Quantifying the impact of air pollution on the urban population of Brazil

Quantificação do impacto da poluição atmosférica sobre a população urbana brasileira

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Abstract

This study aimed to quantify air pollution impact on morbidity and mortality in the Brazilian urban population using locally generated impact factors. Concentration-response coefficients were used to estimate the number of hospitalizations and deaths attributable to air pollution in seven Brazilian cities. Poisson regression coefficients (β) were obtained from time-series studies conducted in Brazil. The study included individuals 65 years old and over and children under five. More than 600 deaths a year from respiratory causes in the elderly and 47 in children were attributable to mean air pollution levels, corresponding to 4.9% and 5.5% of all deaths from respiratory causes in these age groups. More than 4,000 hospital admissions for respiratory conditions were also attributable to air pollution. These results quantitatively demonstrate the currently observed contribution of air pollution to mortality and hospitalizations in Brazilian cities. Such assessment is thought to help support the planning of surveillance and control activities for air pollution in these and similar areas.

Air Pollution; Impacts on Health; Mortality; Urban Health

Introduction

The recognition that ambient air pollution levels can produce adverse effects on human health has motivated a wide debate on the topic. The first studies examining the association between atmospheric pollution and health effects date from the first half of the 20th century and reported significant increases in morbidity and mortality in cities of developed countries [1,2]. Following this initial wave of research, a series of laboratory and epidemiological studies were performed in order to properly characterize this association. The amount and diversity of studies published in recent decades reinforce the identification of air pollution as an important risk factor for human health.

More recently, a growing body of studies in developing countries has also shown that air pollution exerts great pressure on the environment in these areas, with a large potential impact on the population's health, especially in major urban areas [2,3,4,5].

There is thus an increasing need for programs and actions aimed at monitoring and reducing air pollution levels. Several countries have air quality programs, including Brazil. The World Health Organization (WHO) also recommends standard acceptable levels of atmospheric pollutants and includes policies on its agenda to encourage pollution control.

It is thus important to know the impact of current air pollution levels on the population's health in order to determine whether the probable health benefits of pollution control (i.e., benefits potentially achieved by lowering air pollution levels) are worth the costs of their implementation.

An approach used to assess the health impacts of air pollution is the application of concentration-response coefficients (C-R) derived from epidemiological studies on health impact functions [4,5,6,7,8]. Health impact function measures the change in a relevant health endpoint due to a given change in the air pollutant concentration using the C-R coefficients obtained from studies investigating the association between air pollution and different health endpoints.

In most situations, C-R coefficients are obtained from time series analysis of mortality or hospital admissions. Such studies investigate the association between daily counts of deaths (or hospitalizations) and air pollution measurements and have been widely employed in the air pollution literature.

Ideally, the evaluation of air pollution impact on population health is based on local studies [5,6,7,8]. However, few such studies have been conducted in developing countries, including Brazil. The use of results from studies in other countries (generally wealthy and developed) has been questioned, since they are based on different pollutant levels and compositions from those in developing countries. Additionally, health impact estimates refer to populations with different socioeconomic conditions and with distinct morbidity, mortality, and vulnerability patterns [5,6,7,8,9].

Therefore, the current study aims to provide a quantitative estimate of the impact of ambient air pollution levels on morbidity and mortality in the Brazilian urban population, using locally generated data.

Methodology

This study follows the methodology applied in recent assessments [5,7,8] on the health impacts of air pollution. In such studies, the expected number of health effects is modeled as an exponential function of the explanatory variables and the change in the number of health effects, (ΔE), where ambient concentrations of pollutant *P* and change by ΔP are given by:

$$\Delta E = [\exp(\beta.\Delta P)-1].Pop.BRd \quad (1)$$

where:

ΔE = variation in the expected health endpoint number;

β = regression coefficient associated with pollutant of interest (a measure of health effect per unit of pollution, often referred to as the C-R coefficient);

ΔP = variation in ambient concentration of pollutant *P*;

Pop = exposed and susceptible population;

BRd = baseline incidence rate of effect for a specific endpoint in the population under study (Pop), usually expressed as the number of events per 100,000 persons during a baseline year;

For the present analysis, only studies with comparable methodologies and conducted exclusively in Brazilian cities were used to obtain the C-R coefficients. In order to obtain the largest possible number of such studies, an exhaustive literature review was performed, using PubMed and SciELO indexers, as well as LILACS and REPIDISCA databases.

These studies generally use Poisson regression to quantify air pollution health effects, including potential confounders (e.g., meteorological and seasonal variables) in the model. Regression coefficients (β) from Poisson regression models for each specific endpoint and age group were selected from these studies, and a pooled estimate was obtained using a fixed-effects model with inverse variance weighting [6,7,8,9]. The calculations were only performed when there were at least three different estimates (β) for the same outcome and age group.

Only age groups that are more frequently referred to in the literature as susceptible to air pollution effects were included, that is: elderly ($\geq$ 65 years) and children under 5. Some published studies that examined slightly different age groups (e.g.: > 60 or < 13 years) were included, since it was felt that the impact of these small differences would not affect the type of analysis proposed by the present study.

Importantly, in this study the health impact of air pollution was calculated for a hypothetical scenario in which the goal for air pollutant control would be equal to zero. Thus, ΔE represents an estimation of endpoints due to the observed air pollution level, in this case represented by the pollutant's annual mean.

In order to obtain current and reliable air pollution levels for Brazilian state capitals, written requests were sent to the respective municipal environmental agencies [10,11,12]. Searches were also performed on the websites of some of these agencies.

Fine particulate matter (PM_{10}) was the pollutant analyzed here, since it is the one most consistently evaluated in the literature and also the most frequently measured by environmental agencies in Brazil. In cities where only total suspended particles (TSP) were measured, PM_{10} was estimated based on the proportion PM_{10} = 0.55*TSP [6]. Ambient concentration of the pollutant was defined as the average of the annual means observed in each site from 1998 to 2005 in order to avoid chance error caused by the possible occurrence of extreme values during a given year.

All necessary data for calculating the baseline incidence rates of health events were obtained from the Departamento de Informática do SUS (DATASUS; the Data and Information Technology Department of the Brazilian Unified National Health System). The study period included the years 1998 through 2005.

The baseline incidence rate of each endpoint was calculated based on the mean number of occurrences in each city during the study period, divided by the city's total population. The population in the year 2000 was used as the basis, since it coincides with the National Census.

Results

The literature review retrieved 22 citations of studies conducted in Brazil linking air pollution and health effects. Among these, nine publications were included for calculating the C-R coefficients. The others were excluded for at least one of the following reasons: not an ecological time series study; did not use Poisson regression; did not provide sufficient information to obtain the β; or focused on a different age group from those chosen for the present study. All articles included in the analysis were time series studies with daily counts of events and control of potential confounding factors.

Table 1 summarizes the nine articles that were included. Importantly, all were conducted in the Southeast region of Brazil, more specifically in the cities of Rio de Janeiro and São Paulo [13,14,15,16,17,18,19,20,21]. These studies provided regression coefficients that enabled us to calculate C-R coefficients for respiratory deaths and hospital admissions among the elderly and children less than five years old. Regarding respiratory mortality in children, one study that specifically evaluated deaths from pneumonia was included, since it is the cause of nearly 65% of respiratory mortality in this age group.

We obtained data on annual air pollution levels from seven of the largest Brazilian cities (Belo Horizonte, Curitiba, Fortaleza, Porto Alegre, Rio de Janeiro, São Paulo, and Vitória). Most other Brazilian State capitals lacked regular monitoring of air pollution. The results presented here refer to these seven cities, comprising nearly 24 million inhabitants (14% of Brazil's total population).

Air pollution monitoring systems differ among the seven cities. For example, São Paulo has 14 automatic monitoring sites distributed all over the city, including neighborhoods further from downtown. Meanwhile, Curitiba has two monitoring stations, but only one with complete and representative data that could be used to calculate a citywide average. In addition, the period of available data differs among the cities (Table 2), with some having only two years of available data. Fortaleza was the only city where TSP was measured, while all the others provided data on PM_{10}.

Table 1

Summary of articles included in the study.

Reference	City	Study period	Age group (years)	Endpoint
Gouveia et al. [14]	São Paulo and Rio de Janeiro	1996-2000 (São Paulo)/ 1990-1993 and 2000-2001 (Rio de Janeiro)	< 5 and ≥ 65	Respiratory and cardiovascular hospital admissions and mortality
Gouveia et al. [15]	São Paulo	1991-1993	All ages, < 5 and ≥ 65	Respiratory and cardiovascular mortality
Gouveia et al. [16]	São Paulo	1992-1994	< 1 and < 5	Respiratory hospital admissions
Conceição et al. [17]	São Paulo	1994-1997	< 5	Respiratory mortality
Braga et al. [13]	São Paulo	1993-1997	≤ 2, 3-5, 6-13 and 14-19	Respiratory hospital admissions
Braga et al. [18]	São Paulo	1992-1993	< 13	Respiratory hospital admissions
Saldiva et al. [19]	São Paulo	1990-1991	≥ 65	All-cause mortality
Martins et al. [20]	São Paulo	1997-1999	> 60	Respiratory mortality
Daumas et al. [21]	Rio de Janeiro	1990-1993	≥ 65	Respiratory and cardiovascular mortality

Table 2

Under-five and elderly population in seven Brazilian state capitals and mean annual air pollution levels.

City	Population *		PM_{10} (µg/m³) **	Period ***	Monitoring sites (n) #
	< 5 years	≥ 65 years			
Belo Horizonte	178,346	139,283	20.7	2000-2003	3 (1 in 2000 and 2001)
Curitiba	128,386	90,476	23.3	2004-2005	1
Fortaleza	204,402	108,666	49.5	1998-2002	3 (2 in 1998)
Porto Alegre	104,076	113,685	27.8	2002-2005	3
Rio de Janeiro	447,305	534,224	55.5	2000-2003	6
São Paulo	879,506	670,780	49.8	1998-2002	14 (12 in 2001; 10 in 2002)
Vitória	22,436	18,065	27.3	2003-2005	2

* 2000 National Census;

** Annual mean;

*** Years included in calculating the mean annual PM_{10};

\# Number of monitoring sites included in the study.

Table 2 shows descriptive data on the seven cities, such as population by age group and observed air pollution levels. Rio de Janeiro had the highest mean PM_{10}, followed by São Paulo, Fortaleza, Porto Alegre, and Vitória. Despite being listed as the most polluted State capitals in this study, except for Rio de Janeiro they all showed annual levels below the standard air quality for PM_{10} as specified by CONAMA (the National Environmental Council), which is 50µg/m³ [12]. Meanwhile, Curitiba and Belo Horizonte showed the lowest mean PM_{10}.

Tables 3, 4, and 5 show the expected annual number of health events, specifically mortality and hospital admissions of elderly and children attributable to the observed PM_{10} levels in each city, considering the baseline rates for these events in each city.

In relation to respiratory mortality in the elderly, it is estimated that over 600 deaths/year are attributable to the current mean PM_{10}, corresponding to 4.9% of the total respiratory mortality observed in these cities (Table 3).

For children under five years of age, an estimated total of approximately 47 deaths from respiratory causes are attributable to PM_{10} levels, representing 5.5% of all respiratory deaths recorded during the period (Table 4).

It is also estimated that the observed PM_{10} levels in these Brazilian state capitals are responsible for 5.2% of hospital admissions from respiratory causes among children and 8.3% among the elderly, totaling 4,581 admissions per year in the seven cities (Table 5).

Table 3

Expected annual number of respiratory deaths and attributable fraction in the elderly due to observed PM_{10} levels in seven Brazilian state capitals.

City	Mean annual occurrence	Attributable fraction	
		n	%
Belo Horizonte	1,012.8	22.0	2.2
Curitiba	680.7	16.7	2.5
Fortaleza	680.5	35.9	5.3
Porto Alegre	823.8	24.2	2.9
Rio de Janeiro	4,057.5	241.1	5.9
São Paulo	5,104.0	271.3	5.3
Vitória	93.2	2.7	2.9
Total	12,452.5	613.9	4.9

Discussion

This study intended to provide a quantitative estimate of the impact of urban air pollution on the population's health in some of Brazil's largest cities, using health impact functions with C-R coefficients obtained from local studies and the results expressed as attributable effects.

The results for respiratory mortality among both the elderly and under-five children show that around 5% of total annual deaths from this cause in these age groups can be attributed to air pollution levels in these cities. This attributable fraction is quite relevant in both public health and socioeconomic terms. The figures were similar for respiratory hospitalizations in children, but higher values were observed for the elderly, indicating a stronger effect of air pollution in this specific age group. As expected, cities with larger populations exhibited larger absolute numbers of deaths and hospitalizations, while those with higher air pollution levels showed large attributable fractions.

In summary, the results provide evidence that air pollution levels currently experienced by large population groups in major Brazilian urban areas have an important impact on health.

The numbers presented here are compatible with the few recent estimates of the health burden attributable to air pollution in different cities/countries [5,6,7]. For example, Künzli et al. [7] using a similar approach found that air pollution was associated with 6% of total mortality in adults over 30 years old, or more than 40,000 attributable cases a year in Austria, France, and Switzerland.

The present study is the first attempt to estimate the health impact of air pollution that employed data exclusively from Brazilian cities for constructing the C-R coefficients. This approach is expected to reduce the uncertainty involved in risk assessment. The extrapolation of results from studies conducted elsewhere, although frequently found in the literature, has been questioned. It is known that differences regarding populations' health profile, health care systems, and nature and composition of pollution may interfere with the results [5,6,7,8,9,22].

The scope of this study was quite wide. The total population sample represents approximately 21% of Brazil's urban population over 65 years of age and 15% of the urban population younger than five years. We aimed to include the highest possible number of cities, representing all of the country's regions.

The assessment of air pollution's impact on human health involves some uncertainties that are inherent to the process of risk quantification. Interpretation of the findings should thus consider such limitations. An example is the quality of data used to calculate attributable effects. Secondary data were used, with different sources from each city. Some discrepancy in data quality among the cities is expected, both for air pollution measurements and mortality data.

Despite the above, mortality data are quite reliable both in general terms and based on earlier evaluations [23]. The same can be said about hospitalization data, although probably with a larger margin of error, with a general tendency to un-

Table 4

Expected annual number of respiratory deaths and attributable fraction of respiratory mortality among children due to observed PM_{10} levels in seven Brazilian state capitals.

City	Mean annual occurrence	Attributable fraction	
		n	%
Belo Horizonte	75.2	1.9	2.5
Curitiba	45.2	1.3	2.8
Fortaleza	104.8	6.3	6.0
Porto Alegre	43.2	1.4	3.3
Rio de Janeiro	139.3	9.5	6.8
São Paulo	433.7	26.3	6.1
Vitória	3.5	0.1	3.3
Total	845.0	47.0	5.5

Table 5

Expected annual number of respiratory hospital admissions and attributable fraction (%) of admissions due to observed PM_{10} levels in seven Brazilian state capitals.

City	< 5 years			≥ 65 years		
	Mean annual occurrence	Attributable fraction		Mean annual occurrence	Attributable fraction	
		n	%		n	%
Belo Horizonte	9,401.2	241.8	2.6	2,935.2	121.5	4.1
Curitiba	3,207.5	93.0	2.9	2,679.8	125.2	4.7
Fortaleza	11,212.2	701.4	6.3	2,257.5	229.8	10.2
Porto Alegre	4,457.8	154.7	3.5	2,962.7	165.9	5.6
Rio de Janeiro	6,872.5	484.3	7.0	4,055.2	466.0	11.5
São Paulo	17,597.5	1,108.8	6.3	6,272.2	643.1	10.3
Vitória	1,027.2	35.0	3.4	189.7	10.4	5.5
Total	53,775.8	2,819.0	5.2	21,352.0	1,762.0	8.3

derreport in some places. It is also important to note that the hospitalization database used here refers only to the public health system. The results should thus be viewed as conservative estimates.

Meanwhile, the air pollution data may not be as accurate as those for mortality and hospitalization, because the measurements were performed by different institutions in each city, with differences in the number of monitoring stations, strategies for allocating the sites around the city, and especially quality control procedures.

These differences may explain the higher PM_{10} in Rio de Janeiro as compared to São Paulo, which is more industrialized and has more motor vehicles. Considering differences in topography, land-use patterns, level of motorization, and industrialization, the distribution of monitoring sites within a city plays an important role in accurately determining the air pollution levels. For example, if a monitoring station is located next to a busy road, it tends to provide higher measurements than if located farther away from motor vehicle traffic.

This may also explain why Fortaleza, with far fewer motor vehicles than the other cities, less industrialization, and possibly better conditions for air pollution dispersion, showed the third highest air pollution level among the seven cities. Fortaleza was also the only city that measures TSP rather than PM_{10}. Thus, annual air pollution levels presented in this study should be viewed with caution, and direct comparisons between the cities should be avoided.

In addition, in order to avoid chance error caused by the occurrence of extreme values in a given year, we attempted to include measurements from a longer time period. Nevertheless, this was impossible for Curitiba, since data there were only available for two years.

This analysis has considered only the PM_{10} effect on health, since it is the air pollutant most commonly measured by Brazilian environmental agencies. Importantly, the estimates conducted here may thereby underestimate the total impact of atmospheric pollution, which increases when other pollutants (e.g. O_3 and NO_2) are included [5,20].

Despite these caveats, the results quantitatively demonstrate the contribution of air pollution to respiratory mortality and hospitalizations for different causes and age groups in some Brazilian cities. However, these are only some of the measurable effects of air pollution. They represent some of the most serious endpoints, but also the least frequent ones. Cardiovascular events, one of the most important causes of mortality and morbidity among the elderly, were not examined here. Air pollution's impact on public health also includes other endpoints such as pulmonary function disorders, respiratory symptoms, demand for drug therapy, and reduced physical activity. Although these may sometimes even be minor effects at the individual level, they are highly important in public health terms due to their increased frequency, decrease in quality of life, and negative economic consequences such as school and work absenteeism.

Air pollution plays an important role in health deterioration in urban populations and is now considered by the WHO as a serious threat to public health [24]. Recent publications have reaffirmed air pollution as a major cause of hospitalization and death in Brazil and other Latin America cities [1,2,3,4,5,13,14,15,16,17,18,19,20,21,22]. Furthermore, the estimates are generally quite conservative. It is thus necessary to weigh economic and environmental issues by taking actions that promote socioeconomic growth without compromising environmental conditions. It is urgent to implement public policies that not only stop pollution, but also help reduce current air pollution levels. Assessing pollution's impact may help decision-makers to better understand the effects of air pollution and the benefits that can be achieved through control measures.

The results of this study represent a quantitative approach to health risks from air pollution in Brazilian cities. Even considering the study's limitations, it is an important tool to support the planning of air pollution surveillance and control activities in these and similar areas.

Resumo

O objetivo deste estudo foi quantificar o impacto da poluição atmosférica sobre a morbi-mortalidade da população urbana brasileira, usando fatores de impacto gerados no nível local. Foram utilizados coeficientes de concentração-resposta para estimar os números de internações hospitalares e de óbitos atribuíveis à poluição do ar em sete capitais brasileiras. Foram obtidos coeficientes de Poisson (β) a partir de estudos de séries temporais realizados no Brasil. Foram incluídos idosos (≥ 65 anos) e crianças abaixo de cinco anos. Anualmente, mais de 600 óbitos por causas respiratórias entre idosos e 47 em crianças podem ser atribuídos ao nível médio de poluição atmosférica, o que representa 4,9% e 5,5% do total de óbitos por causas respiratórias nesses dois grupos etários, respectivamente. A cada ano, mais de 4 mil internações hospitalares por causas respiratórias também são atribuíveis à poluição do ar. Esses resultados demonstram quantitativamente o impacto atual da poluição atmosférica na mortalidade e hospitalização em cidades brasileiras. Espera-se que o estudo ajude a subsidiar o planejamento de atividades de vigilância e controle da poluição atmosférica, não apenas nessas cidades, como também em outras áreas urbanas semelhantes.

Poluição do Ar; Impactos na Saúde; Mortalidade; Saúde da População Urbana

Contributors

Both authors commented critically on the manuscript and agreed on the final version. N. Gouveia conceived, designed, and coordinated the study and commented on the analysis and interpretation. I. Marcilio helped design the study, developed and conducted the literature search strategy, performed the analysis, and commented on the analysis and interpretation.

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