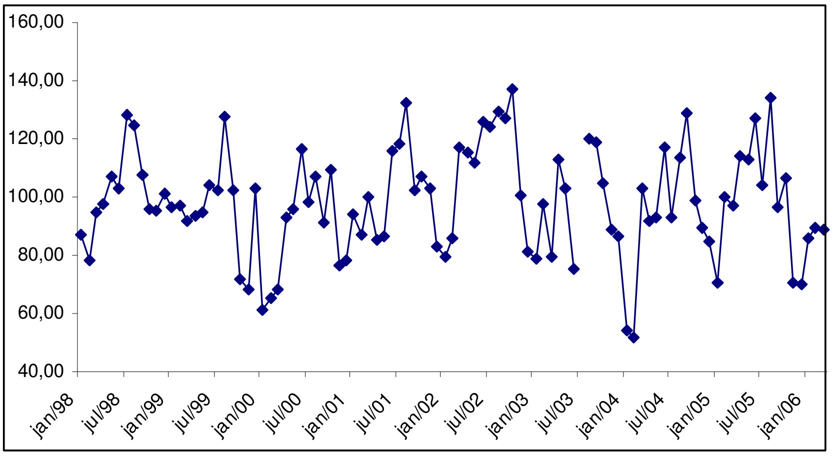

Figure 8 – Nitrogen Dioxide (NO_2) Concentration

Source: CETESB (2006)

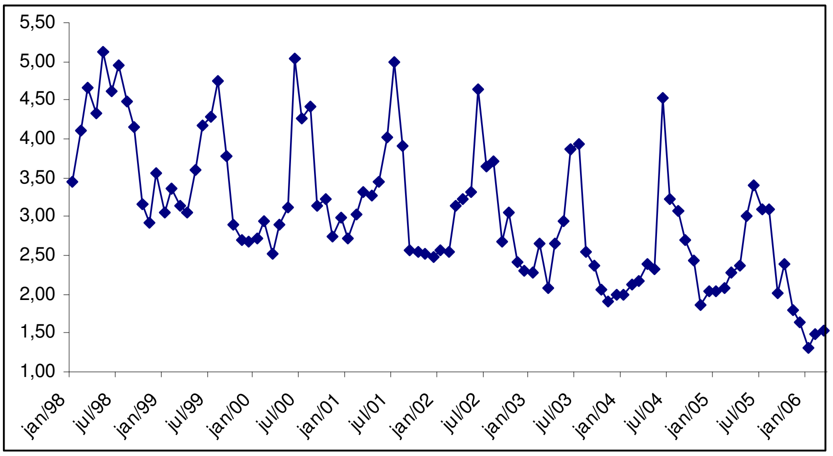

Figure 9 – Carbon Monoxide (CO) Concentration

Source: CETESB (2006)

At Table 3, it is possible to observe the humidity and minimum temperature. The seasonal cycle is much clearer in the minimum temperature variable than on the humidity. But a cycle exists in both of them.

Table 3 – Meteorological Data

Meteorological Variables	1998	1999	2000	2001	2002	2003	2004	2005	2006
Humudity	81,70	79,71	79,46	79,47	78,83	74,04	76,86	77,07	78,39
Temperature	12,06	10,71	9,68	10,63	11,63	14,43	13,84	14,85	18,43

5.1 Descriptive Analysis

A descriptive analysis was made for the dependent and independent variables (available on Table 4). The minimum temperature varied from 2^oC to 18 ^oC, approximately, and humidity from 73 to 85%. The child hospital visits monthly average was 849 for children with less than 1 year old and 818 for children between 1 and 4 years old.

Table 4 – Descriptive Analysis

Variables	Average	Mediana	Moda	Standard Deviation	Variance	Minimum	Maximum
Children under 1 year old	849	761	397	394	155.311	305	2173
Children between 1 and 4 year old	818	781	712	219	47.887	402	1365
Humidity	80,05	80,51	73,12	2,78	7,75	73,12	85,07
Temperature	10,98	11,30	5,20	3,91	15,32	2,00	17,90
PM_{10}	45,83	43,00	35,27	11,81	139,46	28,00	75,91
NO_2	98,70	97,71	93,00	18,67	348,73	51,80	137,17
SO_2	13,46	13,25	12,00	3,93	15,42	6,66	24,17
CO	3,05	2,97	2,53	0,89	0,80	1,32	5,13

Table 5 – Independent Variables Quartiles

Variaveis	Quartis		
	25	50	75
PM_{10}	36,23	43,00	53,86
NO_2	86,67	97,71	112,68
SO_2	10,6	13,25	16,68
CO	2,4	2,97	3,61
IOP	0,8313	0,9775	1,1334

Nitrogen dioxide was the one that had the highest variance meanwhile CO concentration was the most stable one. The two maximum concentrations PM_{10} and NO_2 were above the annually limits.

Quartiles were calculated for the pollutants variables to be used at the dose-dependence analysis and are presented on Table 5. The next step on the study is establishing the correlation between the child hospital visits and its dependent variables.

A Spearman correlation was used to capture the association between child hospital visits because of respiratory diseases and the independent variables (pollutant concentration and meteorological factors). Table 6 shows the statistics obtained

Children under 1 year old presented strong positive association with PM_{10}, NO_2 and $S0_2$. No significant association was observed with CO. For children with age between 1 and 4 years old, the significant association was only obtained with NO_2. Meteorological factors a strong negative association was found. This means that the relation between child respiratory disease hospital visits and meteorological factors is inverse. For example, when temperature has gone down, child hospital visits due to respiratory diseases will go up.

Table 6 – Spearman Correlations

Variables	PM_{10}	SO_2	NO_2	CO	Humidity	Minimum Temperature (oC)
Children under 1 year old	0,40253 *	0,40592 *	0,4614 *	0,11521	-0,24823	-0,66346 *
Children between 1 and 4 years old	0,16826	0,14763	0,36250 *	-0,17872	-0,1862	-0,45884 *

* $p < 0,0083$

Since pollutants concentration have multicolinearity problems, it was also important to analyze the association between themselves. It could be noticed that all pollutants concentrations have strong correlations. Particulate matter was the pollutant which presented the strongest one. Table 7 shows the correlation between the pollutants.

Table 7 – Pollutants Correlation

Variables	SO_2	NO_2	CO
PM_{10}	0,724**	0,696**	0,788**
SO_2		0,497**	0,602**
NO_2			0,471**

5.2 Additive Generalized Models - AGM

The additive generalized model was the framework used to relate the children hospital visits with pollutants concentration. At the first, it was created a model containing all the pollutants, meteorological factors, and annual and monthly dummies.

Pollutants concentrations and meteorological data was smoothing through cubic splines before being added to the model. The results are presented at Table 8 and Table 9.

Table 8 – Children under 1 year old Additive Generalized Models – Initial Model

Explicative Variables	**Coefficient**	**Standard Error**	**z-value**	**p-value**
Intercept	6,0391	0,1927	31,3463	0
Month				
january	-0,1848	0,0206	-8,9874	0
february	-0,3174	0,0215	-14,7669	0
march	-0,1326	0,021	-6,3007	0
april	0,3103	0,0215	14,4419	0
may	0,7638	0,0247	30,9549	0
june	0,6946	0,0346	20,0624	0
july	0,4722	0,034	13,8845	0
august	0,2322	0,0327	7,1122	0
september	0,0877	0,0253	3,4625	0,00054
october	0,0162	0,0226	0,7147	0,47478
november	0,0143	0,0198	0,7223	0,47012
december				
Years				
1998	-0,4671	0,0442	-10,5793	0
1999	-0,4472	0,0405	-11,0486	0
2000	-0,2847	0,0411	-6,92	0
2001	-0,2224	0,036	-6,1835	0
2002	-0,0579	0,0332	-1,7468	0,08068
2003	0,1719	0,0303	5,6836	0
2004	0,1564	0,0333	4,6985	0
2005	0,0659	0,0293	2,2502	0,02444
2006				
Meteorological Variables				
Humidity	0,0049	0,0021	2,3401	0,01928
Temperature	0,0029	0,002	1,4623	0,14366
Pollutants				
PM_{10} *	0,0009	0,0009	1,0211	0,30721
SO_2 *	0,0115	0,0022	5,2236	0
NO_2 *	0,0007	0,0004	1,9078	0,05642
CO *	-0,0299	0,0147	-2,0324	0,04211

At this model SO2 was the pollutant which presented the highest association and CO presented a protection characteristics. Using a backforward selection process, a “final model” was obtained to explain the relation between the variables. Table 10 and 11 show the results for the final models.

Table 9 - Children Between 1 year and 4 years old Additive Generalized Models – Initial Model

Explicative Variables	Coefficient	Standard Error	z-value	p-value
Intercept	7,0819	0,1955	36,2308	0
Month				
january	-0,2392	0,0193	-12,3846	0
february	-0,3185	0,02	-15,8841	0
march	-0,0455	0,0195	-2,3295	0,01983
april	0,2114	0,021	10,0882	0
may	0,2827	0,0253	11,1787	0
june	0,3104	0,0355	8,7426	0
july	0,2268	0,0348	6,5169	0
august	0,1261	0,0325	3,8814	0,0001
september	0,0659	0,0246	2,6792	0,00738
october	0,0501	0,0215	2,3287	0,01987
november	0,0219	0,0185	1,1843	0,23631
december				
Years				
1998	-0,2852	0,0433	-6,5912	0
1999	-0,3349	0,0391	-8,5555	0
2000	-0,1569	0,0395	-3,9721	0,00007
2001	-0,1649	0,0346	-4,7722	0
2002	-0,0573	0,0317	-1,8055	0,071
2003	0,1188	0,0286	4,1562	0,00003
2004	0,0454	0,0318	1,4279	0,15333
2005	0,0844	0,0276	3,0602	0,00221
2006				
Meteorological Variables				
Humidity	-0,0034	0,0021	-1,5696	0,11652
Temperature	0	0,002	0,0083	0,99336
Pollutants				
PM_{10} *	-0,0014	0,001	-1,5105	0,13092
SO_2 *	0,002	0,0022	0,8781	0,37991
NO_2 *	0,0012	0,0004	3,3821	0,00072
CO *	-0,0583	0,0153	-3,808	0,00014

The AGM obtained for children under 1 year old shows that the number of child hospitals visits increases at the end of autumn and begging of winter, in other words, in May, June and July. At the initial model 4,21%, 16,75% and 7,15% of child respiratory diseases hospital visits occurred due to PM_{10}, SO_2 and NO_2 concentrations, respectively. At the final model, on average 17% of child respiratory diseases hospital visits happened because of SO_2 emissions.

Table 10 - Children under 1 year old Additive Generalized Models – Final Model

Explicative Variables	Coefficient	Standard Error	z-value	p-value
Intercept	6,1692	0,1373	44,9232	0
Month				
january	-0,2108	0,0202	-10,4583	0
february	-0,3611	0,0208	-17,3524	0
march	-0,1401	0,0201	-6,9746	0
april	0,3297	0,0194	16,9687	0
may	0,7676	0,0186	41,3376	0
june	0,6648	0,02	33,2342	0
july	0,4263	0,0208	20,5051	0
august	0,1986	0,0235	8,4406	0
september	0,1077	0,0197	5,4558	0
october	0,0594	0,0196	3,0336	0,00242
november	0,0568	0,0193	2,9466	0,00321
december				
Years				
1998	-0,4785	0,0303	-15,8181	0
1999	-0,474	0,0311	-15,2201	0
2000	-0,3168	0,0317	-9,9796	0
2001	-0,2438	0,0291	-8,3905	0
2002	-0,0642	0,0287	-2,2388	0,02517
2003	0,1796	0,0276	6,4951	0
2004	0,1522	0,0295	5,1552	0
2005	0,0699	0,0271	2,5793	0,0099
2006				
Meteorological Variables				
Humidity	0,0041	0,0016	2,4787	0,01318
Pollutants				
SO_2 *	0,0117	0,0021	5,6821	0

To children 1 and 4 years old, SO_2 and NO_2 were responsible for 2,75% and 11,59% of the respiratory diseases hospital visits. At the final model NO2 was responsible for 9,29% respiratory diseases hospital visits. Despite that some statistics obtained at the initial model was not considered statistically significant, it's important to take into consideration, so the next section will point out some numbers calculated from the models.

5.3 Inter-Quartiles Analysis

Based on Table 5 (independent variables quartiles), it was calculated the percentage of influence that pollutants have on child hospital visits because of respiratory diseases. In fact, it was calculated the relative risk of each one of the pollutant quartiles for the two age groups studied. Table 12 present that information.

Table 11 - Children between 1 and 4 years old Additive Generalized Models – Final Model

Explicative Variables	Coefficient	Standard Error	z-value	p-value
Intercept	6,7592	0,0379	178,455	0
Month				
january	-0,2542	0,019	-13,377	0
february	-0,3449	0,0198	-17,456	0
march	-0,0605	0,0185	-3,273	0,00107
april	0,2105	0,0185	11,364	0
may	0,2849	0,0197	14,449	0
june	0,2795	0,0271	10,3	0
july	0,1846	0,0251	7,36	0
august	0,1053	0,0237	4,447	0,00001
september	0,075	0,0194	3,872	0,00011
october	0,0743	0,0186	3,986	0,00007
november	0,0464	0,0177	2,63	0,00853
december				
Years				
1998	-0,279	0,0382	-7,295	0
1999	-0,3093	0,0333	-9,284	0
2000	-0,1357	0,0327	-4,144	0,00003
2001	-0,1522	0,031	-4,908	0
2002	-0,042	0,0295	-1,424	0,15446
2003	0,1541	0,0269	5,736	0
2004	0,0824	0,0272	3,032	0,00243
2005	0,1213	0,0262	4,635	0
2006				
Pollutants				
NO_2 *	0,0009	0,0003	2,632	0,00848
CO *	-0,0465	0,012	-3,874	0,00011

At the initial model 35 thousand children visited the hospitals with respiratory diseases caused by pollutants concentrations. At the final model 27 thousand child hospital visits occurred.

Table 12 – Child Hospital Visits due to Respiratory Diseases Caused by Air Pollutants Concentration – Initial and Final Models

Variables	Average Concentration	Concentration Quartiles		
		25	50	75
Inital Model - Respiratory Diseases Hospital Visits				
Children under 1 year old				
PM_{10}	3.316	2.785	3.316	4.174
NO_2	5.948	5.256	5.948	6.896
SO_2	13.831	10.893	13.831	17.768
Children between 1 and 4 years old				
NO_2	10.078	8.880	10.078	11.730
SO_2	2.176	1.736	2.176	2.748
Total	35.349	29.550	35.349	43.315
Final Model - Respiratory Diseases Hospital Visits				
Children under 1 year old				
SO_2	14.125	12.227	13.812	15.966
Children between 1 and 4 years old				
NO_2	5.355	4.661	5.239	6.016
Total	19.480	16.887	19.051	21.982

Comparing the results obtained with the ones available in the literature, it's possible to realize that the present results are in accordance with what has already been concluded by other scientists. Table 13 shows the results of other studies.

Table 13 – Comparative Studies about the Effects of Air Pollution on Children Respiratory Diseases Hospital Visits

Place	Pollutant Studied	Relative Risk
São Paulo (Braga et al, 1999)	PM_{10}	1,12
São Paulo (Lin et al, 1999)	PM_{10}	1,05
São Paulo (Farhat, 1999)	PM_{10}	1,08
São Paulo (Gouveia et al,2003)	PM_{10}	1,07
	CO	1,02
	SO_2	1,07
Daejon (Cho et al, 2000)	NO_2	1,47
São Paulo		
Children under 1 year old	SO_2	1,01
Children between 1 and 4 years old	NO_2	1,00

The study aimed to visualize the existing association between pollutants concentration and child hospital visits. Despite of not always being statistically significant important correlations were found with particulate matter, nitrogen dioxide and sulphur dioxide. In future studies maybe the use of an index created as a fusion of all the four pollutants concentration would be an important upgrade to epidemiologic studies that deal with pollutants effect on human health.

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