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Association between vehicular emissions and cardiorespiratory disease risk in Brazil and its variation by spatial clustering of socio-economic factors

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ABSTRACT

Many studies have suggested that socio-economic factors are strong modifiers of human vulnerability to air pollution effects. Most of these studies were performed in developed countries, specifically in the US and Europe. Only a few studies have been performed in developing countries, and analyzed small regions (city level) with no spatial disaggregation. The aim of this study was to assess the association between vehicle emissions and cardiorespiratory disease risk in Brazil and its modification by spatial clustering of socio-economic conditions. We used a quantile regression model to estimate the risk and a geostatistical approach (K means) to execute spatial cluster analysis. We performed the risk analysis in three stages. First, we analyzed the entire study area (primary analysis), and then we conducted a spatial cluster analysis based on various municipal-level socio-economic factors, followed by a sensitivity analysis. We studied 5444 municipalities in Brazil between 2008 and 2012. Our findings showed a significant association between cardiorespiratory disease risk and vehicular emissions. We found that a 15% increase in air pollution is associated with a 6% increase in hospital admissions rates. The results from the spatial cluster analysis revealed two groups of municipalities with distinct sets of socio-economic factors and risk levels of cardiorespiratory disease related to exposure to vehicular emissions. For example, for vehicle emissions of PM in 2008, we found a relative risk of 4.18 (95% CI: 3.66, 4.93) in the primary analysis; in Group 1, the risk was 0.98 (95% CI: 0.10, 2.05) while in Group 2, the risk was 5.56 (95% CI: 4.46, 6.25). The risk in Group 2 was 480% higher than the risk in Group 1, and 35% higher than the risk in the primary analysis. Group 1 had higher values (3rd quartile) for urbanization rate, highway density, and GDP; very high values ($\geq$ 3rd quartile) for population density; median values for distance from the capital; and lower values (1st quartile) for rural population density. Group 2 had lower values (1st quartile) urbanization rate; median values for highway density, GDP, and population density; between median and third quartile values for distance from the capital; and higher values (3rd quartile) for rural population density. Our findings suggest that socio-economic factors are important modifiers of the human risk of cardiorespiratory disease due to exposure to vehicle emissions in Brazil. Our study provides support for creating effective public policies related to environmental health that are targeted to high-risk populations.

1. Introduction

Cardiorespiratory diseases are a serious public health problem worldwide. According to the World Health Organization (WHO, 2014a), cardiovascular and respiratory diseases were responsible for 17.5 and 4 million global death in 2012, respectively. Air pollution is considered to be one of the main contributors to cardiorespiratory diseases (Cohen et al., 2005; Fajersztajn et al., 2013). In 2010, 3 million deaths worldwide were caused by air pollution (Lim et al., 2012). Two years later, this number increased to 7 million (WHO, 2014b). Particulate matter ($PM_{2.5}$) specifically contributes to approximately 2 million premature deaths per year, making it as the 13th leading cause of mortality worldwide

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(Lozano et al., 2012).

Among air pollution sources, vehicle emissions are of particular concern (Lipfert and Wyzga, 2008; Gallardo et al., 2012; Réquia Júnior et al., 2015a). Motor vehicle emissions are responsible for 30% of nitrogen oxides (NO_x), 14% of carbon dioxide (CO_2), 54% of carbon monoxide (CO), and 47% of non-methane hydrocarbon (NMHC) in global emissions (Sokhi, 2011). Several studies have shown that traffic-related air pollution is associated with health effects, such as cardiorespiratory diseases (Mortimer et al., 2012; Réquia Júnior et al., 2015b), premature mortality (Lin et al., 2004; Lelieveld et al., 2015), diabetes (Nicole, 2015), and nervous system diseases (Genc et al., 2012). According to Jacobson (2007), both gasoline and ethanol combustion are anticipated to cause at least 10,000 premature deaths in the United States in 2020.

Many studies have demonstrated the spatial heterogeneity of human exposure to air pollution (Tian et al., 2010; Khedairia and Khadir, 2012; Austin et al., 2013; Zou et al., 2014; Carreras et al., 2015; Réquia Júnior and Roig, 2015). Socio-economic factors are considered to be strong modifiers of human vulnerability to air pollution effects. Most of these studies were performed in developed countries, especially in the US and in Europe. Only a few studies on the influence of socio-economic factors on the health risks of air pollution have been performed in developing countries, and they analyzed only small regions (at the city level) with no spatial disaggregation (Troncoso and Cifuentes, 2012; Miranda et al., 2014; Carreras et al., 2015).

Overall, developing countries have specific conditions that alter the association between air pollution and human health (Carreras et al., 2015). These include a higher rate of urban growth, low income, social inequality, and inefficient regulation and control of air pollution sources (D'angiola et al., 2010; Silva et al., 2012; Réquia Júnior et al., 2015b). Air pollution exposure is not tracked as well in certain countries. For example, in terms of air pollution control, Brazil, Argentina, Peru, Colombia, and Mexico have 1.3, 0.24, 0.23, 0.26, and 0.35 stations per one-million inhabitants, respectively (Alves et al., 2014). In contrast, the USA has 16 stations (Alves et al., 2014), Japan has 15 stations (Fukushima, 2006), and Germany has 23 stations (UBA, 2013) stations per one-million inhabitants.

A better understanding of the spatial variation in human exposure to air pollution under various socio-economic conditions in developed and developing countries can reveal the associated risks to health and guide more effective public policies for urban planning, environmental health, and economic development (Fan et al., 2012; Santos-Juusela et al., 2013; Réquia Júnior and Roig, 2015). The aim of this study was to evaluate the association between vehicle emissions and cardiorespiratory disease risk in Brazil and its modification by municipal-level variations in socio-economic conditions.

2. Materials and methods

2.1. Study design and data

We conducted a cross-sectional analysis of the association between vehicle emissions and hospital admissions for cardiorespiratory diseases in Brazil. The study included data for the entire country of Brazil, which has 200 million inhabitants and an area of 8,515,767 km^2 divided into 26 states and a Federal District. These are further divided into 5570 municipalities, which are the smallest regions recognized by the Brazilian political system. The study was performed in three stages: i) statistical analysis – primary analysis; ii) cluster analysis; and iii) statistical analysis – sensitivity analysis (Fig. 1).

Health data collected from the National Health Database (DATASUS, 2013) included the number of annual hospital admissions for circulatory (ICD-10, I00-I99) and respiratory (ICD-10, J00-J99) diseases between 2008 and 2012 for each Brazilian municipality. We used information from the national census provided by the Brazilian Institute of Geography and Statistics (IBGE, 2012) to calculate the rate of hospital admissions (admissions per 1000 people).

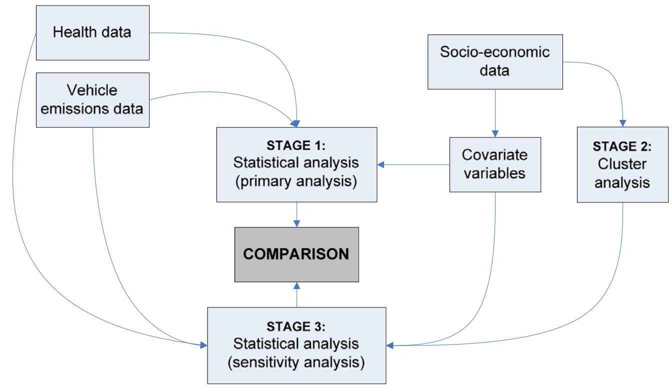

Fig. 1. Stages of the research analysis.

Vehicle emissions data were estimated by our research group in a previous analysis. We predicted the vehicular emissions (tons per year) using a bottom-up method within each of the 5570 municipalities in Brazil from 2001 to 2012 for CO, NMHC, methane (CH_4), NO_x, and PM. For PM emissions, we considered the sum of emissions from exhaust, brakes, tires, and pavement wear. We used the following equation to estimate emissions:

$$E_{x,\,i,\,z,\,y}=\frac{\left[\left(Vf_{x,i,y}\times\alpha_y\right)\times Dt_y\times Ef_{i,z,y}\right]}{10^6} \quad (1)$$

where: *E* are the annual emissions in metric tons; *Vf* is the number of vehicles; α is fraction of fleet in use; *Dt* is the average distance traveled in km/year; *Ef* is the emission factor in grams of pollutant per unit distance – (g/km); *x* is the municipal district (5570); *i* is the year considered to estimate emissions (from 2001 to 2012); *z* is the pollutant type, and; *y*, is the vehicle type.

We considered six vehicle categories: light vehicles (passenger cars), utility vehicles (for transport of passengers or goods), motorcycles, trucks (light, middle, and heavy duty), urban buses, and interstate buses. Finally, to estimate the total emissions of a pollutant *z* for year *i*, and for municipal district *x*, we used the following equation:

$$TAE_{z,i,x} = E_{Lv,z,i,x} + E_{Uv,z,i,x} + E_{Mo,z,i,x} + E_{Tr,z,i,x} + E_{Ub,z,i,x} + E_{Ib,z,i,x} \quad (2)$$

where *TAE* are the emissions, in tons, for light vehicles, *Lv*, utility vehicles *Uv*, motorcycles, *Mo*, trucks, *Tr*, urban buses, *Ub*, and interstate buses, *Ib*. For the socio-economic data, we considered Gross Domestic Product (GDP), urbanization rate (% of urbanized area), highway density (length of highways, km, per municipality area, km^2), distance of municipality from the state's capital (km), total population density, and rural population density. Each socio-economic datum refers to the municipality level. Highway density and distance from the capital were calculated using GIS techniques. Other data were provided by IBGE (2012). We chose distance from the capital to represent socio-economic data because is a proxy indicator of health system quality. In Brazil, main hospitals tend to be located in capitals.

Missing socio-economic data occurred in 126 municipalities and these were removed from our study, which resulted in the analysis conducted in 5444 municipalities in Brazil (98%).

Spatial data generation and processing was done with ArcGIS,