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REVIEW ARTICLE

Impact of exposure to smoke from biomass burning in the Amazon rain forest on human health

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ABSTRACT

This review study aimed to determine the relationship between exposure to smoke from biomass burning in the Amazon rain forest and its implications on human health in that region in Brazil. A nonsystematic review was carried out by searching PubMed, Google Scholar, SciELO, and EMBASE databases for articles published between 2005 and 2021, either in Portuguese or in English, using the search terms “biomass burning” OR “Amazon” OR “burned” AND “human health.” The review showed that the negative health effects of exposure to smoke from biomass burning in the Amazon have been poorly studied in that region. There is an urgent need to identify effective public health interventions that can help improve the behavior of vulnerable populations exposed to smoke from biomass burning, reducing morbidity and mortality related to that exposure.

Keywords: Fires; Air pollution; Risk factors; Risk assessment; Rainforest; Brazil.

INTRODUCTION

The Amazon is the largest tropical rain forest in the world, covering an area of 5.5 million km^2, the majority of the area (60%) being located in Brazil. It represents half of the remaining tropical forest area and has the greatest biodiversity in the world. About 27 million people live in the area known as “Legal Amazon” area in Brazil (Figure 1), which includes nine Brazilian states.(1,2)

The Amazon rain forest has two distinct seasons. High precipitation volumes are observed in the rainy season (> 250 mm/month), which typically occurs between December and March. It also rains in the dry season, which occurs between May and September, but precipitation is lower (20-70 mm/month).(3) Forest fires predominate during the dry season,(4) with a tenfold increase in atmospheric pollutant concentrations,(5) impacting human health.(6)

This review study aimed to determine the relationship between exposure to smoke from biomass burning in the Amazon rain forest and its implications on human health in that region in Brazil

DATA SOURCE

A nonsystematic literature review was carried out by searching PubMed, Google Scholar, SciELO, and EMBASE databases for articles published between 2005 and 2021, in Portuguese or English, using the following search words: “biomass burning” OR “Amazon” OR “burned” AND “human health.” The bibliographic search was conducted between November of 2020 and May of 2021. A total of 126 scientific articles were initially retrieved, of which 72 effectively contemplated the theme of fire smoke in the Brazilian Amazon and its repercussions on human health. In addition, the Brazilian National Institute for Amazon Research(7) database was consulted.

FIRES OR WILDFIRES?

Amazon fires can be classified into three major types.(8,9) The first type is deforestation fire, which includes clear-cutting of the forest that is left to dry and the subsequent burning of cut trees as a means of preparing the soil for agriculture and cattle farming.(8) The second type of fire is associated with the maintenance of previously cleared areas to eliminate cut trees and clear weeds for agricultural

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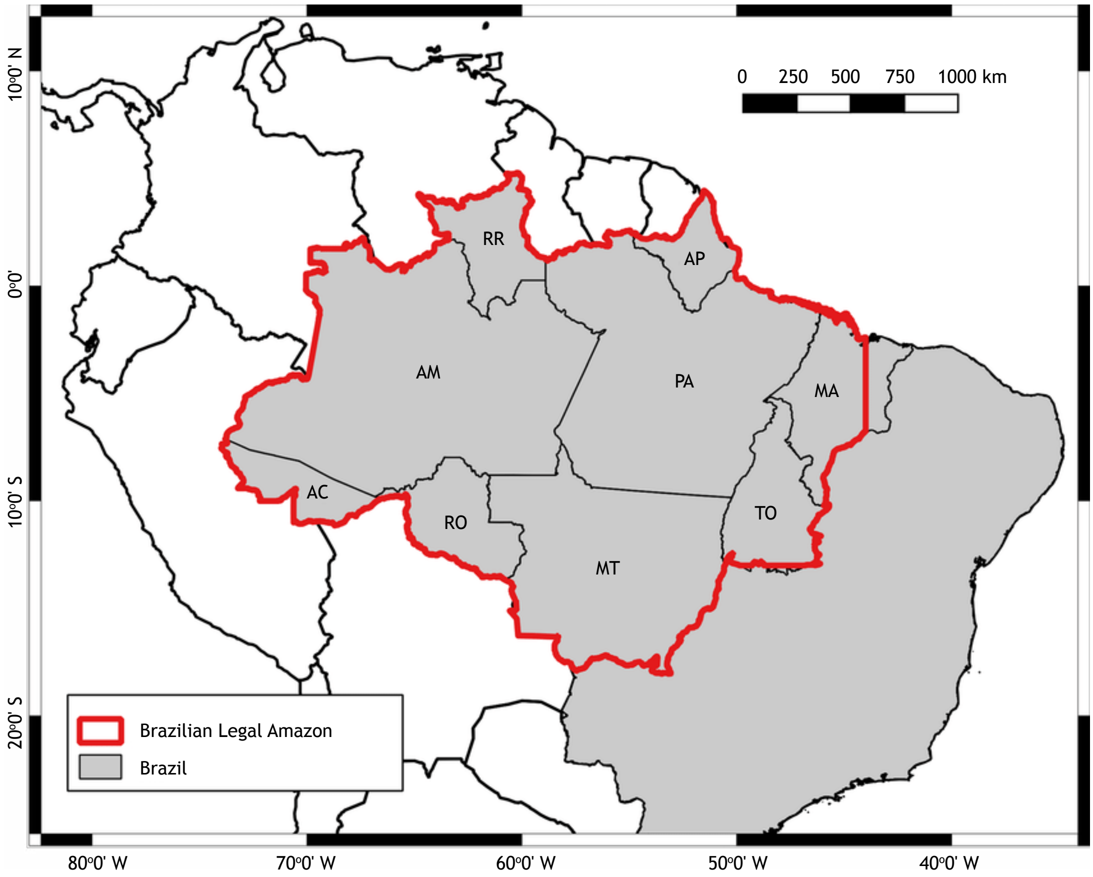

Figure 1. Brazilian Legal Amazon boundaries, including nine federal states. AC: Acre; AM: Amazonas; AP: Amapá; MA: Maranhão; MT: Mato Grosso; PA: Pará; RO: Rondônia; RR: Roraima; and TO: Tocantins. Modified from Müller-Hansen et al.(1)

and cattle farming activities. This type of fire can dry out the surrounding forest and increase vulnerability to fire in subsequent years. Not all fires in previously cleared areas are intentional, and some expand beyond the intended limits.(8) The third type of fire is called wildfires, which consume the standing forest, either for the first time, where the flames are mainly restricted to the understory, or as repeated events, resulting in more intense fire.(8)

Deforestation, maintenance of cleared areas, and forest fires account for 8%, 39%, and 53% of fire outbreaks,(9) respectively, with distinct social and environmental impacts.(8) However, all of these events result in significant pollutant emissions into the atmosphere. In the Amazon, the different types of fires are of anthropic origin, because natural fires rarely occur(9) due to the high moisture content in the soil and vegetation.(10-14)

Intense droughts occurred in 2005, 2007, and 2010, which increased the number of human-caused fires. Because of this, fires in the Amazon have become a persistent environmental problem, partially linked to the growing incidence of deforestation that should not be underestimated, but rather considered when implementing measures to protect the Amazon rain forest.(9,15) Nevertheless, a recent study reported a reduction in deforestation rates between 2004 and 2012, with a 30% decrease in particulate matter (PM) concentrations during the dry season, preventing up to 1,700 premature deaths per year and demonstrating the direct benefits of maintaining forest areas.(11,16)

To date, independent estimates indicate that 15-20% of natural forest cover in the Legal Amazon has been deforested.(2,10,17-19) The latest report from the 2019 Greenhouse Gas Emissions and Removal Estimating System(17) indicated that deforestation, especially in the Amazon, increases the emissions of pollutants. In the last five decades, the amount of greenhouse gases released into the atmosphere by the land-use change sector increased to 23% and accounts for 44% of the total emissions in Brazil.(18)

If the deforested area continues to increase, there is a possibility of reaching a tipping point where the ecosystem will have no resilience to recover, being gradually transformed into a degraded tropical savannah landscape.(15) Synergies between deforestation and climate change are estimated to make forests hotter and drier, and thus, more likely to sustain uncontrolled fires(8,19) with impacts on human health.(3,20) Regional climate projections suggest that fire regimes in the

Amazon will intensify, affecting the outdoor and indoor air quality in rural and urban communities.(13,15,20,21)

FIRE EMISSIONS AND AIR QUALITY

Forest fire emissions are physically and chemically complex; smoke formation, physical weathering, chemical weathering, and atmospheric transport are influenced by several factors such as fuel type, fire type, landscape characteristics, rate of fuel consumption, and weather conditions.(22,23)

The main primary emissions that aggravate air quality and remain a public health concern include PM, carbon monoxide, nitrogen oxide, benzene—which is a primary volatile organic organic compound—and trace metals. Air quality is further affected by the formation of secondary pollutants such as ozone, secondary VOCs (such as acetone), and polycyclic aromatic hydrocarbons (PAHs). However, these secondary products are even more difficult to predict due to the various factors involved.(24-27)

The northern region of Brazil has no continuous air quality monitoring networks,(28) except for a pioneering initiative established by the Federal University of Acre, which started monitoring PM with a mean diameter of < 2.5 µm ($PM_{2.5}$) in 22 cities in the state of Acre in 2019.(29) Results showed that, during the dry season, the mean $PM_{2.5}$ concentration in the 22 cities was around 40 µg/m^3, often exceeding the limit recommended by the WHO (24-h mean of 25 µg/m^3).(5,29,30)

The chemical $PM_{2.5}$ composition from Amazonian wildfires shows a predominance of organic compounds (about 80%), containing 10-15% of smoke particles known as black carbon. Inorganic compounds correspond to 10-20% of $PM_{2.5}$, sulfates being the most abundant ones.(30)

The levels of PAHs and VOCs present in smoke from Amazonian fires can be relatively high and include potentially carcinogenic substances, such as pyrene (benzo[a]pyrene equivalent), formaldehyde, and benzene.(31) Recurrent exposure to smoke emissions may increase the risk of cancer in the exposed population.(23) A study conducted in the state of Rondônia showed that the risk of lung cancer due to long-term exposure to benzo[a]pyrene equivalents present in fire smoke emissions was twice as high as that recommended by the WHO.(32)

Some particles can remain in the atmosphere for days to weeks and travel long distances, sometimes hundreds of kilometers,(23,24) affecting the concentration of pollutants in regions far from the source. As examples, we can mention the presence of particles from the Australian forest fires in the city of Porto Alegre in early 2020(33) and that from the Amazon basin and Bolivia in the city of São Paulo in August of 2019,(34) as well as that on the Andean snow layer and glaciers shown in satellite images, raising the hypothesis that part of the black carbon found in that region was possibly originated from fires in the Amazon.(35)

AIR POLLUTION AND HEALTH EFFECTS

Three main mechanisms explain the biochemical, physiological, and clinical effects of exposure to air pollution particles.(27) First, inhaled particles can react with pulmonary neural receptors and activate the reflex that is involved in the chemical and electrical communication between the lung and the nervous system. The return signals from the brain that travel through the autonomous nervous system can trigger an increase in blood pressure levels and changes in heart rhythm.(25) Second, air pollutants interact with alveolar-capillary membranes and generate oxidative stress reactions, as well as local and systemic inflammatory responses.(36) These responses induce oxidation and blood lipid disorders, platelet activation, and prothrombotic changes in proteins, affecting blood vessel functions and increasing blood coagulation.(25) Third, ultrafine $PM_{0.1}$ (mean diameter < 0.1 µm) can be translocated across the alveolar membrane and act systemically at a distance from the lung.(31)

Biochemical and physiological responses contribute to a series of functional changes, including endothelial dysfunction, as well as lesion activation and formation. Local changes in the lungs increase pulmonary responses that can affect airway function and decrease resistance to viruses and bacteria, increasing the risk of infections.(24,37)

FOREST FIRE SMOKE AND HEALTH EFFECTS

Emission and atmospheric transport of smoke from forest fires are a growing and costly global public health problem that mainly affects vulnerable communities and more sensitive people, such as children (infants and toddlers), pregnant women, fetuses, middle-aged people, the elderly (> 65 years of age), people with lung and/or heart disease, (active and passive) smokers, workers prone to occupational diseases, and socially vulnerable populations.(38-42)

The physical and chemical characteristics of air pollutants, whether from urban areas or wildfire emissions, are dynamic, varying in time and space; hence, the assessment of their impacts remains a challenge. In addition, current efforts to study the effects of smoke from forest fires are limited due to the lack of air quality measurements in the northern region of Brazil.(28) Table 1 lists some of the most relevant studies on the effects of wildfire smoke in the Amazon on human health in Brazil.

Forest fire smoke consists mainly of PM, especially $PM_{0.1}$. The PM concentration is higher close to the emitting source. During periods of active fire, $PM_{2.5}$ was significantly associated with respiratory effects due to the direct deposition of inhaled particles in the lungs, consequently causing local oxidative stress and inflammation and being potentially likely to overflow into systemic circulation.(25,36)

Previous studies showed that lung cell exposure to PM_{10} (mean diameter < 10 µm) significantly increases

Table 1. Main studies evaluating the effects of fire smoke on human health in the Brazilian Amazon.

Study	Year	City or region	Pollutants considered	Population group	Outcome studied	Type of study
Mascarenhas et al.(47)	2008	Rio Branco, AC	$PM_{2.5}$	Several age groups	Respiratory disease-related ER visits	Ecological time-series study
Carmo et al.(37)	2010	Alta Floresta, MT	$PM_{2.5}$	Several age groups	Outpatient visits due to respiratory disease	Epidemiological study
Ignotti et al.(48)	2010	Tangará da Serra and Alta Floresta, MT	$PM_{2.5}$	Children and older people	Hospitalizations due to respiratory disease	Ecological time-series study
Prass et al.(50)	2012	Porto Velho, RO	Number of fires	Children and pregnant women	Low birth weight	Retrospective cohort study
Carmo et al.(42)	2013	Rio Branco, AC	$PM_{2.5}$	Children	Hospitalizations due to respiratory diseases	Ecological time-series study
Andrade Filho et al.(46)	2013	Manaus, AM	$PM_{2.5}$	Children	Hospitalizations due to respiratory disease	Ecological time-series study
Jacobson et al.(44)	2014	Tangará da Serra, MT	PM_{10}, $PM_{2.5}$, "black carbon"	Children	Changes in PEF	Longitudinal study
Cândido da Silva et al.(49)	2014	Tangará da Serra and Alta Floresta, MT	$PM_{2.5}$ and CO	Children and pregnant women	Low birth weight	Retrospective cohort study
Reddington et al.(16)	2015	Amazon	$PM_{2.5}$	Several age groups	Premature deaths	Computational modeling and risk assessment
de Oliveira Alves et al.(31)	2015	Porto Velho, RO	PM_{10} and PAH	N/A	N/A	Chemical characterization of PM_{10} and health risk assessment
Silva et al.(45)	2016	Rio Branco, AC	O_3 and $PM_{2.5}$	Children	N/A	Toxicological risk assessment
de Oliveira Alves et al.(32)	2017	Porto Velho, RO	PM_{10} and PAH	N/A	Toxic and mutagenic effects on lung cells	Exposure tests of lung cells to fire PM_{10}
de Oliveira et al.(36)	2018	Porto Velho, RO	$PM_{2.5}$ and Hg	Children and teenagers	Oxidative stress biomarkers	Cross-sectional study
Nawaz et al.(51)	2020	Amazon	$PM_{2.5}$	Several age groups	Premature deaths	Computational modeling and risk assessment

$PM_{2.5}$: particulate matter with a diameter < 2.5 µm; PM_{10}: particulate matter with a diameter < 10 µm; CO: carbon monoxide; PAH: polycyclic aromatic hydrocarbons; AC: Acre; RO: Rondônia; AM: Amazonas; and MT: Mato Grosso.

the levels of reactive oxygen species and inflammatory cytokines, the risk of autophagy, and DNA damage. Continued exposure to PM_{10} activates cell apoptosis and necrosis.(32) Respiratory morbidities include asthma, COPD, bronchitis, and pneumonia.(43-46) Poor socioeconomic conditions increase the association between exposure to $PM_{2.5}$ from forest fires and hospital and ER admissions due to asthma and heart failure.(6,41,47,48)

A significant and positive relationship was found between ozone concentrations during the fire period and ER admissions due to asthma(6) in areas surrounding a forest fire. Heavy smoke can cause eye irritation, corneal abrasions, and a significant reduction of visibility, increasing the risk of traffic accidents.(40)

The fetus can also be exposed to high PAH levels in the uterus, which is particularly worrisome in early life because this exposure can occur during the so-called "susceptibility window", a period that impacts structural mechanisms and cell signaling and that can result in the development of diseases in adulthood.(25) The exposure of pregnant women to PM in the first trimester of pregnancy has been associated with a higher risk of low birth weight. That exposure at any time during pregnancy increases the risk of preterm birth.(25,49,50)

Children are especially vulnerable to PM exposure. Because they are in growing and developing, they have greater tidal volume in proportion to their body weight, less efficient nasal filtering, which facilitates that particles move deeper into their lungs, and greater outdoor exposure. In addition, as they have long life expectancy, the adverse effects of that exposure may have lifelong consequences. Even healthy children may experience upper airway symptoms, as well as increased coughing and wheezing, when exposed to forest fire smoke.(25)

People living in areas affected by forest fires have presented an increased risk of mental illness, including post-traumatic stress disorder, depression, and insomnia, due to traumatic experiences, loss of property, and need for displacement.(40)

Biomass burning fire emissions across Brazil significantly contribute to premature deaths, the largest fires occurring in the northern region of Brazil. Nawaz et al.(51) reported that premature deaths were attributed to fire emissions and accounted for 10% of all $PM_{2.5}$-related premature deaths in Brazil during the 2019 fire season.

FIRES AND COVID-19

Recent studies have established pathophysiological factors and epidemiological associations between PM exposure and viral infections.(52) Landguth et al.(53) recently reported that exposure to high $PM_{2.5}$ concentrations during the forest fire season might positively be associated with increased incidence of influenza in the following season.

The association between air pollution and incidence of COVID-19 has been documented.(54) PM can carry viruses indoors, impair immunity, increase individual susceptibility to pathogens, and facilitate the entry of viruses into the respiratory tract, possibly causing more serious infections.(55)

Recent ecological studies suggest a link between exposure to high $PM_{2.5}$ levels and increased COVID-19(56) mortality, although the influences of other factors, such as population density, socioeconomic factors, and compliance with social distancing measures, should also be considered.(21,57)

Populations more vulnerable to forest fire smoke exposure are also susceptible to SARS-CoV-2 infection. Exposure to wildfire smoke may also increase the likelihood of SARS-CoV-2 infection, as well as the severity of COVID-19.(58)

A study in the city of San Francisco, one of the regions affected by forest fires in California, USA, documented a positive association of $PM_{2.5}$ and carbon monoxide levels with increased numbers of daily cases of SARS-CoV-2 infection, highlighting the important contribution of such environmental pollutants as triggering factors for COVID-19 and mortality. The increased incidence of COVID-19 and associated deaths were also related to exposure to environmental forest fire pollutants ($PM_{2.5}$, carbon monoxide, and ozone) in ten different localities in the state of California.(58,59)

According to Navarro et al.,(60) the concomitant occurrence of SARS-CoV-2 infection and inhalation of forest fire smoke may increase the risk of COVID-19 among forest firefighters due to the transport of SARS-CoV-2 by PM and regulation of angiotensin-converting enzyme II, facilitating the entry of the virus into epithelial cells. Exposure to smoke from uncontrolled fires may also increase the risk of developing more severe forms of COVID-19, such as cytokine release syndrome, hypotension, and ARDS.(60)

Increased deforestation and the specter of drought may worsen the COVID-19 pandemic and endanger the lives of people living in the Amazon.(61) Fires from the Amazon account for 80% of the regional $PM_{2.5}$ pollution increase and affect 24 million Amazonians. Thus, we highlight that the potential relationship between $PM_{2.5}$ exposure and COVID-19 has special relevance to public health in Brazil, where infection and mortality rates are among the highest in the world,(62) especially in vulnerable populations who may be highly exposed (e.g., indigenous people, whose COVID-19 mortality rates are almost twice as high as the Brazilian average).(21)

Manaus, the capital of the state of Amazonas, was one of the Brazilian cities most affected by the COVID-19 pandemic. A previous study on serum antibody detection indicated that 76% of the population of Manaus had been infected by SARS-CoV-2 until October of 2020, a percentage higher than that estimated to reach collective immunity (67%).(63) In Manaus, the so-called first wave peaked in April of 2020, reaching 120 deaths per day due to ARDS. In this context, the strong resurgence of COVID-19 in January of 2021 was surprising, immune evasion and increased transmissibility of SARS-CoV-2 variants being indicated as possible causes.(64) It is interesting to note that the peaks of the first and second waves of COVID-19 in Manaus occurred during the rainy season, when fires are not common. This fact suggests the absence of a direct association between short-term exposure to wildfire emissions and COVID-19 morbidity and mortality in the region. However, long-term exposure may increase the vulnerability of the population to viral infections. A recent study reported that the spatial distribution of COVID-19 in Brazil stems from multiple causes, including health care service inequalities, the flow of people and connection networks between cities, as well as the lack of national coordination and synchrony in the implementation of nonpharmacological measures to contain the spread of the virus, such as the use of masks and mobility restrictions.(65)

AIR QUALITY MONITORING NETWORKS

Increased awareness of the health risks posed by wildfires compels public health authorities and health care professionals to advise at-risk people to adopt measures that will prevent exposure to wildfire smoke.(25,66)

One primary source of available and up-to-date information to assist public health and health care professionals is the Wildfire Smoke: Guide for Public Health Officials(67): it is a useful guideline to help public health officials prepare for wildfire smoke and provides information that can be shared with the public in order to protect themselves during such events.

Emission containment (land/fire management practices) and preventive efforts against exposure, in addition to the identification of susceptible populations, can help prepare for air pollution episodes and ensure that the population at risk will be evacuated from harmful areas when the events threaten their safety. Hence, effective public health communication strategies should be developed in collaboration with communities, public health officials, health care professionals, state officials, and fire officials, because the impacts of wildfire smoke on public health will continue to increase.(68-71)

It is essential to expand the air quality monitoring network in the states included in the Legal Amazon. Without such monitoring, the size of the environmental problem related to exposure to pollutants emitted by fires cannot be determined. This hinders the creation of effective public policies to reduce this problem. State environmental agencies are responsible for monitoring air quality, disseminating accurate and clear information about it, and providing optimal communication through public awareness campaigns aimed at empowering people to modify their behavior in order to improve their health and the quality of the air they breathe.(24)

GENERAL RECOMMENDATIONS FOR REDUCING EXPOSURE IN AREAS WITH FOREST WILDFIRE/FIRE SMOKE(67)

- Avoid strenuous or prolonged work: if a person is working outdoors, pay attention to the occurrence of symptoms; they are an indication that exposure needs to be reduced
- Reinforce hydration for airway protection
- If it is necessary to advise the patient to stay indoors, indoor air should be kept as clean as possible
- If air conditioning systems are used at home, keep the fresh air inflow closed and the filter clean to prevent additional particles from contaminating indoor air
- If there are no air conditioning systems at home, staying indoors with the windows closed in extremely hot weather can be dangerous; the use of alternative shelters, such as staying at a relative's or a friend's place or at a shelter with cleaner air, is recommended
- If driving is necessary, turn on the car's air conditioning system in recirculation mode to prevent smoky air from entering the car, although the capacity of these filters is limited
- Avoid activities that increase indoor pollution, such as the use of anything that burns (wood-burning fireplaces, gas stoves, candles, incense sticks, mosquito repellent devices, among others)
- Patients should be encouraged to quit smoking, because smoking increases the amount of pollutants in the lungs of smokers and those around them
- Advise your patients to visit a referral health care facility when presenting with new cardiovascular or respiratory symptoms or if other existing health problems worsen

FINAL CONSIDERATIONS

Exposure to wildfire emissions is an important and growing clinical and public health problem. Weather pattern changes, including droughts, increase the risks for wildfires and comorbidities. Exposure to Amazon wildfire smoke impacts the health of populations at a higher risk, including those with heart or chronic lung disease, the elderly, children, pregnant women, and fetuses.

Public policies are needed to improve the communication of actionable information by public health care professionals so that populations prone to being exposed to fire smokes are able to act accordingly, improving their health and quality of life effectively.

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