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A review of emissions and concentrations of particulate matter in the three major metropolitan areas of Brazil

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ABSTRACT

We critically assessed numerous aspects such as vehicle fleet, type of fuel used in road vehicles, their emissions and concentrations of particulate matter ≤2.5 µm ($PM_{2.5}$) and ≤10 µm (PM_{10}) in three of the most polluted metropolitan areas of Brazil: the Metropolitan areas of São Paulo (MASP), Rio de Janeiro (MARJ) and Belo Horizonte (MABH). About 90% of the Brazilian LDVs run on ethanol or gasohol. The HDVs form a relatively low fraction of the total fleet but account for 90% of the PM from road vehicles. Brazilian LDVs normally emit 0.0011 g (PM) km^{-1} but HDVs can surpass 0.0120 g (PM) km^{-1}. The emission control programs (e.g., PROCONVE) have been successful in reducing the vehicular exhaust emissions, but the non-exhaust vehicular sources such as evaporative losses during refueling of vehicles as well as wear from the tyre, break, and road surface have increased in line with the increase in the vehicle fleet. The national inventories show the highest annual mean $PM_{2.5}$ (28.1 µg m^{-3}) in the MASP that has the largest vehicle fleet in the country. In general, the PM_{10} concentrations in the studied metropolitan areas appear to comply with the national regulations but were up to ~3-times above the WHO guidelines. The current Brazilian air quality standards are far behind the European standards. There has been a progress in bringing more restrictive regulations for air pollutants including PM_{10} and $PM_{2.5}$ but such steps also require suitable solutions to control PM emissions from motor vehicles and mechanical processes.

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1. Introduction

Air quality deterioration is a major environmental concern in many modern cities, including urban centres of Latin America (Onursal and Gautam, 1997; Park and Kim, 2005). Amongst several pollutants capable of affecting air quality, particulate matter (PM) is one of the main pollutants showing the greatest impact on human health (Heal et al., 2012). The PM is commonly divided into coarse and fine particles (Miranda et al., 2011; Kumar and Goel, 2016). Fine particles comprise mass concentration of particles with an aerodynamic diameter equal to or less than 2.5 µm ($PM_{2.5}$) whereas coarse particles include diameters ranging from 2.5 to 10 µm ($PM_{2.5-10}$) (Mariani and de Mello, 2007). The scope of this article includes both the fine and coarse particles, which together are referred to as PM_{10}.

Vehicular emissions are a significant source of PM, especially fine particles (Onursal and Gautam, 1997). Over the past few years, an increase in motor vehicles and industrial activities in urban areas have worsened the atmospheric contamination by PM; such conditions give rise to numerous public health problems (Faiz et al., 1996; Fernández et al., 2000). Exposure to elevated levels of PM can have severe impacts on human health, and in particular cause respiratory and cardiovascular diseases and premature deaths (Lanki et al., 2006; Saldiva et al., 1994). Thus, PM has become an important matter due to its impact on health and the environment (Jimoda, 2012), resulting in the formulation of guidelines and standards by international bodies and local governments and to protect public health. While the threshold values help in safeguarding public health, exposure to pollutants could still affect human health at the PM concentrations below the levels recommended by the air quality guidelines (Baldauf et al., 2009; Kumar et al., 2015; Martins et al., 2009). Regarding climate change, $PM_{2.5}$ in many Brazilian cities is characterised by high fraction of carbonaceous compounds that have a direct impact on the radiative balance, and the inorganic fraction, on the cloud microphysics processes (Miranda et al., 2011).

During the last decade, developing countries such as Brazil have been facing rapid economic growth that has triggered an increase in the vehicle fleet and air pollution in urban centres, especially in the capitals and their metropolitan areas (Faiz et al., 1996; Miranda et al., 2011). Three of the major Brazilian metropolitan areas – Metropolitan Areas of São Paulo (MASP), Rio de Janeiro (MARJ) and Belo Horizonte (MABH) – located in the southeast region of the country, are noteworthy for their economic importance. Together, these account for ~60% of the national Gross Domestic Product (IBGE, 2012). Moreover, these are the most populated regions in Brazil, concentrating 12% of the national vehicle fleet and a large number of industries. For that reason, we have selected these three regions as a focus of this review article.

The countries in South America were colonized by Spanish and Portuguese. The urban settlements followed the style of European towns with the buildings and important houses concentrated in the central part of the cities. The growth of the periphery of the cities in South America was motivated by the access to jobs and public services. This resulted in an increase in commuting time, with direct effects on both time lost during the commute and excessive emissions of pollutants. The spatial distribution of the vehicles indicates that the oldest cars (comprising most of the high-emitters) are usually concentrated in the periphery of the Brazilian cities (CETESB, 2016). Many other countries in South America, Africa, and Asia are facing similar urban transition.

Monitoring of air pollutants is very uneven in the Latin America countries, and usually restricted to the large cities (Clean Air Institute, 2012; UNEP, 2016). Some countries do not have their own air quality standards. The importance of the evaluation of air quality in these emerging cities is important to protect the health of their inhabitants. For example, Romieu et al. (2012) described the results of the ESCALA Project (Estudio de Salud y Contaminacion del Aire en Latinoamerica) that considered cities in Brazil, Chile, and Mexico. For most cities, they found that PM_{10} concentrations were associated with increased mortality from cardiopulmonary, respiratory, cardiovascular, cerebrovascular-stroke, and chronic obstructive lung diseases.

The discussion presented here is focused on the three biggest metropolitan areas of Brazil, which are undergoing fast and disorganised growth, and face challenges in implementing regulations for air pollution emissions from mobile sources. Despite the historical and local characteristics, the trajectory of the urbanisation growth in the Brazilian cities can be viewed as a representative example of cities in developing countries, since Brazil is the largest country in Latin America.

The MASP is the largest metropolis in Brazil, with a population of more than 21 million inhabitants; this includes 39 cities covering a surface area of approximately 8000 km² (IBGE, 2015; Miranda et al., 2011). The biggest and most important city is São Paulo, which is the capital of the state of São Paulo. This region presents a tropical climate with wet (October to April) and dry (May to September) seasons; January and June are the hottest and coldest months of the year, respectively (Miranda et al., 2011).

The second largest Brazilian metropolis is the MARJ, with the most relevant city being Rio de Janeiro, which is also the capital of this state and a place for 2016 Olympic Games. This metropolitan area has almost 13 million inhabitants distributed throughout 21 cities across a surface area of ~6800 km² (IBGE, 2015; Miranda et al., 2011). February and July are the hottest and coldest months in the MARJ, respectively. The MARJ is also characterised by a tropical climate with wet (January to April) and dry (December) seasons. The city of Rio de Janeiro also presents a local topography that, when combined with factors such as unplanned land use, sea breeze circulations and the existence of the Guanabara Bay, contributes to an irregular dispersion and distribution of pollutants in the area (Onursal and Gautam, 1997; Soluri et al., 2007).

The MABH is the third largest metropolis in Brazil. Belo Horizonte is its main city and the capital of Minas Gerais state. The MABH has 5.7 million inhabitants distributed throughout a surface area of ~9500 km², which is divided into 34 cities (IBGE, 2015; Miranda et al., 2011). The region is also characterised by a tropical climate with wet (October to March) and dry (April to September) seasons; January and July are the hottest and the coldest months of the year, respectively. The region has a topography characterized by mountains that determine the circulation of the pollutants.