Air pollution and respiratory diseases among children in Brazil

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Abstract

Objective
To assess the effects of air pollution levels on respiratory morbidity among children from 1999 to 2000.
Methods
Daily records of health center attendance due to respiratory diseases among children were obtained from the public health system in Curitiba, State of Paraná, Brazil. Daily levels of particulate matter (PM_{10}), smoke, NO_2 and O_3 were obtained from both Paraná State Environmental Institute and the Development Technology Institute, a non-governmental agency. Daily measurements of temperature and relative humidity were obtained from the National Institute of Meteorology. Generalized additive Poisson regression models were used to assess the relationship between respiratory diseases and air pollution, controlling for long-term seasonality using loess (a non-parametric smoothing function), weather and weekdays. A significance level of 5% was adopted in all the analyses.
Results
All pollutants presented an effect on respiratory diseases among children. An increase of 40,4 $\mu g/m^3$ in the 3-day moving average of smoke was associated with an increase of 4.5% (95% CI: 1.5-7.6) in the attendance of children with respiratory diseases.
Conclusion
The results suggest that air pollution promotes adverse effects on children's respiratory health even when pollutant levels are lower than the air quality standards.

INTRODUCTION

The problems stemming from air pollution started to be considered as a question of public health from the time of the industrial revolution, when today's urban development system began. In the 1980s, Brazil's urban development rate reached a level of 68.9%. At that time, the population growth of the Curitiba metropolitan region (State of Paraná) was 5.8% per year, much greater than in the other metropolitan regions of Brazil.[11,14]

Although this growth diminished during the following decade (to 3% per year), the city of Curitiba has not emerged unscathed from this process. This can today be perceived through a variety of factors, among which the air quality and its possible repercussions in the form of respiratory diseases.

Air pollution affects people's health even when its levels are below what the current legislation determines. The age groups most affected are children[3,4,8] and the elderly.[2,9,1213] These groups are greatly susceptible to the deleterious effects of pollution. Some studies have shown a positive association for morbidity and also mortality in relation to respiratory problems among children.[3,4,8]

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The lack of information regarding the relationship between air pollution and respiratory diseases in the city prompted the investigation of such relationships in the present study. Thus, the objective of the study was to verify the relationship between air pollutants and morbidity due to diseases of the respiratory tract among the child population

METHODS

This work is a time-series ecological study[10] performed in the municipality of Curitiba, State of Paraná, Brazil. Daily records of the outpatient attendance of children with respiratory diseases at the city's health centers within its public health system, were obtained from the Municipal Health Department. These data relate to the attendance of children within the age group of 0 to 14 years. The period assessed was from January 1, 1999, to December 31, 2000. The respiratory diseases were coded in accordance with the International Classification of Diseases, 9th Revision (ICD-9: 460 to 519).

Data on the daily levels of particulate matter (PM_{10}) and smoke were obtained from the Paraná State Environmental Institute (*Instituto Ambiental do Paraná*), from measurements at a station. Data relating to nitrogen dioxide (NO_2) and ozone (O_3) were supplied by the Development Technology Institute (*Instituto de Tecnologia para o Desenvolviment* - Lactec), from measurements at two stations (in Curitiba's Industrial City and in the residential district of Santa Cândida). The averages from hourly measurements over 24-hour periods for NO_2, PM_{10} and smoke and the peak hourly measurement for O_3 were considered to be representative of the daily concentrations of these pollutants.[5] Braga et al[3] (1999) showed that the averages of the daily levels of pollutants at each monitoring station adequately represented the mean pollutant levels in the city of São Paulo. On the basis of that study, the averages for the pollutants NO_2 and O_3 that were measured in the two stations were calculated as representative of the city's mean levels.

Atmospheric data were obtained from the meteorological station of the Polytechnic Center of the National Meteorology Institute (*Instituto Nacional de Meteorologia* - INMET), which is located around 6 km from the center of the city of Curitiba. From readings taken at 9:00 a.m., 3:00 p.m. and 9:00 p.m., figures for the daily averages for the relative humidity of the air and the minimum temperature, for the period from 1999 to 2000, could be obtained.

Descriptive statistics were calculated for all the variables included in the study. The Pearson correlation coefficient was calculated between the air pollutants and the number of individuals attended at the health centers per day, and also in relation to the atmospheric variables, with the aim of verifying whether these data presented linear associations.

The number of children attended as outpatients each day because of respiratory diseases (ICD-9: 460 to 519) was considered to be the dependent variable, and the mean daily pollutant levels for PM_{10}, smoke, O_3 and NO_2 were the independent variables. The control variables were the number of days elapsed (t=1, 2, 3, ..., N; where N is the last day of the series), for adjusting the long-term seasonality; the days of the week (indicator variable), for adjusting the short-term seasonality; the daily minimum temperature (°C); and the relative humidity of the air (%). The latter two were for controlling the meteorological effect.

The daily number of children attended because of respiratory diseases is a counted event and, for this reason, it presents Poisson's distribution. Since the relationships between the dependent variable and the control variables are not necessarily linear, it is important to adopt a regression model that allows such relationships to be estimated in the most appropriate manner. To satisfy these two principles, generalized additive models (GAM)[6] were adopted for Poisson's regression, using nonparametric smoothing functions (*loess*).[6]

To control for long-term seasonality, the *loess* function was utilized for removing the basic long-term seasonal patterns, thereby eliminating variability due to chance occurrences. The smoothing parameter for days elapsed was chosen in such a way as to obtain minimization of the autocorrelation of model residues. To control for short-term seasonality, an indicator variable for the days of the week was adopted. A linear relationship between the dependent variable and the air pollutants, minimum temperature and mean humidity was assumed.

The biological manifestations of the effects of pollution on health appear to present behavior that shows a lag in relation to the individual's exposure to the polluting agents.[3] In other words, attendance provided on a given day is probably related to the pollution on that day, but also to the pollution that there was on preceding days. Thus, it was decided to utilize daily values and moving averages over two and three days for the pollutants, in which, for example, the three-day moving average is the average for the pollution on the day in question and the two days preceding it.

With regard to defining the final regression model, the percentage increases in the number of children attended because of respiratory diseases, and their

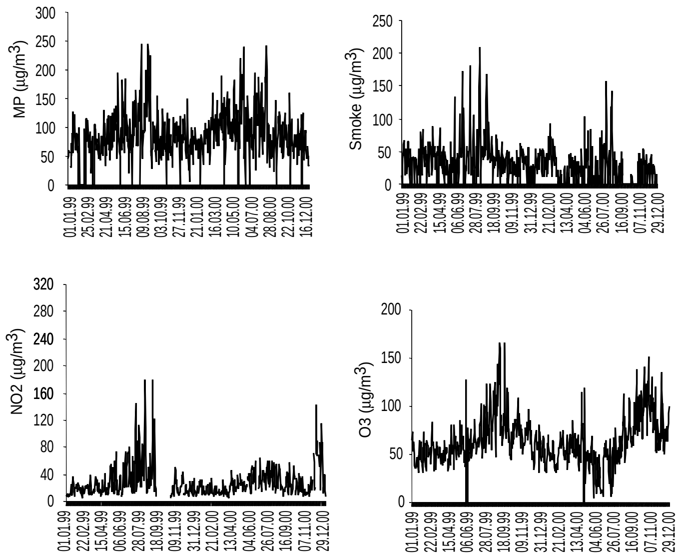

Figure 1 - Daily mean concentrations for the pollutants analyzed in the city of Curitiba (1999-2000).

respective confidence intervals, were estimated for the interquartile variation (the difference between the third and first percentiles) in the concentrations of the pollutants.

The significance level of α=5% was adopted for all the regression analyses. The statistical packages utilized were SPLUS for Windows, version 4.5, and SPSS 10.0 for Windows.

RESULTS

During the study period, 81,229 children were attended due to all the respiratory causes included in chapter VIII of ICD-9.

From Figure 1, it can be seen that in 1999 the PM_{10} exceeded the daily limit for air quality (150 μg/m^3) twice, smoke six times and O_3 (160 μg/m^3) twice. NO_2 did not exceed its limit (320 μg/m^3). For the year 2000, the PM_{10} again exceeded its limit twice and smoke just once, while NO_2 and O_3 did not exceed the acceptable levels for air quality defined by the National Council for the Environment (*Conselho Nacional do Meio Ambiente* - Conama)[7]

Table 1 presents the descriptive statistics for the daily levels of the air pollutants, minimum temperature, relative humidity of the air and respiratory diseases.

All the air pollutants were positively correlated with each other (Table 2). The greatest correlation was found between the PM_{10} and NO_2, thereby indicating a linear association between these pollutants.

An inversely proportional relationship was also observed between the pollutants, the minimum temperature and the relative humidity of the air. For the respiratory diseases, a positive and statistically significant correlation was seen between these and the PM_{10}, smoke and NO_2. The only correlation that was not statistically significant was with O_3.

Table 3 presents the results from the generalized additive models for the study period. It can be seen that the association between the air pollution and attendance due to respiratory diseases was statistically significant for the PM_{10}, NO_2 and smoke, both for the daily concentrations and for the two and

Table 1 - Descriptive analyses of the variables in the study.

Variables	Days (N)	Mean	Standard deviation	Minimum	Maximum
Pollutants					
PM (μg/m^3)	687	90.39	37.37	20.00	245.0
Smoke (μg/m^3)	548	40.24	26.37	9.00	210.0
NO_2 (μg/m^3)	672	27.17	21.32	5.32	179.19
O_3 (μg/m^3)	688	63.71	24.97	4.86	166.4
Weather					
Temperature	727	12.97	4.55	-3.50	21.8
Humidity	728	85.35	7.09	58.70	99.50
Patients					
No. of patients attended*	731	11.12	51.99	0.00	281.0

*The number of patients attended per day because of respiratory illnesses is a dependent variable controlled by minimum temperature, mean humidity, days of the week and long-duration seasonality.

Table 2 - Pairwise Pearson correlation coefficients between the pollutants, weather variables and respiratory diseases.

Variables	NO_2 (μg/m^3)	O_3 (μg/m^3)	Minimum Temperature (°C)	Relative Humidity (%)	Respiratory diseases
PM (μg/m^3)	0.53*	0.23*	-0.35*	-0.36*	0.29*
Smoke (μg/m^3)	0.46*	0.20*	-0.17*	-0.08*	0.22*
NO_2 (μg/m^3)	1.00	0.17*	-0.30*	-0.28*	0.30*

*Statistically significant correlation (p<0.05)

Table 3 - Regression coefficients, relative risk and the respective 95% confidence intervals for the pollutants included in the model.

Pollutants	Regression coefficient	Standard error	Relative risk	95% CI
NO_2	0.00087	0.00037	1.0009	1.0001 -1.0016
NO_2 - two-day average	0.00095	0.00039	1.0010	1.0002 -1.0017
NO_2 - three-day average	0.001119	0.00043	1.0011	1.0003 -1.0020
O_3	0.00035	0.000298	1.0004	0.9998 -1.0009
O_3 - two-day average	0.00059	0.00031	1.0006	1.000 -1.0012
O_3 - three-day average	0.0007	0.00033	1.0007	1.0001 -1.0013
PM	0.0008	0.00022	1.0008	1.0004 -1.0012
PM - two-day average	0.001	0.00024	1.0011	1.0006 -1.0016
PM - three-day average	0.001197	0.00025	1.0012	1.0007 -1.0017
Smoke	0.00074	0.0003	1.0007	1.0002 -1.0013
Smoke - two-day average	0.00098	0.00033	1.0010	1.0003 -1.0016
Smoke - three-day average	0.00035	0.00035	1.0011	1.0004 -1.0018

three-day moving averages, For the O_3, only the three-day moving average presented a statistically significant effect. The relative risks were generally greater for the three-day moving averages, which demonstrates the cumulative effect of exposure to air pollutants. In the case of O_3, the effect was also increasing and cumulative, although only the estimate for the three-day moving average presented statistical significance.

Figure 2 shows the percentage increases in outpatient attendance due to increases of one interquartile in the three-day moving averages for the pollutants. It can be noted that, for this lag period, all pollutants presented a positive and significant association with the outcome adopted.

DISCUSSION

Although this was an ecological study,[10] in which the study unit was a group of individuals that could represent a district, a city or even a country, rather than individual observation, it is stressed that such studies have been shown to be efficient with regard to dealing with the effects of pollution on health.[1-4,8,9,12,13]

The decision to work with the total number of respiratory diseases and not according to specific respiratory diseases came from the probability that, in so doing, the diversity of diagnoses among the various services that furnished the original data would be diminished. The use of increasingly sophisticated regression models allowed the possible confounding factors that could interfere in the data analysis to be controlled with greater efficacy. The choice of GAM for the analysis came from the fact that this model allows for adjustment of nonlinear functions for variables that present such behavior. The utilization of Poisson's regression allowed analysis of counted events, such as the number of children attended because of respiratory diseases.[6]

Positive associations were found between the pollutants (PM_{10}, smoke, NO_2 and O_3) and respiratory diseases among children in Curitiba. These effects are similar to what has been found in other Brazilian cities, especially with regard to the findings from the city of São Paulo,[3,4,8] both in relation to the diversity of the associated pollutants and the magnitude of the estimated effects.

The increased incidence of respiratory diseases during the colder periods of the year is due to two main factors: the low temperatures and the increases in the concentrations of primary pollutants.[1,2,12,13] O_3 is a secondary pollutant that depends on the presence of sunlight and precursors such as nitrogen oxides and hydrocarbons.[5] Dry winters with sunny days provide all the conditions for rises in the levels of this photochemical agent, in the same way as happens in other seasons of the year. Thus, O_3 did not present a high correlation with the other variables analyzed in the present study, since its concentration does not vary in the same way as for the other primary pollutants. Despite this, its oxidizing activity and capacity for inducing inflam-

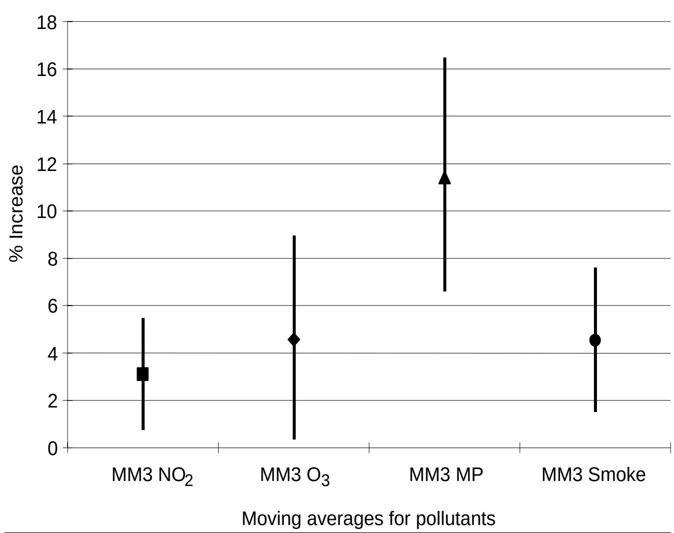

Figure 2 - Percentage increases in admissions of children for respiratory diseases caused by per-unit increases in the three-day moving averages (MM3) for NO_2 (27.17 µg/m³), O_3 (63.71 µg/m³), PM (90.39 µg/m³) and smoke (40.24 µg/m³).

matory processes gives this pollutant the role of the villain in causing or aggravating respiratory diseases, as has been reported by other studies.[4,8]

NO_2 was the only air pollutant that did not exceed the limits established for air quality, even though it was positively correlated with respiratory diseases. This reinforces the hypothesis that, even when such pollutants do not exceed the standard limits,[5] they may cause effects that are harmful to health. The association between pollution and morbidity/mortality does not display a safe level for pollutants: in other words, no safe level for pollution has been characterized such that, below this level, the pollution would not have any effect.[3,9,12]

Even though the analyses utilized models that included one or, at most, two pollutants, it is difficult to attribute the deleterious effects of air pollution on health to just one of these pollutants. The mixing of these elements in the atmosphere may modify their individual toxicity, thereby adding power to their individual effects.

On the basis of the results found, it can be inferred that the air pollution levels in Curitiba, despite not being very high, or even when not exceeding the air quality standard (as in the case of NO_2), do interfere in the morbidity profile of the child population in the city.

It is hoped that the results found will be useful, since they allow the risks to which the population is exposed to be measured, and provide backing for drawing up measures aimed at minimizing such risks. Furthermore, the results contribute towards the planning of environmental or urban healthcare and towards improving public policies.

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REFERENCES

1. Anderson HR, Leon AP, Bland JM, Bower JS, Strachan DP. Air pollution and daily mortality in London: 1987-1992. *BMJ* 1996;312:665-9.
2. Atkinson RW, Anderson HR, Sunyer J, Ayres J, Baccini M, Vonk JM et al. Acute effects of particulate air pollution on respiratory admission: results from APHEA 2 project. Air pollution and health: a European Approach. *Am J Respir Crit Care* 2001;164(10 Pt 1):1860-6.
3. Braga ALF, Conceição GMS, Pereira LAA, Kishi HS, Pereira JCR, Andrade MF et al. Air pollution and pediatric respiratory hospital admissions in São Paulo, Brazil. *J Environ Med* 1999;1:95-102.
4. Braga ALF, Saldiva PHN, Pereira LAA, Menezes JJC, Conceição GMS, Lin CA et al. Health effects of air pollution exposure on children and adolescents in São Paulo, Brazil. *Pediatr Pulmonol* 2001;31:106-13.
5. [Cetesb] Companhia de Tecnologia de Saneamento Ambiental. Relatório de qualidade do ar no estado de São Paulo, 2002. São Paulo; 2003.
6. Hastie TJ, Tibshirani RJ. Generalized additive models. London: Chapman and Hall; 1995.
7. [IAP] Instituto Ambiental do Paraná. Relatório da qualidade do ar na região metropolitana de Curitiba, PR, 2000. Paraná; 2001.
8. Lin AC, Martins MA, Farhat SL, Pope III CA, Conceição GMS, Anastácio MV et al. Air pollution and respiratory illness of children in São Paulo, Brazil. *Pediatr Perinat Epidemiol* 1999;13:475-88.
9. Martins LC, Latorre MRDO, Cardoso MRA, Gonçalves FLT, Saldiva PHN, Braga ALF. Poluição atmosférica e atendimentos por pneumonia e gripe em São Paulo, Brasil. *Rev Saúde Pública* 2002;36:88-94.
10. Morgenstern H. Ecologic Studies in epidemiology: concepts, principles, and methods. *Ann Rev Public Health* 1995;16:61-81.
11. Santos M. A urbanização brasileira. 3ª ed. São Paulo: Hucitec; 1996.
12. Schwartz J, Dockery DW. Particulate air pollution and daily mortality in Steubenville, Ohio. *Am J Epidemiol* 1992;135;12-9.
13. Schwartz J, Marcus A. Mortality and air pollution in London: a time series analysis. *Am J Epidemiol* 1990;131:185-94.
14. Ultramari C, Moura R. Metrópole – Grande Curitiba: teoria e prática. Curitiba: IPARDES; 1994.