A systematic review of the physical and chemical characteristics of pollutants from biomass burning and combustion of fossil fuels and health effects in Brazil

Revisão sistemática das características físico-químicas dos poluentes atmosféricos provenientes das queimadas e combustíveis fósseis e efeitos na saúde no Brasil

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Abstract

The aim of this study was to carry out a review of scientific literature published in Brazil between 2000 and 2009 on the characteristics of air pollutants from different emission sources, especially particulate matter (PM) and its effects on respiratory health. Using electronic databases, a systematic literature review was performed of all research related to air pollutant emissions. Publications were analyzed to identify the physical and chemical characteristics of pollutants from different emission sources and their related effects on the respiratory system. The $PM_{2.5}$ *is composed predominantly of organic compounds with 20% of inorganic elements. Higher concentrations of metals were detected in metropolitan areas than in biomass burning regions. The relative risk of hospital admissions due to respiratory diseases in children was higher than in the elderly population. The results of studies of health effects of air pollution are specific to the region where the emissions occurred and should not be used to depict the situation in other areas with different emission sources.*

Environmental Pollutants; Air Pollutants; Particulate Matter; Respiratory Tract Diseases

Introduction

Exposure to air pollutants has been shown by several epidemiological and toxicological studies to have noxious effects on human health [1,2,3]. Environmental exposure to particulate matter (PM) has been widely studied because of its physical characteristics and multi-elemental composition which varies depending on the emission source [4,5].

The main sources of PM emissions are fossil fuel combustion and biomass burning [6,7]. Globally, Brazil makes a significant contribution to PM emissions because some regions of the country have extremely high levels of air pollution. In the South and Southeast Regions, the development of automobiles and industry are the main cause of these high levels [8], whereas in the southern and eastern Brazilian Amazon the expansion of agribusiness and forest fires are the main contributors to PM emissions, especially in the region known as the "Arc of Deforestation" [9].

Aerosol particles in the atmosphere influence the Earth's radiation balance and climate, atmospheric chemistry, visibility and human health on a local to global scale. The transport and deposition chemistry of these particles and their effects on solar radiation and human health depend largely on their size, distribution, composition, morphology and surface area [10]. These characteristics are important, especially in the Brazilian Amazon region where forest burning is widespread during the dry season. Studies show that individuals living in exposed areas located far from the source can demonstrate the same adverse respiratory effects as those experienced by individuals at the source itself [11].

At the height of the dry season, between July and October, the Brazilian Amazon Region is responsible for approximately 70% of biomass burning in Brazil (Instituto Brasileiro do Meio Ambiente. http://www.ibama.gov.br/prevfogo/areas-tematicas/monitoramento/dados-de-focos-de-calor, accessed on 10/Mar/2010) leading to significant damage to the savanna and Amazon Forest. On average, forest fires in the Brazilian Amazon are responsible for 67% of $PM_{2.5}$ emissions [12,13]. In other regions of Brazil, most fires are a result of sugarcane plantation burning [14]. However, in metropolitan areas of Brazil the primary cause of PM emissions are motor vehicles [15].

The health effects of atmospheric particles are influenced by particle size (aerodynamic diameter). The diameter of atmospheric particles ranges from 1nm to 100μm. PM_{10} and $PM_{2.5}$ particles have an aerodynamic diameter of less than 10μm and 2.5μm, respectively. Ultrafine particles, or $PM_{0.1}$ particles, have a thermodynamic diameter of less than 0.1μm. $PM_{2.5}$ particle fractions are called "fine particles" and those particles with a diameter of between 10μm and 2.5μm are called "coarse particles" [3,4].

The concentration, size, chemical composition and toxicological characteristics of pollutants, including PM, are determined by the emission source [4,16]. This study aims to present an overview of the scientific literature on the characteristics of air pollutants, especially particulate matter and their respiratory health effects, from the different types of sources of pollutant emissions in Brazil published between 2000 and 2009.

Materials and methods

Study design

A systematic literature review of all research related to vehicular, industrial and biomass burning pollutant emissions published between 2000 and 2009 was performed using electronic databases. Reviews of earlier studies were also conducted [14,17,18,19,20]. Priority was given to publications on the physical and chemical characteristics of particulate matter from the different types of emission sources followed by studies related to respiratory system effects. The following criteria were used to select and analyze studies regarding the effects of PM on the respiratory system: study area, year of publication, source characteristics, susceptible group and health outcomes. Reviews and studies that did not show the outcome of respiratory diseases were excluded. Articles on the physical and chemical characteristics of PM were then reviewed using the following criteria: source characteristics, study area, year in which the data was collected, particle concentration and chemical composition. Only those studies that included information on particle size, concentration and elemental composition of aerosols were included.

To compare the respiratory effects of exposure to PM and the relative risk (RR) of mortality and hospitalization in children and the elderly, increments of 10μg/m^3 in PM_{10} levels were used. RR was recalculated for those articles that did not show a variation in concentrations of 10μg/m^3, and the standard error and coefficient (β) were calculated for mortality and hospitalization related to variations in PM_{10} concentrations. Gouveia & Fletcher [21,22] and Braga et al. [23] calculated the standard error and β using RR and confidence interval (CI). This review only included the results of articles where RR and CI figures were described in tables or the text.

Search strategy

The search was conducted in Spanish, English and Portuguese in the following bibliographic databases: (i) Scientific Electronic Library Online (SciELO); (ii) Medical Literature Analysis and Retrieval System Online (MEDLINE); (iii) Latin American and Caribbean Health Science Literature (LILACS); (iv) U.S. National Library of Medicine (PubMed); (v) Scopus. Several descriptors and keywords in the title or abstract of the study were combined. The following terms were used: "air pollution"; "particulate matter"; "aerosol*"; "aerosol composition"; "biomass burning"; "sugarcane", "emission sources"; "health effects"; "mortality"; "asthma"; "respiratory disease"; "pneumonia*"; "Amazon*"; "Brazil".

Reports, texts, inventories and guides produced by the Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA; http://lba.inpa.gov.br/lba/), the World Health Organization (WHO; http://www.who.int/topics/air_pollution/en/), the Environment Protection Agency (EPA; http://www.epa.gov/air/airpollutants.html) and the National Institute for Space Research (INPE; http://sigma.cptec.inpe.br/queimadas/) were used as information sources for the discussion of the literature. Articles published in 2010 and which were not indexed during the search period were included in the discussion of results.

Results

Published articles

Between 2000 and 2009, a total of 137 articles were published on the characteristics of PM from distinct emission sources and their effects on human health in Brazil. Ninety articles (66%) deal with the adverse respiratory effects of air pollution of which 54 (60%) were selected [21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74]. The remaining 47 articles (34%) were on the physical and chemical characteristics of pollutants, of which 39 (83%) met the inclusion criteria for this review [7,8,12,13,52,58,65,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106].

Approximately 20 publications dealt with the physical and chemical characteristics of vehicular, industrial and biomass burning pollutant emissions. The number of studies conducted in biomass burning areas was greater than the number conducted in metropolitan areas for all years apart from 2004, 2008 and 2009. The largest numbers of articles on fires were published in 2005, with 5 publications, whereas the largest numbers of articles on industrial sources and motor vehicles were published in 2008.

Most of the articles reviewed on health effects arising from exposure to particles derived from industry and motor vehicles in metropolitan areas were published in 2009. With respect to biomass burning, a total of 13 articles were published between 2000 and 2009.

Physical and chemical characteristics of pollutants derived from biomass burning

A summary of the articles concerning the main physical and chemical characteristics of pollutants derived from biomass burning is presented in Table 1. The Amazon biome was the most studied area in articles on the physical and chemical characteristics of PM [77,82]. Studies in this region show that PM_{10} and $PM_{2.5}$ were predominantly composed of organic compounds [75,78,81,86], and in the case of $PM_{2.5}$ these substances made up 70% to 92% of its composition [75]. Among the organic elements, Black Carbon (BC) made up between 5% and 15% of $PM_{2.5}$, with values ranging from 5.5μg/m³ to 16μg/m³ during peak burning [76,77]. During the dry season in the Southeast Region of Brazil, BC levels from burning sugarcane were lower than those measured in the Brazilian Amazon [52,84].

In the Amazon biome, high concentrations of biogenic elements were identified for PM_{10} during the rainy season [87]. During the dry season, $PM_{2.5}$ is predominantly composed of BC, sulphates (SO_4^{2-}), nitrates (NO_3) and metals [12,77,87]. Yamasoe et al. [75] investigated the chemical composition of $PM_{2.5}$ relating to the burning phases or stages and detected that potassium (K), chlorine (Cl) and sulphate (SO_4^{2-}) were the dominant chemical elements. Ammonia (NH_3) was also found in fractions of $PM_{2.5}$ during the dry season in the Brazilian Amazon [77,81]. These same characteristics were observed in the Southeast Region of Brazil in areas of sugarcane burning [52,80,84].

In biomass burning areas in the Southeast Region of Brazil and Brazilian Amazon region, studies identified concentrations of metals such as zinc (Zn), iron (Fe), lead (Pb), copper (Cu) and mercury (Hg) in the elemental composition of $PM_{2.5}$. It is probable that mining activities are responsible for the concentrations of Hg [12,75,76].

In the Brazilian Amazon, concentrations of PM_{10} and $PM_{2.5}$ were higher during the dry season, reaching peaks of 600μg/m³ and 350μg/m³ respectively [77], It should be noted however that this information comes from an article that referred to data collected in the 1990s. Sugarcane burning areas showed average $PM_{2.5}$ levels ranging from 9.3μg/m³ to 238μg/m³ (σ 14.5μg/m³) [84]. Currently, the Amazon biome shows peak $PM_{2.5}$ concentrations of between 225μg/m³ (between September and November 2002) [85] and 450μg/m³ (September 2005) [65], whereas the Southeast Region, in areas of sugarcane burning, mean levels of Total Suspended Particles (TSP) of 47μg/m³ with a standard deviation of 26.4μg/m³ and peak value of 138μg/m³ were identified between 2003 and 2004 [58].

Physical and chemical characteristics of pollutants from industrial activities and motor vehicles

The physical and chemical characteristics of particles derived from industrial activities and motor vehicles in urban areas in Brazil are summarized in Table 2. The most studied sites in articles on emissions of these pollutants were the metropolitan regions of São Paulo and Rio de Janeiro [7,8,90,91,94,95,98,99,102,103,105].

In metropolitan areas, PM is made up of mainly organic elements [95,100]. In the city of Campinas, São Paulo, studies show that $PM_{2.5}$ is made up of 48% elemental carbon and 22% organic carbon [100]. The main organic element was BC, representing 18% to 31% of $PM_{2.5}$ in Rio de Janeiro [103]. In the Metropolitan Region of São Paulo, the ionic elements made up 21% of the chemical composition of PM. SO_4^{2-}, NO_3 and NH^{+}_4 were the most abundant inorganic components in the chemical

Table 1

Articles on the physical and chemical characteristics of pollutants from biomass burning in Brazil published between 2000 and 2009.

References	Year	Location	Study period	Pollutants	Results/Chemical composition
Yamasoe et al. [75]	2000	Amazon Forest and Brazilian savanna (Brasília and Rondônia State)	August/September 1992	$PM_{2.5}$	70-92% of $PM_{2.5}$ mass consists of organic material. Dominant chemical elements: Cl^-, SO_4^{2-}, K^+, BC
Artaxo et al. [76]	2000	Amazon Forest (Alta Floresta, Mato Grosso State)	August/September 1995	Particles aerosols	During the drought, the maximum levels of PM were approximately 300μg/m^3. The maximum concentrations of BC were 17.5μg/m^3 (5-15% of aerosol mass). A total of 56% of PM mass is associated with the biomass burning component. Chemical elements: biomass burning (BC, S, I, K, Br and Zn); biogenic components (P, K, Ca, Mn, Mg and Sr); sea salt component (NaCl); mining activity components (Hg)
Artaxo et al. [77]	2002	Amazon Forest and pasture (Rondônia State)	1999	TSP, BC, CO and NO_2, $PM_{2.5}$	In the dry season, levels of $PM_{2.5}$ ranged from 250μg/m^3-350μg/m^3, with an average of 66.9μg/m^3. The maximum levels of CO and NO_2 were 8ppm and 16ppb, respectively. The BC concentrations in the $PM_{2.5}$ were 16μg/m^3. Twenty one chemical elements were identified, including: S, Al, Si and K
Mayol-Bracero et al. [78]	2002	Amazon Forest and pasture (Rondônia State)	October 1999	PM_{10}, $PM_{2.5}$, BC	The organic composition of PM was identified using concentration values of TC, BC, and OC. TC is composed of approximately 16% BC and 56% water-soluble organic carbon
Maenhaut et al. [12]	2002	Amazon Forest (Alta Floresta, Mato Grosso State)	1996 to 1998	PM_{10} $PM_{2.5}$, BC	In dry season, the levels of $PM_{2.5}$ and PM_{10} ranged from 20μg/m^3 to 200μg/m^3 and 15μg/m^3 to 80μg/m^3, respectively. The average concentrations of PM_{10} and $PM_{2.5}$ ranged from 37±25 and 63±55μg/m^3. On average, 67% of $PM_{2.5}$ are derived from biomass burning. The main chemical elements in $PM_{2.5}$ in biomass burning are: BC, K, S, Zn, Rb and Br
Graham et al. [79]	2003	Amazon Forest	July 2001	PM_{10} and $PM_{2,5}$	On average, 16% of the OC in the $PM_{2.5}$ was due to biomass burning
Guyon et al. [13]	2004	Amazon Forest and pasture (Rondônia State)	1999	PM_{10}, $PM_{2.5}$, BC	19 trace elements were identified. In dry season, the PCA identified three components: (1) Biomass burning and soil dust BC, Si, P, S, K, Mn, Fe, Zn; (2) Biogenic aerosols P, S, K; and (3) Soil dust Fe and Mn
Allen et al. [80]	2004	Sugarcane (Araraquara, São Paulo State)	1999 to 2001	PM_{10} and $PM_{2.5}$	For sugarcane burning plumes Na^+, NH_4^+, $HCOO^-$, CH_3COO^-, Cl^- and NO_3^- were present at higher concentrations in fine fractions
Trebs et al. [81]	2005	Amazon Forest and pasture (Rondônia State)	September/November 2002	$PM_{2.5}$	The contribution of ionic components in the fractions was below 20%, indicating a predominance of organic material
Artaxo et al. [82]	2005	Amazon Forest (Alta Floresta, Mato Grosso State)	1992 to 2002	PM_{10}, $PM_{2.5}$, BC	The concentrations of inhalable particles ranged between 100μg/m^3 to 600μg/m^3

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Table 1 (continued)

References	Year	Location	Study period	Pollutants	Results/Chemical composition
Mahowald et al. [83]	2005	Amazon Forest and pasture (Alta Floresta, Mato Grosso State and Rondônia State)	1996 to 2002	$PM_{2.5}$ and PM_{10}	Biomass burning is responsible for 23% of the flow of phosphorus in the Brazilian Amazon. In the chemical speciation of PM 21 elements were identified,, including: Mg, Al , Si, P, S, Cl, K, Ca, Ti, V, Fe, Zn and Cu
Lara et al. [84]	2005	Sugarcane (Piracicaba, São Paulo State)	1997 to 1998	PM_{10}, $PM_{2.5}$, and BC	PM_{10} concentrations ranged between 9.3μg/m³ to 238μg/m³. The sugarcane is the main source of $PM_{2.5}$, representing 60% of $PM_{2.5}$. The levels of $PM_{2.5}$, PM_{10} and BC were highest during the dry season. In the chemical speciation of PM 21 elements were identified, including: BC, Al, Si, P, S, Cl, K, Cr, Mn, Cu, Zn and Pb
Chand et al. [85]	2006	Amazon Forest and pasture (Rondônia State)	September/November 2002	$PM_{2.5}$ and CO	The levels of $PM_{2.5}$ ranged from 2μg/m³ to 225μg/m³ and from 300-3,500ppb for CO
Cançado et al. [52]	2006	Sugarcane (Piracicaba, São Paulo State)	1997 to 1998	$PM_{2.5}$	In the chemical speciation of PM, 21 elements were identified, including; Al, Si, P, S, Cl, K, P, Ca, Ti, Cr, Cu, Ni, Zn. Chemical elements related to biomass burning component: Si, S, K, Cl, Fe, Br
Arbex et al. [58]	2007	Sugarcane (Piracicaba, São Paulo State)	2003 to 2004	TSP	The average concentration was 46.8μg/m³. Minimum and maximum values were between 6.7μg/m³ and 137.8μg/m³
Fuzzi et al. [86]	2007	Amazon Forest (Rondônia State)	September/November 2002	PM_{10} and CO	In the dry season, aerosols were predominately composed of organic elements, only 10% of soluble inorganic salts. Sulphates were the main anions
Pauliquevis et al. [87]	2007	Amazon Forest (Balbina, Amazonas State)	1998 to 2002	PM_{10} and $PM_{2.5}$	The average concentrations of $PM_{2.5}$ and PM_{10} ranged from 62μg/m³ to 31μg/m³ and 72μg/m³ to 21μg/m³, respectively. Chemical elements in the $PM_{2.5}$: BC, K, S, Al, Si, P
Mascarenhas et al. [65]	2008	Amazon Forest (Rio Branco, Acre State)	September 2005	$PM_{2.5}$	The values for $PM_{2.5}$ exceeded the quality standard during 23 days in September 2005, with maximum values reaching 450μg/m³

BC: black carbon; OC: organic carbon; PCA: principal components analysis; PM: particulate matter; TC: total carbon; TSP: total suspended particles.

constitution of $PM_{2.5}$. In the makeup of $PM_{2.5-10}$ and $PM_{2.5}$, NO_3 and SO_4^{2-} represented 60% of the inorganic compounds in $PM_{2.5}$. The concentration of sulphates was 38% higher in fine fractions than in course fractions [98].

In metropolitan areas in the South and Southeast Regions of Brazil, high concentrations of metals, especially Zn, Pb, Cr, manganese (Mn) and cadmium (Cd) were measured in PM [8,101,102]. In Rio de Janeiro, elevated concentrations of calcium (Ca), magnesium (Mg), Fe, aluminum (Al) and Zn were identified in the elemental composition of $PM_{2.5}$. The presence of Cd, nickel (Ni), Pb and Cu is related to emissions from industry and motor vehicles [102]. In steel manufacturing regions in the state of Rio de Janeiro, Pb concentrations reached values of 140ng/m³ in the elemental composition of PM [107].

Polycyclic Aromatic Hydrocarbons (PAHs) were also detected in the chemical composition of PM emitted in metropolitan areas. In Volta Redonda, Rio de Janeiro State, high concentrations of PAHs, such as benzene (52-93μg/m³), toluene (17-30μg/m³) and xylene (1.7-3μg/m³) were found [8]. In the Southern Region of Brazil, in areas with substantial industrial activity, such as Porto Alegre, the mean value of PAHs ranged between 0.04μg/m³ and 2.3μg/m³ with

Table 2

Articles on the physical and chemical characteristics of pollutants from industrial activities and vehicles in Brazil published between 2000 and 2009.

References	Year	Location	Study period	Pollutants	Results/Chemical elements
Castanho & Artaxo [7]	2001	Metropolitan region of São Paulo	June/September 1997, January/March 1998	PM_{10} and $PM_{2.5}$	Motor vehicles represented 28% and 24% of the $PM_{2.5}$ in winter and summer, respectively. In the winter, the $PM_{2.5}$ consist of 40±16% organic carbon, 21±4% BC, 20±10% ammonium sulfates and 12±2% soil components
Gioda et al. [8]	2004	Volta Redonda/Rio de Janeiro State	1995 to 1996 and April/May 1999	TSP, PM_{10}, benzene, toluene, xylene, SO_2	Average daily concentrations: TSP (54-163μg/m³), PM_{10} (44μg/m³ to 78μg/m³), benzene (52μg/m³ to 93μg/m³), toluene (17μg/m³ to 30μg/m³), xylene (1.7-3μg/m³) and SO_2 (186μg/m³). High concentration elements: Pb, Cr, and Zn
Bertran et al. [88]	2004	Institute for Technological Research of São Paulo	-	PM	Particle shape: spherical, very compact and smooth cenospheres with sizes of 0.6μm to 1.5μm. The elements Al, Si, S and V had higher concentrations
Braga et al. [89]	2004	Candiota region, Rio Grande do Sul State	2000 to 2001	PM_{10}, $PM_{2.5-10}$ and $PM_{2.5}$	Average concentration: PM_{10} was 13.09μg/m³ for HV and 14.85μg/m³ for Dichotomous. The maximum values were 40.17μg/m³ in the Pedras Altas station. Levels of $PM_{2.5-10}$ and $PM_{2.5}$ were 9.66 and 5.19μg/m³, respectively
Quitério et al. [90]	2004	Industrial region of Santa Cruz/Rio de Janeiro	2001 to 2002	TSP	The geometrical mean of TSP ranged between 87μg/m³ and 40μg/m³. Concentration levels of metals were high. Chemical elements from components analysis: metallurgical activity (TSP, Ca, Mo, Mn, Fe, Zn, Cu and Ni) and steel industries (Mg, K and Al)
Miranda et al. [91]	2005	Metropolitan region of São Paulo	July/August 2002	NO_2, PM_{10}, $PM_{2.5}$, and O_3	Concentrations of 24h PM_{10} exceed the national standard of 150μg/m³. The principal elements detected in $PM_{2.5}$ were: S, K, Al and Fe, soil dust and combustion products
Dallarosa et al. [92]	2005	Metropolitan region of Porto Alegre, Rio Grande do Sul State	2001 to 2002	PM_{10} and PAHs	The PM_{10} levels ranged between 7.37μg/m³ and 89.7μg/m³. Fourteen PAHs were identified. The average concentrations ranged between 0.04μg/m³ and 2.3μg/m³. The benzo(ghi)perileno (BGP) showed the highest concentrations
Braga et al. [93]	2005	Rio Grande do Sul State	2001 to 2002	PM_{10} and $PM_{2.5}$	The average concentrations of PM_{10} and $PM_{2.5}$ ranged from 5μg/m³ to 115μg/m³ and from 1μg/m³ to 44μg/m³, respectively. S, Cl, S, V, Cr, Mn, Ni, Cu and Zn have high emission factor related to the $PM_{2.5}$
Carvalho-Oliveira et al. [94]	2005	Metropolitan region of São Paulo	April 2003	$PM_{2.5}$ and PAHs	Chemical elements in the $PM_{2.5}$: As, Br, Co, Cl, Fe, La, Mn, Sb, Sc and Th. PAHs: benzene, toluene, etil-benzene e xylene. The concentrations were higher for nonstrike days

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Table 2 (continued)

References	Year	Location	Study period	Pollutants	Results/Chemical elements
Miranda et al. [95]	2005	Metropolitan region of São Paulo	1999 to 2000	PM	The mass distribution has two modes: 0.8μm and 8μm. PM is composed mainly of organic elements: BC elements derived from soil as well as S, Br and Cu
Pereira et al. [96]	2007	Bus station, Salvador, Bahia State	September/October 2004 and July 2005	TSP and PM_{10}	The maximum levels of TSP and PM_{10} ranged between 16.9μg/m^3 to 354μg/m^3 and 13.9μg/m^3 to 393μg/m^3, respectively. Zn and Cu were the main elements related to anthropogenic sources. Fe had the highest concentration, with minimum and maximum values of 7.03ng.m^{-3} and 650ng.m^{-3}
Queiroz et al. [97]	2007	Sete Lagoas, Minas Gerais State	January/February 2005	TSP and PM_{10}	In 53% of days sampled, the PM_{10} values exceeded 50μg/m^3 (16-132μg/m^3). Components analysis of PM_{10}: Al, Ba, Cr, Fe, Dy, Mg, Mn, Na, V and Zn. Sources of emission: iron, concrete and ceramic production
Bourotte et al. [98]	2007	Metropolitan region of São Paulo	May/July 2002	$PM_{2.5-10}$ and $PM_{2.5}$	The concentrations of $PM_{2.5-10}$ and $PM_{2.5}$ ranged between 4.13μg/m^3 and 62μg/m^3 and 2.82μg/m^3 to 26.6μg/m^3, respectively. The inorganic elements make up 21% of $PM_{2.5}$. Chemical components: $PM_{2.5}$ (SO_4^{2-}, NO_3^-, NH^+_4) and $PM_{2.5-10}$ (NO_3^-, SO_4^{2-}, Ca^{2+} and Cl^-). NO_3^- and SO_4^{2-} were predominant and greater than 60%. SO_4^{2-} was 38% higher in $PM_{2.5}$. NH_4^- was 13 times higher in the $PM_{2.5}$
Silva et al. [99]	2008	Metropolitan region of Rio de Janeiro	2005	PM_{10}	Chemical elements: Cd, Ce, Cu, La, Mo, Ni, Pb, Pd, Rh, Sb and Sn. Mo, Pd and Rh were due to pollution arising from the degradation of auto catalysts
Miranda et al. [100]	2008	Campinas, São Paulo State	December 2003 and August 2004	PM_{10}, $PM_{2.5-10}$ and $PM_{2.5}$	Average annual concentrations: PM_{10} (20.85μg/m^3), $PM_{2.5-10}$ (10.17μg/m^3) and $PM_{2.5}$ (10.68μg/m^3). $PM_{2.5}$ is composed of 48% carbon elements, 22% organic carbon. Chemical elements: Al, V, S, Mn, SO_2, Fe, Zn, K, H_2SO_4
Godói et al. [101]	2008	Metropolitan region of Curitiba, Paraná State	December 2005 and January 2006	PM	Chemical elements: Al, Si, Fe, S, Cl, K and Ca arising from biomass burning, soil or limestone particles; Ti, Cr and Mn arising from limestone and silica rocks; Zn and Cu released from wood combustion or vehicles
Toledo et al. [102]	2008	Metropolitan region of Rio de Janeiro	September 2004 and August 2005	TPS and PM_{10}	The average levels of PM_{10} ranged between 42μg/m^3 and 169μg/m^3 for the period. The maximum value was 312μg/m^3. In PM_{10} high concentrations of Ca, Mg, Fe, Al and Zn were identified. Cd, Ni, Pb and Cu were released from industrial activity and vehicles

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Table 2 (continued)

References	Year	Location	Study period	Pollutants	Results/Chemical elements
Godoy et al. [103]	2009	Metropolitan region of Rio de Janeiro	September 2003 and December 2005	PM_{10} and $PM_{2.5}$	48 chemical elements were identified in PM. BC made up 18-31% of $PM_{2.5}$. Chemical elements in the $PM_{2.5}$: soil dust (Al, K, Fe and Ce); vehicles (As, Cu, Cd, Sb, Pb and BC); oil combustion (Ni, V and SO_4^{2-}); evaporation from the sea (Na and Mg)
Teixeira et al. [104]	2009	Rio Grande do Sul State	2003 to 2004	PM_{10}, $PM_{2.5-10}$ and $PM_{2.5}$	22 chemical elements were identified. The $PM_{2.5}/PM_{10}$ ratio was less than 50%. Course mode chemical elements: Al, Si, Ca, Mg, Ti, K, Na and Fe. In $PM_{2.5}$, S had the highest concentrations. $PM_{2.5}$ had a higher concentration of Cr, Co, Zn, Ni and Cu than the $PM_{2.5-10}$ particles
Sánchez-Ccoyllo et al. [105]	2009	São Paulo City Tunnel	March/May 2004	PM_{10}, $PM_{2.5-10}$, $PM_{2.5}$ and BC	BC emission for PM_{10}, $PM_{2.5-10}$ and $PM_{2.5}$ was 29x, 4x e 6x times higher for heavy-duty metals than for light-duty vehicles. Chemical elements: Fe, Br, Al, Si, S, Cu, Zn and Pb. Fe, Al and S had the highest concentrations
Jacomino et al. [106]	2009	Sete Lagoas, Minas Gerais State	January and February 2005	PM_{10}	The concentrations of PM_{10} ranged between 16μg/m³ and 132μg/m³ for the period. Components analysis of PM_{10}: soil and asphalt dust (Sc, Th, Fe, Ba, Zn); industries activity (Ga, Na, Al and V); asphalt dust or industrial processes (Dy and Cr). Dominant chemical elements in PM_{10}: Na, Fe, Cl and Ba

BC: black carbon; PAH: polycyclic aromatic hydrocarbons; PM: particulate matter; TSP: total suspended particles.

benzo(ghi)perylene (BGP) having the highest concentration [92].

In the metropolitan region of São Paulo, combustion of diesel and gasoline made up 28% of emissions of $PM_{2.5}$ during the winter [7]. In São Paulo, the average level of $PM_{2.5}$ was 54μg/m³, with a peak of 186.2μg/m³ between 1996 and 2000 [49]. In Rio de Janeiro, the average concentration of PM_{10} was 84.7μg/m³, with a peak of 199μg/m³ in 2004 [70]. The average level of PM_{10} in Rio de Janeiro ranged between 42 μg/m³ and 169μg/m³ between 2004 and 2005 [102].

Types of studies, health outcomes and susceptible groups

Articles about air pollution, with emphasis on $PM_{2.5}$ and its effects on human health in Brazil were analyzed using the following criteria: study site, subject group and health outcomes (Table 3). Of the 54 articles selected, 33 (61%) [21,22,23,25,26,27,28,29,31,32,33,34,35,36,37,38,41,43,44,45,46,47,48,49,51,56,60,62,63,68,71,73,74] referred to studies conducted in the Metropolitan Region of São Paulo. Emissions in the cities of Rio de Janeiro [30,35,40,42,64,69], São José dos Campos (São Paulo) [50], Porto Alegre (Rio Grande do Sul) [54,56], Curitiba (Paraná) [39,56], Itabira (Minas Gerais) [55] and Vitória (Espírito Santo) [57] were also studied. In regions in the Brazilian Amazon, where air pollution is derived from biomass burning, only five studies were published between 2000 and 2009 [59,61,65,66,72]. Respiratory effects were also investigated in areas of sugarcane burning, especially in the state of São Paulo [24,52,53,58,67].

Hospital admissions and deaths from respiratory diseases made up the main health outcomes associated with elevated levels of air pollutants, corroborating international studies [1,2]. Structural and functional alterations in lung tissue, circulatory and inflammatory mediators were investigated by experimental studies [26,37,43,48,51,54,63,67,68,71,73]. In the metropolitan regions of São Paulo and Rio de Janeiro, 18 ecological time-series studies were conducted between 2000 and 2009 [21,22,23,27,28,31,32,35,36,38,41,42,44,46,49,64,69,74]. Children, adolescents and the elderly were the main interest groups for studies that researched

Table 3

Studies on air pollution and health effects conducted in urban and biomass burning areas, according to location, study type, subject group and respiratory health outcomes published in Brazil between 2000 and 2009.

References	Year	Location	Study	Subject group	Outcomes
Gouveia & Fletcher [21]	2000	São Paulo	Ecological time-series studies	Children (< 5 years)	Hospital admissions (RD)
Gouveia & Fletcher [22]	2000	São Paulo	Ecological time-series studies	Children (< 5 years) and elderly	Mortality (RD and CVD)
Arbex et al. [24]	2000	São Paulo (sugarcane region)	Descriptive studies	All	Hospital admissions (RD)
Benício et al. [25]	2000	São Paulo	Descriptive studies	Children (< 5 years)	Prevalence of diseases and respiratory symptoms
Cury et al. [26]	2000	São Paulo	Experimental studies	Mice	Lung injury and induction of tumors
Martins et al. [27]	2001	São Paulo	Ecological time-series studies	Elderly	Emergency room visits (RD)
Conceição et al. [28]	2001	São Paulo	Ecological time-series studies	Children (< 5 years)	Mortality (RD)
Braga et al. [23]	2001	São Paulo	Ecological time-series studies	Children and adolescent	Hospital admissions (RD)
Cifuentes et al. [29]	2001	Santiago, São Paulo, Mexico City and New York	Health impact assessment	All	Mortality and hospitalization due to RD; premature deaths, chronic bronchitis cases, asthma attacks and person-day loss or other restricted activity
Brilhante & Tambellini [30]	2002	Rio de Janeiro	Descriptive studies	All	Emergency room visits
Martins et al. [31]	2002	São Paulo	Ecological time-series studies	Elderly	Emergency room visits (RD)
Martins et al. [32]	2002	São Paulo	Ecological time-series studies	Elderly	Emergency room visits by pneumonia and influenza
Botter et al. [33]	2002	São Paulo	Descriptive studies	Elderly	Mortality
Ribeiro & Cardoso [34]	2003	São Paulo	Descriptive studies	Adolescent (11-13 years)	Prevalence of diseases and respiratory symptoms
Gouveia et al. [35]	2003	São Paulo and Rio de Janeiro	Ecological time-series studies	Children (< 5 years) and elderly	Hospital admission and Mortality (RD and CVD)
Gouveia et al. [36]	2003	São Paulo	Ecological time-series studies	All	Mortality (RD and CVD)
Soares et al. [37]	2003	São Paulo	Experimental studies	Mice	Presence of micronuclei in blood erythrocytes in mice. The frequency of micronuclei was dependent on the levels of PM_{10}, NO_2 and CO
Freitas et al. [38]	2004	São Paulo	Ecological time-series studies	Children, adolescent and elderly	Hospital admissions (RD) and mortality (all causes)
Bakonyi et al. [39]	2004	Curitiba, Paraná State	Ecological time-series studies	Children and adolescent (0 to 14 years)	Outpatient visits (RD)
Rios et al. [40]	2004	Rio de Janeiro	Descriptive studies	Children and adolescent (13 to 14 years)	Prevalence of asthma
Martins et al. [41]	2004	Metropolitan region of São Paulo	Ecological time-series studies	Elderly	Mortality (RD)

(continues)

Table 3 (continued)

References	Year	Location	Study	Subject group	Outcomes
Daumas et al. [42]	2004	Rio de Janeiro	Ecological time-series studies	Elderly	Mortality (RD and CVD)
Rivero et al. [43]	2005	São Paulo	Experimental studies	Rats	Cardiovascular and pulmonary alterations with markers of systemic inflammation after exposure to the PM_{10} and $PM_{2.5}$
Gonçalves et al. [44]	2005	Metropolitan region of São Paulo	Ecological time-series studies	Children and adolescent (< 13 years)	Hospital admissions (RD)
Miraglia et al. [45]	2005	São Paulo	Health impact assessment	Children and elderly	Burden of disease with the application of DALY
Farhat et al. [46]	2005	São Paulo	Ecological time-series studies	Children and adolescent (< 13 years)	Emergency room visits (RD) and hospital admission (RD)
Bell et al. [47]	2006	México City, Santiago, São Paulo	Health impact assessment	All	Mortality, asthma attacks, emergency room visits, chronic bronchitis
Lemos et al. [48]	2006	São Paulo	Experimental studies	Rats	Functional alterations of respiratory and cardiac tissue
Gouveia et al. [49]	2006	São Paulo	Ecological time-series studies	Children (< 5 years) and elderly	Hospital admission (RD and CVD)
Nascimento et al. [50]	2006	São José dos Campos, São Paulo State	Ecological time-series studies	Children (< 10 years)	Hospital admissions by pneumonia
Camargo et al. [51]	2006	São Paulo	Experimental studies	Rats	Increase in the amount of acidic mucus in the respiratory epithelium of rats exposed to the PM_{10} and NO_2
Cançado et al. [52]	2006	Piracicaba, São Paulo State (sugarcane region)	Ecological time-series studies	Children, adolescent (< 13 years) and elderly	Hospital admissions (RD)
Lopes & Ribeiro [53]	2006	São Paulo (sugarcane region)	Descriptive studies	All	Hospital admissions (RD)
Pereira et al. [54]	2007	Porto Alegre, Rio Grande do Sul State	Experimental studies	Rats	Evidence of oxidative stress and mechanism responsible for acute respiratory effects
Braga et al. [55]	2007	Itabira, Minas Gerais State	Ecological time-series studies	Children, elderly and adults	Emergency rooms (RD and CVD)
Solé et al. [56]	2007	São Paulo, Santo André, Curitiba and Porto Alegre	Descriptive studies	Adolescent (13 to 14 years)	Symptoms of asthma, rhinitis and eczema
Castro et al. [57]	2007	Vitória, Espírito Santo State	Descriptive studies	Children (< 6 years)	Daily records of RD, asthma and pneumonia
Arbex et al. [58]	2007	São Paulo (sugarcane region)	Ecological time-series studies	All	Hospital admissions (asthma)
Ignotti et al. [59]	2007	Mato Grosso (Brazilian Amazon)	Descriptive studies	Children (< 5 years)	Hospital admissions and mortality (RD)
Marcílio & Gouveia [60]	2007	Metropolitan regions	Health impact assessment	Children and elderly	Hospital admissions and mortality (RD)

(continues)

Table 3 (continued)

References	Year	Location	Study	Subject group	Outcomes
Duarte et al. [61]	2007	Acre (Brazilian Amazon)	Descriptive studies	All	Hospital admissions and mortality (RD)
Miraglia et al. [62]	2007	São Paulo	Health impact assessment	All	Hospital admissions and mortality (RD) and CVD), fetal deaths
Mauad et al [63]	2008	São Paulo	Experimental studies	Rats	Reduction of volume and lung capacity in rats exposed to pollution
Moura et al. [64]	2008	Rio de Janeiro	Ecological time-series studies	Children (1 month and 12 years)	Emergency room visits due to acute respiratory symptoms
Mascarenhas et al. [65]	2008	Mato Grosso (Brazilian Amazon)	Descriptive studies	All	Emergency rooms visits (RD)
Rosa et al. [66]	2008	Mato Grosso, (Brazilian Amazon)	Descriptive studies	Children and adolescents (< 15 years)	Hospital admissions (RD)
Mazzoli et al. [67]	2008	São Paulo (sugarcane burning)	Experimental studies	Rats	Intratracheal instillation of TSP from sugarcane burning was associated with alterations in the physiologic mechanisms and lung tissue
Maatz et al. [68]	2009	São Paulo	Experimental studies	Rats	Functional heart alterations after 2 hours of exposure to the $PM_{2.5}$
Moura et al. [69]	2009	Rio de Janeiro	Ecological time-series studies	Children (1 month and 12 years)	Emergency room visits (symptoms or airway obstruction disease)
Castro et al. [70]	2009	Rio de Janeiro	Panel studies	Children and adolescents (6 to15 years)	Decreased lung capacity
Damasceno-Rodrigues et al. [71]	2009	São Paulo	Experimental studies	Rats	Oxidative stress in adult rats and damage due to fetal exposure
Rosa et al. [72]	2009	Mato Grosso (Brazilian Amazon)	Descriptive studies	Children and adolescents (6 to 7 and 13 to 14 years)	Prevalence of asthma
Lopes et al. [73]	2009	São Paulo	Experimental studies	Rats	Exposure to the levels of PM in urban areas increases and induces outcomes such as emphysema. This response may be influenced by oxidative stress
Arbex et al. [74]	2009	São Paulo	Ecological time-series studies	> 40 years	Emergency rooms visits (RD-COPD)

COPD: chronic obstructive pulmonary disease; CVD: cardiovascular disease; DALY: disability-adjusted life years; RD: respiratory disease; TSP: total suspended particles.

the adverse health effects of air pollution. Twenty-six studies analyzed the respiratory outcomes in children and adolescents [21,22,23,25,28,34,35,38,39,40,44,45,46,49,50,52,55,56,57,59,60,64,66,69,70,72] and 14 articles made reference to the elderly [22,27,31,32,33,35,38,41,42,45,49,52,55,60].

Few studies were found concerning the effects of air pollution from biomass burning on human health in Brazil. In the Brazilian Amazon, the number of emergency room visits for respiratory diseases in children under the age of 10 was positively correlated with concentrations of $PM_{2.5}$ [65]. Descriptive studies show a high prevalence of asthma and an increase in morbimortality due to respiratory diseases in municipalities in the subequatorial Amazon region in biomass burning areas [59,61,66,72].

Effects of pollution on the respiratory system

Air pollution studies in Brazil were predominantly conducted in the metropolitan areas of São Paulo and Rio de Janeiro. The results of 18 time-series ecological studies were published, of which eight reported relative risk and 95% confidence interval (95%CI) of hospital admissions and deaths due to respiratory diseases in children and the elderly associated with increments of 10μg/m³ in the concentration of PM_{10} (Figure 1).

Gouveia & Flecther [21,22] estimated RR = 1.004 (95%CI: 0.998-1.010) for hospital admissions due to respiratory diseases in children (< 5 years old) and RR = 0.999 (95%CI: 0.967-1.031) for the number of deaths due to respiratory diseases associated with an increase of 10μg/m³ in the concentration of PM_{10} in São Paulo (Figure 1a). Subsequently, in 2003 and 2006 Gouveia et al. [35,49] associated the variation of PM_{10} with 6.7% and 2.2% increases respectively in hospitalizations due to respiratory diseases in children (Figure 1a). In Rio de Janeiro, Gouveia et al. [35] found RR = 1.018 (95%CI: 1.004-1.033) for hospitalizations related to respiratory diseases in children (Figure 1a).

Braga et al. [23] evaluated exposure to air pollutants and hospital admissions due to respiratory diseases in children and adolescents (0-20 years old) in São Paulo. The results showed RR = 1.026 (95%CI: 1.022-1.029) in children under the age of 2 and RR = 1.009 (95%CI: 1.001-1.017) in children aged 3-5, associated with increments of 10μg/m³ with a lag period of 4 days (Figure 1a). Freitas et al. [38] estimated a 1.3% increase (RR = 1.013, 95%CI: 1.010-1.016) in hospital admissions due to respiratory diseases associated with increments of 10μg/m³ in the concentration of PM_{10} (Figure 1a).

With regard to the elderly, the largest relative risk of death due to respiratory diseases was found by Martins et al. [41]. Increments of 10μg/m³ of daily levels of PM_{10} are associated with a 5.4% increase (RR = 1.054, 95%CI: 1.023-1.086) in mortality due to respiratory diseases in the elderly (Figure 1b). Increments of 10μg/m³ in the daily levels of PM_{10} increased hospital admissions in the elderly due to respiratory diseases by 3.5% (RR = 1.035, 95%CI: 1.012-1.059) in Rio de Janeiro [35] (Figure 1b). In São Paulo, results calculated RR = 1.019 (95%CI: 1.011-1.027) and RR = 1.009 (95%CI: 1.005-1.013) respectively for hospitalization due to respiratory diseases and death due to respiratory diseases in the elderly associated with an increase of 10μg/m³ in levels of PM_{10} [36] (Figure 1b).

According to results from a study in São Paulo carried out by Gouveia et al, children show a higher risk of hospitalization due to respiratory diseases than the elderly, with RR = 1.067 (95%CI: 1.049-1.086) associated with an increase of 10μg/m³ in the levels of PM_{10} [35] (Figure 1a). However, the risk of death due to respiratory diseases is higher among the elderly than in children for the same variation in PM_{10} levels. With respect to the elderly population over the age of 65 in São Paulo, the percentage increase in the number of deaths was 5.4% [41].

Discussion and conclusion

Studies show that individuals living in biomass burning areas are exposed to short-term, high concentrations of PM_{10} and $PM_{2.5}$ whereas individuals living in industrial regions, are chronically exposed to lower concentrations. In metropolitan areas, where peak concentrations of PM are smaller, high levels of pollutants were also found, especially during thermal inversions [15,49,70]. These pollutants include fungal spores, toxins, bacterial products, pollen and endotoxins. The effects of exposure depend not only on the concentration of pollutants, but also on the time of year, duration of exposure and the toxicity of the particles to which an individual is exposed [3,4].

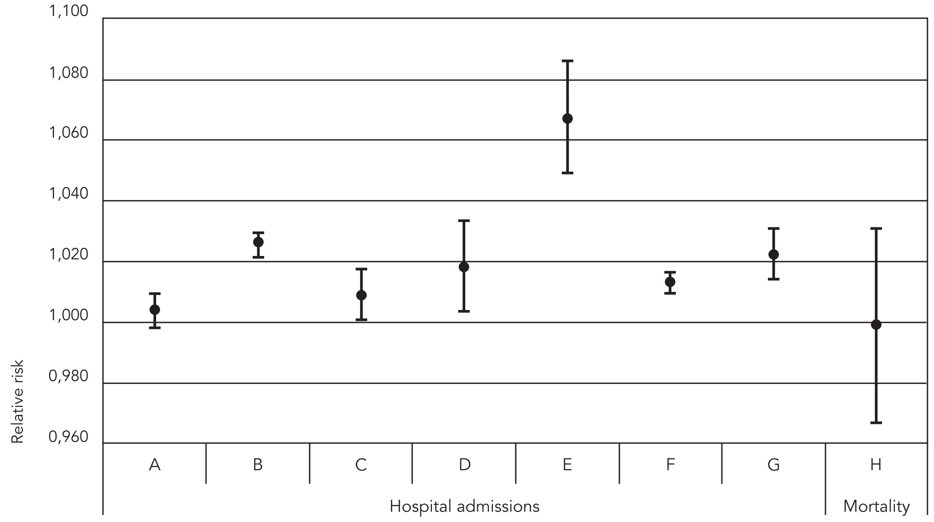
In terms of adverse health effects, several respiratory problems resulting from the acute inhalation of PM were witnessed in the Southeast Region and in the Brazilian Amazon in both children and the elderly [107,108,109]. Air pollution has a direct effect on the cardiovascular system. Unfortunately however, this effect was not studied in the subequatorial Amazon region. Although, long-term exposure has been shown to be related to a lower life expectancy and increased risk of mortality from cardiopulmonary diseases in urban areas in the United States of America, this effect has still not been investigated in Brazil [2,110]. In contrast, the adverse effects of short-term exposure to PM depends on the degree of toxicity of the physical and chemical characteristics of the emissions source [16]. In terms of particle size, $PM_{2.5}$ shows the greatest potential risk to human health resulting from inhalation, deposition and penetration deep into the pulmonary alveoli [4]. Deposition of fine and ultrafine particles, primarily by diffusion, in the respiratory tract increases with decreasing particle size [16].

This physiological mechanism related to high exposure levels may explain the existence of a considerable number of cases of respiratory disease in some municipalities in the Amazon region, especially in vulnerable children and the elderly. The physical and chemical characteristics of $PM_{2.5}$ receive greater attention in the literature in biomass burning areas in the Brazilian Amazon due to the link between the scientific network and the international project *the Large Scale Biosphere-Atmosphere Experiment in Amazonia*. Unfortunately, few studies related to the adverse health effects of $PM_{2.5}$ have been carried out in this region.

Figure 1

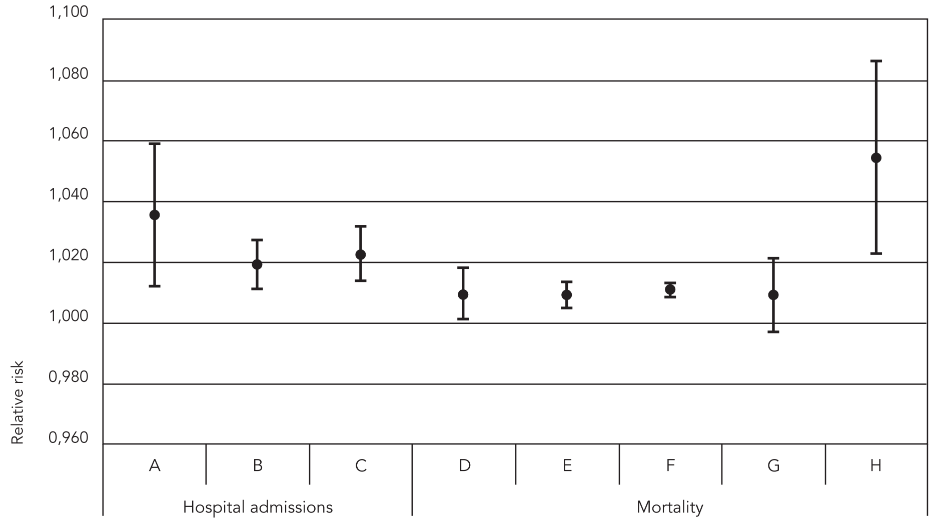
Studies with relative risk and 95% confidence interval for hospital admissions and death from respiratory diseases in children (1a) and the elderly (1b), associated with 10μg/m3 increments in PM_{10} levels in Brazil between 2000 and 2009.

1a) Children



Source: Gouveia & Fletcher [21] (A); Braga et al. [23] (B); Braga et al. [23] (C); Gouveia et al. [35] (D); Gouveia et al. [35] (E); Freitas et al. [38] (F); Gouveia et al. [49] (G); Gouveia & Fletcher [22] (H).

1b) Elderly



Source: Gouveia et al. [35] (A); Gouveia et al. [35] (B); Gouveia et al. [49] (C); Gouveia & Fletcher [22] (D); Gouveia et al. [35] (E); Freitas et al. [38] (F); Daumas et al. [42] (G); Martins et al. [41] (H).

Apart from higher concentrations of metals in urban areas, the elemental composition of PM particles released in biomass burning areas was similar to that of particles released in metropolitan areas. In the state of Minas Gerais, in the cities of Ouro Preto and Sete Lagoas, particles showed high concentrations of metals due to the presence of mining and industry sources, but these results were not related to health effects [97,111]. In a recent study by Zanobetti et al. [112], the mass of $PM_{2.5}$ showed high concentrations of arsenic, nickel, chromium and bromine which were associated with increased hospital admissions in elderly residents in 26 cities in the United States.

PAHs were found in PM in metropolitan regions of Rio de Janeiro and Porto Alegre and showed genotoxic effects [8,92]. In regions where biomass burning occurs, PAHs receive little attention in the literature, but one study in the Brazilian Amazon found the presence of various hydrocarbons with potentially carcinogenic effects: fluoranthene, benzo(a)anthracene, benzo(e) pyrene indeno-(cd)pyrene, dibenzo(ah)anthracene and benzo(a)pyrene [113].

With respect to the organic composition of PM, BC stands out as the main chemical constituent of particles released in biomass burning areas, where higher concentrations are experienced in fires areas, and urban areas. A study carried out in the Amazon biome during the 1995 dry season shows peak concentrations of BC in fine particulate mass at levels (17.5µg/m³) that exceed annual levels of $PM_{2.5}$ acceptable for human health [3,76]. BC is associated with known trace elements of emissions from burning such as S, K, Cl, Ca and Zn [6]. It has the capacity to absorb radiation and is the principle factor in the reduction of visibility caused by air pollution [114]. Experimental and epidemiological studies show that exposure to ultrafine particles of BC are associated with increases in inflammatory cells, reduced alveolar macrophage activity and cardiovascular disease [115,116].

For all emission sources, SO_4^{2-} was the most highly concentrated element of all the inorganic components of $PM_{2.5}$. This formation of sulfates involves the conversion of SO_2 to sulfuric acid (H_2SO_4) [117]. Experimental studies show that acute exposure to H_2SO_4 produces inflammatory responses in humans and animals [3,4,118] and its corrosive characteristics may influence $PM_{2.5}$ lung deposition and lung compartment clearance rates [117].

Eventually, at low temperatures, H_2SO_4 is neutralized by the presence of ammonia (NH_4). Thus, in areas in the Amazon region, lower NH_4 deposition rates during the dry season could lead to increases in the availability of H_2SO_4 in fine fractions of $PM_{2.5}$, so increasing adverse health effects [88]. However, in urban areas, due to the number of motor vehicles, emissions of SO_2 are higher than in biomass burning areas, contributing to the formation of H_2SO_4.

Studies project an annual growth rate of 3.5% in sales of smaller vehicles through to 2015 and of 2.2% as from 2016, leading to increases of SO_2, NO_2 and PM emissions [119]. The studies that detected a link between daily changes in PM and daily mortality generally showed that the effects were greater in the elderly and among individuals with selected underlying diseases. Several epidemiological studies have associated daily levels of these pollutants with cardiopulmonary effects [49,55,70]. Research on exposure to multipollutants has been widely conducted with respect to PM and the adverse health effects associated with constituents of particulate mass [5,67,112]. However, adverse effects from simultaneous exposure to all these pollutants have gained little attention in Brazil.

Several time-series studies were conducted in metropolitan areas to investigate the health effects of air pollution [21,22,23,27,28,31,32,35,36,38,41,42,44,46,49,64,69,74]. Published in 2007, the first studies on the health effects of air pollution in biomass burning areas in the Brazilian Amazon were limited to descriptive studies and focused mainly on asthma [59,61,65,66,72]. Time-series studies conducted in the subequatorial Amazon showed that daily levels of $PM_{2.5}$ measured during the peak of the dry season led to an increase in the percentage of hospital admissions and outpatient visits due to respiratory diseases in children and the elderly [107,109]. These results corroborate with those observed in the Southeast Region of Brazil in areas where sugarcane burning occurs [52].

Time-series studies are essential to investigate the acute health effects of air pollution. However, certain limitations of study design make it difficult to estimate uncertainties surrounding environmental factors, exposure and outcome. Individual details are not included in the analysis and it is possible that some outcomes may include the effects of exposure to other pollutants and factors [36,120]. Longitudinal and experimental studies with a more detailed analysis of exposure and outcome at the individual level and multiple air pollutants could reduce uncertainties related to the effects of atmospheric particulates on health.

Children, one of the groups that are most sensitive to the effects of air pollution, showed greater susceptibility to respiratory problems due to variation in PM levels. This is due in part to the influence of children's anatomical and physiological characteristics on the deposition and removal of inhaled particles [121]. Moreover, immunological immaturity interferes with recovery from damage caused by pollution [122].

The fractions of PM deposited in the tracheobronchial region can be removed during the first 24-48 hours by mucociliary activity [123], whilst the particles that reach the alveolar regions are only cleared, preferably by the action of macrophages or by alternative mechanisms, after a period of weeks or even months [124]. Therefore, individuals exposed to higher concentrations of PM living in areas where biomass burning lasts on average for only three months of the year (in the Brazilian Amazon for example) may experience better physiological recovery than those individuals in urban areas who are subject to constant exposure.

This overview of Brazilian anthropogenic sources of exposure to air pollution is dependent on the availability and quality of information found in scientific databases in the public domain. The differences in methodologies used by these studies to measure exposure and the physical and chemical characteristics of anthropogenic sources of air pollutants may limit the comparison of results. However, based on the concordance between results, considerations may be made on the physical and chemical characteristics of the pollutants and the adverse effects of air pollution on health. It should be noted that this is a systematic overview and not an exhaustive review of current data. Only selected areas related to human health have been discussed.

This systematic review suggests that the exposure-response relationship between daily changes in PM aerosol and daily outcomes differs between Brazilian biomass burning areas and metropolitan areas in terms of time, duration and toxicity of particles. In general, the data consistently shows that the current Brazilian air pollution standards [125] are not protecting human health from exposure to air pollution in metropolitan and biomass burning areas . Clearly, these standards may be considered "unhealthy", suggesting that the Brazilian government and private sector need to discuss and establish specific standards and regulations for $PM_{2.5}$. The São Paulo government is currently considering standards, however, national legislation to address the protection of human health on a countrywide basis is necessary.

In conclusion, the results of these studies on the effects of air pollution on health are specific to the study area and may not be applicable to areas with different anthropogenic emission sources. In Brazil, children are the group that is most sensitive to hospitalizations and deaths due to respiratory diseases followed by the elderly. However, there is a need for further study of the health effects of PM in the Brazilian Amazon. Although epidemiological studies have demonstrated a relationship between PM aerosol and its detrimental effects on health, these associations are fraught with uncertainties due to methodological limitations and the synergistic effects of environmental factors and pollutants and the physical ramifications of PM.

Resumo

O objetivo deste estudo foi revisar as publicações científicas em relação às características dos poluentes atmosféricos, especialmente material particulado (PM), e os efeitos respiratórios na saúde, segundo diferentes fontes de emissões, no período de 2000 a 2009, no Brasil. Revisão sistemática da literatura realizada em bases de dados eletrônicas. Foram analisadas publicações relacionadas às características físico-químicas dos poluentes, segundo diferentes fontes de emissões e estudos relativos aos efeitos no sistema respiratório. O PM é composto predominantemente de compostos orgânicos e 20% de elementos inorgânicos. Altas concentrações de metais foram identificadas em áreas metropolitanas quando comparadas às regiões de queimadas. O risco relativo de internações hospitalares por doenças respiratórias em crianças foi superior àqueles encontrados em idosos. Os resultados dos estudos sobre os efeitos da poluição do ar na saúde não devem ser transferidos para áreas com diferentes fontes de emissão.

Poluentes Ambientais; Poluentes do Ar; Material Particulado; Doenças Respiratórias

Contributors

B. F. A. Oliveira contributed to the analysis of the bibliographical references from the database search, structuring and drafting of the article and discussions on preparing the article. E. Ignotti and S. S. Hacon collaborated in the review and selection of the publications, and in the revision of the article.

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