# Fires and Public Health in the Brazilian Amazon

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## Abstract

Can access to health services mitigate the impacts of natural disasters in the developing world? This paper documents the health consequences of forest fires in the Brazilian Amazon and examines whether access to public healthcare can mitigate potential adverse effects. I link comprehensive hospitalization records with satellite information on fire locations and wind patterns to identify the causal impact of forest fires on health outcomes for individuals across all age groups. Upwind fires increase hospital admissions for infants and children, which are driven by increases in respiratory hospitalizations for infants and children under five and in circulatory hospitalizations for children from 6 to 12 years old. These effects are substantially more negative for municipalities with limited access to public healthcare services, particularly those with few community health centers. The findings suggest an essential role for healthcare delivery in mitigating the impacts of climate change.

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# 1 Introduction

The Amazon rainforest, the world's largest rainforest, spans 6 million square kilometers and is home to over 20 million people in Brazil alone. The recent escalating deforestation rates and the surge in forest fires in the Brazilian Amazon have become a matter of increasing concern (Alencar et al., 2020; MapBiomas, 2020). This is not only due to their implications for climate change but also because of the potential health impacts on the numerous communities in the region. Unlike wildfires in developed nations like the US and Canada, most forest fires in the Amazon are human-caused and tied to economic activities, posing challenges in studying their health effects. Furthermore, there is limited research on the local health consequences of these fires and the increased air pollution they generate. Additionally, the role of access to public healthcare services in mitigating these effects, particularly for low-income individuals, remains an understudied aspect.

This paper documents the health consequences of fires in the Brazilian Amazon and examines whether access to public healthcare services can mitigate potential adverse effects. I use detailed hospitalization records for all municipalities in the region and focus on the impact on hospital admissions for various age groups and causes. I examine how those outcomes are affected by the presence of public healthcare facilities, particularly community health centers. Additionally, I investigate the impact on mortality rates for different age groups and the importance of public healthcare infrastructure, such as the number of physicians and hospital beds.

To deal with the potential confounding economic effects of fire activity, precisely because forest fires are linked to economic practices that could positively impact health outcomes, I combine satellite information on fire locations and wind patterns to differentiate upwind from nonupwind fires for each municipality. I use the wind direction when each fire is detected and define upwind as those in which the wind was blowing in the direction of the municipality's city center. The identification assumption is that while upwind and nonupwind fires similarly correlate with economic confounders, upwind fires have a more pronounced impact on local air pollution due to the direction the wind was blowing when the fire happened, i.e., an exogenous factor.

I calculate the monthly number of upwind and nonupwind fires for each municipality and link them to comprehensive hospitalization and mortality records to identify the causal effect of forest fires on health for different age groups. By comparing the differential impact of upwind relative to nonupwind fires after controlling for municipality and time fixed effects and atmospheric conditions, I can estimate the health impacts of exogenous variations in air pollution caused by forest fires.

I first show that high-intensity fires significantly increase air pollution, measured by PM2.5 concentrations, in municipalities in the Brazilian Amazon. Moreover, distinguishing upwind from nonupwind fires reveals that fires upwind from a municipality's city center increase local air pollution concentrations substantially more than nonupwind fires. One additional upwind fire increases PM2.5 concentrations by approximately four times more than a nonupwind fire. After establishing the differential impact of upwind fires on local air pollution, I estimate the effects on different health outcomes using the variation in the number of upwind relative to nonupwind fires.

The main results show that upwind fires increase hospital admissions among infants and children. These effects are primarily driven by respiratory hospitalizations for infants and children under five and hospitalizations due to circulatory diseases for children aged 6 to 12. One additional upwind fire increases respiratory hospitalizations for infants by approximately 0.09 more than a nonupwind fire, representing a standardized effect of 5% on the dependent variable mean. For children 6 to 12 years old, an additional upwind fire increases hospital admissions caused by circulatory diseases by approximately 0.014 more than a nonupwind fire, or approximately 18%.

I also examine the effects on mortality and find that upwind fires increase child and adult mortality rates. One additional upwind fire increases mortality rates for children under five by approximately 0.02 more than a nonupwind fire, representing a differential increase of approximately 8%. For adults, an additional upwind fire increases mortality rates by around 0.11 more than a nonupwind fire, or 2.4%.

After showing that upwind fires increase hospital admissions and mortality rates, I study whether better access to public healthcare services can mitigate the adverse effects of forest fires on health. This analysis is particularly relevant as numerous municipalities in the Brazilian Amazon are remote and relatively impoverished, with a considerable portion of their population relying solely on the public healthcare system for medical assistance. I show that the adverse effects of fires on hospitalizations and mortality are larger in municipalities with limited access to public healthcare services, particularly those with few community health centers to mitigate the effects of increasing air pollution.

By comparing the effects of upwind and nonupwind fires in municipalities with few community health centers, I show that upwind fires increase respiratory hospitalizations by approximately 8% for infants and 4% for children under five. The effects on hospital admissions caused by circulatory diseases for children aged 6 to 12 is around 40%. On the other hand, for municipalities with a more extensive network of community health centers and clinicians, the effects are much smaller and are not statistically significant.

The adverse effects on mortality are also significantly larger in municipalities with few community health centers and clinicians. Upwind fires increase child and adult mortality by approximately 15% and 2.9% in municipalities with few community health centers, respectively. The effects are much smaller and are not statistically significant for municipalities with a more extensive network of community healthcare centers. Finally, I find similar results when assessing heterogeneity in the number of clinicians within the public healthcare system and hospital beds.

Overall, the results suggest that fire activity can be spuriously correlated with improved economic activity. However, when I distinguish upwind from nonupwind fires, the adverse health effects from fires that exogenously spread more air pollution outweigh potential gains. Furthermore, the findings highlight the critical role of healthcare delivery in mitigating the negative impacts of fires.

While the health burden of air pollution is well-studied, most of the evidence comes from developed countries or focuses on industrial sources of air pollution (Currie and Neidell, 2005; Currie, Neidell and Schmieder, 2009; Graff Zivin and Neidell, 2013; Ward, 2015; Schlenker and Walker, 2016; Deryugina et al., 2019; Anderson, 2020; Molitor, Mullins and White, 2023). Among the studies for developing countries, many of them are restricted to urban areas (Greenstone and Hanna, 2014; Arceo, Hanna and Oliva, 2016) or focus on infrequent events such as pollution generated by major forest fires or wildfire waves (Sastry, 2002; Jayachandran, 2009; Frankenberg, McKee and Thomas, 2012; Kim et al., 2017; Tan-Soo and Pattanayak, 2019; Requia et al., 2021).

This paper explores a distinct context. I focus on a region where most of the population resides in rural areas, and the primary source of air pollution stems from recurrent forest fires. Moreover, in contrast to research that often focuses on isolated, massive air pollution incidents arising from rare events like major forest fires, communities in the Brazilian Amazon confront a distinct reality. Forest fires are human-caused and frequent throughout the year, persisting even outside the typical fire season and exerting a consistent and sustained impact on residents. This context allows me to examine the health effects of recurrent yet relatively continuous forest fires, setting it apart from previous research.

Moreover, most quasi-experimental studies for developing countries assessing the health consequences from more moderate sources of air pollution, such as agricultural fires, tend to focus on a narrow set of health outcomes (Pullabhotla and Souza, 2022) and specific age groups (Rangel and Vogl, 2019; Pullabhotla, 2019; Pullabhotla et al., 2023). The closest study to this paper is by Sant'Anna and Rocha (2020), which also investigates the health effects of fire-related air pollution in the Brazilian Amazon but does not examine the role of public health care.[1] This paper adds to the literature through two main contributions. The first contribution is assessing the health consequences of forest fires among low-income populations in developing countries. It provides valuable insights into how the health effects of fires can differ for low-income communities compared to better-off individuals, shedding light on the challenges developing nations face with climate change. Additionally, it provides a comprehensive analysis of the effects across all age groups, examining how these impacts vary across different population segments.

Second, I document the importance of access to public healthcare services in mitigating the adverse effects of fires on health within a developing country. Although a few studies show that access to healthcare services can alleviate the adverse effects of environmental exposures on health (Rocha and Soares, 2015; Mullins and White, 2020), the evidence is still limited. Moreover, this is the first study to document how public healthcare services can mitigate the adverse effects of forest fires on health in a developing country where a substantial portion of the population is impoverished.

The rest of the paper is organized as follows. Section 2 provides background information on forest fires, air pollution and public health in the Brazilian Amazon. Section 3 describes the different datasets used in the paper. Section 4 presents the empirical strategy, and Section 5 presents the main results, including the heterogeneous effects concerning access to public healthcare services. Section 6 concludes the paper.

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[1] Sant'Anna and Rocha (2020) instrument air pollution exposures at the municipality level by interacting average monthly wind direction with the count of fires in neighboring municipalities, without using the precise location of each fire and the direction the wind was blowing when the fire was detected. Moreover, they do not look at fires within each municipality in their analysis, restricting to fires that happened in neighboring municipalities.

## 2 - Forest Fires, Air Pollution and Public Health in the Brazilian Amazon

The Brazilian Amazon has witnessed two distinct phases since 2000 in the trajectory of deforestation. In the early 2000s, a set of conservation policies put in place by the federal government were effective in curbing deforestation, leading to significant reductions by the end of the first decade (Assunção, Gandour and Rocha, 2015; Assunção, Gandour and Rocha, 2019; Assunção, Gandour, Rocha and Rocha, 2020). However, in 2014, the region entered a different phase marked by an alarming resurgence in deforestation following a period of economic crisis and reduced environmental regulation (Burgess, Costa, and Olken, 2023).

With the recent surge in deforestation rates, there has been a corresponding increase in the number of fires in the region. The majority of these fires are human-caused and directly associated with deforestation practices, often involving illegal activities (Alencar et al., 2020; MapBiomas, 2020). These fires are typically ignited by loggers, cattle ranchers, miners, and land grabbers using the 'slash-and-burn' technique. This method entails clearing forested land and burning the remaining vegetation after removing valuable trees. Not only do these fires have significant environmental implications, but they also pose substantial local consequences for public health, generating high levels of air pollution.

[FIGURE 1 HERE]

Figure 1 displays maps of fires and air pollution concentrations for municipalities in the Brazilian Amazon between 2014 and 2019 based on data from the Brazilian Space Institute (INPE). Figure 1a presents the map with each municipality's average number of fires per year. Figure 1b shows the map of yearly PM2.5 concentrations in each municipality. The figures show a strong spatial correlation between fires and air pollution in the region.

[FIGURE 2 HERE]

Figure 2 displays the time series of average monthly fires and PM2.5 concentrations for municipalities in the Brazilian Amazon between 2014 and 2019. The figure shows a strong temporal correlation between fires and air pollution. There is also a clear seasonal pattern, with more fires and air pollution during the dry season (July to October).

In addition to the escalating deforestation and the surge in fires and air pollution, the Brazilian Amazon faces a complex landscape concerning public healthcare infrastructure, particularly in the more remote and rural areas. While a considerable portion of the population in the region primarily relies on the public healthcare system for medical assistance, there is significant heterogeneity in the availability and accessibility of healthcare services.

[FIGURE 3 HERE]

Figure 3 displays the map with the number of community health centers in each Brazilian Amazon municipality, one of the most essential primary healthcare facilities within the Brazilian public healthcare system. The map shows the significant heterogeneity in the availability of community health centers among cities in the region and a lack of access to these essential primary healthcare facilities in many of them.

The figure illustrates that overall, there is a significant lack of public healthcare infrastructure in poorer and remote areas in the country (Costa, Nunes and Sanches, 2023). Moreover, previous research has shown that access to different types of services within the Brazilian public healthcare system can have positive impacts on health outcomes (Rocha and Soares, 2010; Rocha and Soares, 2015; Fontes, Conceição and Jacinto, 2018; Castro et al., 2019; Bhalotra, Nunes and Rocha, 2023).

# 3 - Data

## 3.1 - Fires and Pollution

I obtained remote-sensing fire data from the Brazilian Space Agency (INPE) based on images from various U.S. satellites. I restrict to the data from NASA's AQUA satellite, which passes over Brazil daily during the late afternoon (between 4 pm and 6 pm) and is the reference satellite considered by INPE. The data contain information on the precise location and time each fire was detected. The data also have information on the fire radiative power (FRP) of each fire starting in 2018, which is the rate of radiative energy emitted at the moment of detection. This information is important because it allows me to distinguish between high-intensity and low-intensity fires. Therefore, I will focus on the 2018-2019 period and high-intensity fires, defined as fires with FRP values above the annual median FRP for all municipalities in the region.[2]

I combine the fire data with data from the Environmental Health Information System (SISAM), also developed by INPE through numerical calculations based on satellite images and models from NASA and the European Centre for Medium-Range Weather Forecasts (ECMWF). The data contain four daily observations (recorded at 12 am, 6 am, 12 pm and 6 pm) at the municipality level with information on wind direction and speed, air temperature, relative humidity and cumulative rainfall, and the concentration of important air pollutants.[3] I collapse the air temperature, relative humidity and cumulative rainfall data into monthly observations for 2018-2019. I do the same for PM2.5 concentrations, which I also use in some estimations. Finally, I use the information on wind direction to define and differentiate upwind from nonupwind fires, as explained below.

I also use data on the geolocation of each municipality's city center obtained from the Brazilian Institute of Geography and Statistics (IBGE) to restrict the analysis to fires within different buffers surrounding each city center. In the main specifications, I use 50km radius buffers. The idea behind this approach is that fires in neighboring municipalities relatively close to the city center might be more critical than fires that occurred in the same municipality but were far from the city center when assessing potential health impacts. This is particularly important in the Brazilian Amazon region, where many city centers are closer to neighboring municipalities' borders than their municipality's centroid, as illustrated in Figure 3.

[FIGURE 4 HERE]

For each municipality's city center, I match all fires that happened within the 50km buffer surrounding it with the wind direction recorded at 6 pm in that municipality from the SISAM data. This time coincides with the hours when the AQUA satellite passes over Brazilian territory and detects active fires. Using the geolocation of each fire, the wind direction at the time of detection, and the city center's geolocation, I categorize fires as either upwind or nonupwind relative to each municipality's city center. First, I calculate the angle between each fire's location and the city center. Subsequently, I use the wind direction

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[2] I stopped the analysis in 2019 due to the COVID-19 pandemic in early 2020, as its health implications could potentially influence the results.

[3] For cumulative rainfall, there is a single daily observation. For 2019, the only pollutant available in the data is PM2.5.

to determine the difference between the direction of the wind and the angle between the fire and the city center. Fires are classified as upwind when the wind direction aligns closely with the angle between the fire and the city center, i.e., when the difference between the two angles is small. There is a trade-off between allowing for larger differences (which results in more fires defined as upwind) and smaller differences (which gives more precision in the definition of upwind fires). In the main specifications, I use a 35-degree threshold (i.e., when the difference between wind direction and the angle between the fire and city center is smaller than 35 degrees) to define upwind fires.[4]

To assess the differential effects of upwind and nonupwind fires on air pollution, the primary pollution data that I use are monthly gridded data for fine particulate matter (PM2.5) concentrations developed by van Donkelaar et al. (2021). The authors combine satellite retrievals of aerosol optical depth, chemical transport modelling, and ground-based measurements to allow for seasonal and episodic exposure and aid air-quality management. From the gridded data, I calculate monthly PM2.5 concentrations (measured in $\mu g/m^3$) within various buffer distances around each municipality's city center, with my main specifications employing 50km radius buffers.[5] The data on PM2.5 concentrations are combined with the fire data after defining fires as high or low intensity and upwind or nonupwind. [6]

## 3.2 - Hospital Admissions and Mortality

The primary data source I use for health outcomes is the Information System of Hospitalizations (SIH), from by the Brazilian Ministry of Health. The data contain individual-level information on all hospital admissions funded by the public healthcare system. The SIH includes data on the cause of hospitalization according to the international classification of diseases (ICD-10 for the most recent period) and socio-demographic details of the patients, in particular age, which allows me to investigate how the effects of fires on hospital admissions differ across different age groups. I collapse the data by the patient's municipality of residence and the month of hospitalization for 2018-2019. I calculate monthly hospitalization rates (represented as total hospitalizations per 100,000 residents) by the cause of

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[4] In the appendix, I also present results using different thresholds to distinguish upwind and nonupwind fires.

[5] Using other radii yields very similar results.

[6] In the appendix, I also present the results of the differential effects of upwind and nonupwind fires on air pollution using data on monthly PM2.5 concentrations at the municipality level from SISAM. The results are very similar to the main results that use the data from van Donkelaar et al. (2021).

hospitalization and for different age groups.

For analyzing the effects on mortality, I draw upon data from the Information System of Mortality (SIM), also from by the Brazilian Ministry of Health, which provides information on all officially registered deaths at the individual level in the country. Similarly to the hospitalization data, it contains information on the age of the deceased individual, the date of death and the municipality of residence and death. I also aggregate the data by municipality of residence and month of death for 2018-2019 and computed monthly mortality rates (total deaths per 100,000 residents) for different age groups.

The collapsed health outcomes datasets are linked with the fire data, forming two distinct panels at the municipality of residence and the reference month (hospital admission or death) level for 2018-2019, which are my primary estimation samples.

## 3.3 - Access to Public Healthcare Services

To examine the heterogeneous effects of access to public healthcare services, I rely on administrative data from the National Register of Health Establishments (CNES) provided by the Brazilian Ministry of Health. The CNES has monthly data at the municipality level containing information on the quantity and categories of healthcare facilities, healthcare professionals, and hospital beds.

In my primary analyses, I emphasize the role of different types of public healthcare facilities, particularly community health centers, when studying the effects on hospitalizations. However, I also consider the number of physicians within the public healthcare system and the availability of public hospital beds and general hospitals when assessing impacts on mortality. These data allow me to investigate variations in the health effects of fires based on the accessibility and capacity of the public healthcare system and assess the extent to which public healthcare services can mitigate adverse health effects caused by fires.

## 3.4 - Summary Statistics

[TABLE 1 HERE]

Table 1 presents summary statistics for municipalities in the Brazilian Amazon for the 2018-2019 period. The data are at the month/year level from 2018-2019. Panel A provides information on fires, environmental outcomes and some socio-demographic characteristics of municipalities. Panel B displays data on hospital admissions. Panel C focuses on mortality. Panel D offers an overview of the supply of public healthcare services.

Several noteworthy features emerge from the data. Firstly, the average PM2.5 concentration during the period is remarkably high, particularly considering that approximately 40% of the population resides in rural areas and the region is predominantly forested. It is higher than the mean for Brazil, even when accounting for only urban areas. Secondly, the data illustrate that the Brazilian Amazon is characterized by high humidity and substantial rainfall. One might expect a region with such climatic characteristics to experience few natural fires, which is not the case.

From Panel B, we observe that respiratory and circulatory diseases constitute approximately 10% and 6% of total monthly hospital admissions, respectively. However, there is substantial variation across different age groups. Respiratory hospitalizations represent approximately 29% of hospital admissions for infants, 33% for children under 5, and 23% for children aged 6 to 12. In contrast, circulatory hospitalizations account for less than 1% of admissions in these age groups. In Panel C, we note that the majority of deaths in the region occur among adults and the elderly, while infants and children contribute to around 8% of total deaths.

Finally, Panel D shows that the region's supply of public healthcare services is limited. Notably, about 40% of municipalities do not have a community healthcare center. Furthermore, there is a low number of physicians, particularly clinicians, within the public healthcare system and public hospital beds.

# 4 - Empirical Strategy

I initiate the analysis by investigating the effects of high-intensity fires on air pollution. I follow a similar empirical strategy used by Rangel and Vogl (2019). First, I use the total number of fires as described in the equation below:

$$Y_{it} = \delta + \alpha \text{fires}_{it} + X'_{it}\beta + \gamma_i + \phi_t + \varepsilon_{it} \tag{1}$$

where $i$ indexes municipality and $t$ indexes time (month/year). $Y_{it}$ is PM2.5 concentration (in µg/m$^3$) within a 50km radius around the city center of municipality $i$ and month $t$.[7] The

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[7] I also present the results using PM2.5 concentrations at the municipality level in the appendix.

variable $\text{fires}_{it}$ is the total number of high-intensity fires within a 50km radius of municipality $i$'s city center at time $t$. I include municipality and time fixed effects $\gamma_i$ and $\phi_t$, respectively. The variable $X_{it}$ includes a set of weather controls given by average temperature, humidity and cumulative rainfall, and $\delta$ is a constant term.

For the analysis of the effects of fires on health, the distinction between upwind and nonupwind fires is crucial due to potential endogeneity issues in estimating equation (1). In particular, the estimated health effects using the total number of fires may suffer from bias since it can capture both increases in economic activity from fires, which could positively impact health, and increases in air pollution, which negatively affect health outcomes. However, by distinguishing upwind and nonupwind fires, I can disentangle potential economic gains from health costs associated with fire activity.

To distinguish between upwind and nonupwind fires, I run the following regression:

$$Y_{it} = \delta + \alpha^u \text{upfires}_{it} + \alpha^n \text{nonupfires}_{it} + X_{it}'\beta + \gamma_i + \phi_t + \varepsilon_{it} \tag{2}$$

where $\text{upfires}_{it}$ is the number of upwind fires within a 50km radius of municipality $i$'s city center at time $t$ and $\text{nonupfires}_{it}$ is the number of nonupwind fires. In all estimations, I apply cluster-robust standard errors at the municipality level. The hypothesis that I want to test by running equation (2) using PM2.5 concentration as the dependent variable is whether $\alpha^u > \alpha^n$, i.e., whether upwind fires from municipality $i$'s city center have a more significant impact on increasing local air pollution than nonupwind fires.

Regarding the health effects of fires, the identification hypothesis is that while upwind and nonupwind fires similarly correlate with economic confounders, upwind fires have a more pronounced impact on local air pollution due to the direction the wind was blowing when the fire happened, i.e., an exogenous factor. After controlling for municipality and time fixed effects and atmospheric conditions, I can separate the potential economic gains from health costs associated with fire activity by comparing the differential impact of upwind relative to nonupwind fires. Hence, I will focus on the estimation of equation (2) and compare the difference between the coefficients from upwind and nonupwind fires, given by $\alpha^u - \alpha^n$, which captures the differential impact of upwind fires relative to the overall association between fires and pollution.[8]

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[8] Although the focus is on estimating the differential effects of upwind and nonupwind fires, i.e., using equation (2), I also present the results using the total number of fires, i.e., from equation (1).

To analyze the effects of fires on hospital admissions, which is the main focus of this paper, the dependent variable $Y_{it}$ is going to be hospitalization rates (total hospital admissions per 100,000 population) for different age groups and causes in municipality $i$ at month $t$.

Finally, for the effects of fires on mortality, I use a distributed-lag model including both the lagged number of fires and the contemporary number to deal with potential displacement effects and persistent and delayed effects of fires on mortality rates (Burke, Hsiang and Miguel, 2015). Specifically, I run the following regressions:

$$Y_{it} = \delta + \alpha_1 \text{fires}_{it} + \alpha_2 \text{fires}_{it-1} + X_{it}'\beta + \gamma_i + \phi_t + \varepsilon_{it} \tag{3}$$

$$Y_{it} = \delta + \alpha_1^u \text{upfires}_{it} + \alpha_2^u \text{upfires}_{it-1} + \alpha_1^n \text{nonupfires}_{it} + \alpha_2^n \text{nonupfires}_{it-1} + X_{it}'\beta + \gamma_i + \phi_t + \varepsilon_{it} \tag{4}$$

where $Y_{it}$ represents mortality rates (total deaths per 100,000 population) for different age groups in municipality $i$ and date $t$ and $\text{fires}_{it-1}$, $\text{upfires}_{it-1}$ and $\text{nonupfires}_{it-1}$ are the monthly number of fires, upwind fires and nonupwind fires in date $t-1$ (i.e., one month before).

# 5 - Results

In this section, I first assess the impacts of high-intensity forest fires on local air pollution and examine the differential effects of upwind and nonupwind fires. Then, I use variations in the number of upwind relative to nonupwind fires to estimate the causal effects of fires on hospital admissions, focusing on the impacts on hospitalizations caused by respiratory and circulatory diseases for infants and children. Moreover, I also investigate the effects on mortality rates. Finally, I assess whether access to public healthcare services can mitigate the adverse health effects of fires on hospital admissions and mortality.

## 5.1 - Effects of Fires on Air Pollution

I begin my analysis by assessing the impacts of high-intensity fires on local air pollution and the differential effects of upwind and nonupwind fires. Table 2 displays the results for estimating equations (1) and (2) using PM2.5 concentrations at city centers as the dependent variable. In Panel A, I investigate the effects of the total number of high-intensity fires on local air pollution. In Panel B, I differentiate upwind from nonupwind fires.

[TABLE 2 HERE]

The results from Panel A show that high-intensity fires strongly correlate with PM2.5 concentrations, even after controlling for average temperature, humidity, and cumulative rainfall. One standard deviation increase in the monthly number of fires corresponds to an approximately 9% increase in local monthly PM2.5 concentrations.

Moreover, Panel B shows that upwind fires increase PM2.5 concentrations significantly more than nonupwind fires. After controlling for atmospheric conditions, upwind fires contribute to an approximately fourfold rise in local air pollution compared to nonupwind fires. This difference becomes even more pronounced when we compare the coefficients for upwind and nonupwind fires. An additional upwind fire increases local air pollution by approximately 0.18 more than a nonupwind fire, resulting in a standardized increase of approximately 3.3% in PM2.5 concentrations. The results using PM2.5 concentrations at the municipality level are similar and displayed in the appendix.

After establishing the differential impacts of upwind and nonupwind fires on local air pollution, I estimate the effects on health outcomes.

## 5.2 - Effects of Fires on Hospital Admissions

In Table 3, I present the results of equations (1) and (2) using monthly hospitalization rates for different age groups as the dependent variable. Panel A uses the total number of high-intensity fires, while Panel B uses upwind and nonupwind fires.

[TABLE 3 HERE]

The results from Panel A show that the effects of all fires on hospitalizations are generally minor and not statistically significant, which can be related to potential health benefits from increased economic activity linked to fire incidents. By differentiating upwind from nonupwind fires in Panel B, I can disentangle the economic gains from the health costs incurred due to fires.

The results from Panel B show that upwind fires increase hospitalization rates across all age groups, with particularly pronounced and statistically significant effects on infants and children. Specifically, a one standard deviation increase in the monthly number of upwind fires results in approximately a 1.4% rise in hospital admissions for infants and a 1% increase for both children under five and those aged 6 to 12. In contrast, nonupwind fires are associated with reduced hospital admissions, although the effects are not statistically significant for most age groups, except infants.

This evidence suggests that while fire activity can be spuriously correlated with economic improvements that could positively impact health outcomes, the adverse health effects of fires that exogenously spread more air pollution due to wind direction appear to outweigh the potential positive effects.

## 5.3 - Effects on Hospital Admissions for Respiratory and Circulatory Diseases

To delve deeper, I now focus on hospital admissions related to respiratory and circulatory diseases, as these categories are more susceptible to the effects of fires and the air pollution they generate (Dominici et al., 2006; Ward, 2015). Tables 4 and 5 show results for respiratory and circulatory hospitalizations, respectively.

[TABLE 4 HERE]

Table 4 shows that, when considering all fires in Panel A, there is a decrease in hospital admissions due to respiratory diseases, particularly significant for infants and children under 5. However, Panel B reveals a different pattern when distinguishing upwind from nonupwind fires. Upwind fires are associated with increased respiratory hospitalizations, especially among infants. In contrast, nonupwind fires reduce hospital admissions for respiratory diseases.

A one standard deviation increase in the monthly number of upwind fires leads to a significant increase of approximately 4.5% in respiratory hospital admissions for infants. Adverse effects are also observed for children under 5, although the estimates are less precise. Moreover, comparing the coefficients for upwind and nonupwind fires, we find that an additional upwind fire increases respiratory hospitalizations for infants by approximately 0.09 more than a nonupwind fire, representing a standardized increase of roughly 5% in the dependent variable mean.

[TABLE 5 HERE]

The results from Table 5 show a similar pattern, with upwind fires increasing circulatory hospitalizations for almost all age groups, excluding children under five. In contrast, nonupwind fires decrease hospital admissions for circulatory diseases across age groups. The differential effects of upwind and nonupwind fires are most pronounced and statistically significant for children aged 6 to 12.

A one standard deviation increase in the monthly number of upwind fires leads to a substantial 13.70% increase in circulatory hospital admissions for children aged 6 to 12 years. By comparing the difference between the upwind and nonupwind coefficients, we have that an additional upwind fire increases circulatory hospitalizations for this age group by approximately 18%.

Having looked at the effects of fires on hospital admissions for different age groups and causes, I proceed by assessing the impacts on mortality rates.

## 5.4 - Effects of Fires on Mortality

Table 6 presents the results from estimating equations (3) and (4), where I use a distributed-lag model including both the lagged number of fires and the contemporary number to deal with potential displacement effects and persistent and delayed effects of fires on mortality rates.

[TABLE 6 HERE]

In Panel A, the results suggest that both contemporary and lagged numbers of fires generally lead to decreased mortality rates across most age groups. However, a different pattern emerges when differentiating upwind from nonupwind fires in Panel B.

The results in Panel B reveal that while the contemporary number of fires does not significantly affect mortality rates, the lagged number of upwind fires significantly increases monthly deaths for children under five and adults. Specifically, a one standard deviation increase in the lagged number of upwind fires results in a 6.4% increase in child mortality and a 1.8% increase in adult mortality. Conversely, lagged nonupwind fires are associated with statistically significant decreases in mortality rates for these age groups.

Comparing the coefficients for lagged upwind and nonupwind fires, we find that an additional upwind fire increases child mortality by approximately 0.02 more than a nonupwind fire, representing a differential increase of approximately 8%. For adults, an additional upwind fire increases mortality rates by about 0.11 more than a nonupwind fire, or 2.4%.

These results provide additional evidence of the complex relationship between fires, economic activity, and health outcomes, as well as the importance of distinguishing upwind from nonupwind fires to disentangle potential economic improvements from the health costs of fire activity.

In the last part of this section, I study whether access to public healthcare services can mitigate the adverse health effects of fires on health. This analysis is particularly relevant as numerous municipalities in the Brazilian Amazon are remote and relatively impoverished, with a considerable portion of their population relying solely on the public healthcare system for medical assistance.

The main results focus on the number of community health centers, but I also show results exploring other types of healthcare services, such as the number of clinical physicians working within the public healthcare system[9].

## 5.5 - Mitigating Effects of Public Health Care

Table 7 presents the heterogeneous effects of upwind and nonupwind fires on hospital admissions for different age groups depending on the number of community healthcare centers per capita in each municipality. Panel A displays the results for municipalities with community health centers per capita below the median, while Panel B presents the results for municipalities above the median.

[TABLE 7 HERE]

The results reveal that the impacts of upwind fires on hospitalizations are more adverse in municipalities with fewer community health centers. In these areas, upwind fires increase hospital admissions for all age groups, with significant effects observed for all except the

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[9] In the appendix, I present additional results for the effects of fires on mortality rates exploring heterogeneity in the number of public hospital beds and general hospitals

elderly. The most substantial effects are observed for infants, children under five, and those aged 6 to 12. A one standard deviation increase in the monthly number of upwind fires leads to an increase of approximately 2% in hospital admissions for infants and children under five and a 2.4% increase for children from 6 to 12 years old. The effects for municipalities with above-median community healthcare centers are much smaller and not statistically significant.

Tables 8 and 9 focus on the effects of fires on hospitalizations caused by respiratory and circulatory diseases for infants and children. The results show that upwind fires provoke substantial and statistically significant increases in hospital admissions caused by these diseases in underserved municipalities. By comparing the effects of upwind and nonupwind fires in municipalities with few community health centers, upwind fires increase respiratory hospitalizations by approximately 8% for infants and 4% for children under five. The effects on hospital admissions caused by circulatory diseases for children aged 6 to 12 is around 40%. On the other hand, for municipalities with a more extensive network of community health centers and clinicians, the effects are much smaller and are not statistically significant.

In the appendix, I also present additional results exploring heterogeneity depending on the presence of community health centers and the number of clinical doctors, showing that the adverse effects of fires on hospital admissions caused by respiratory and circulatory diseases for infants and children are more significant for municipalities that don't have a community health center and with fewer clinicians.

[TABLE 8 HERE]

[TABLE 9 HERE]

Tables 10 and 11 explore the heterogeneous effects on mortality rates. Table 10 shows the impact on mortality rates for different age groups depending on the number of community healthcare centers, while Table 11 explores heterogeneity depending on the number of clinical doctors in the public healthcare system.

[TABLE 10 HERE]

[TABLE 11 HERE]

The results from Table 10 demonstrate that the adverse effects on mortality are also significantly larger in municipalities with few community health centers and clinicians. Upwind fires increase child and adult mortality by approximately 15% and 2.9% in municipalities with few community health centers, respectively. The effects are much smaller and are not statistically significant for municipalities with a more extensive network of community healthcare centers. Table 11 shows similar results when assessing heterogeneity in the number of clinicians within the public healthcare system. While municipalities with more clinicians do not experience significant increases in mortality rates due to either upwind or nonupwind fires, the effects are strong in cities with few clinicians. Upwind fires lead to a 16.8% escalation in mortality rates for children under five and a 4.2% increase for adults.

In the appendix, I also show similar effects on adult mortality rates depending on the number of public hospital beds and the number and presence of general hospitals. In sum, the findings underscore the pivotal role of healthcare delivery in mitigating the adverse effects of fires on public health in the Brazilian Amazon. Better access to public healthcare services, especially community health centers, is crucial in reducing the harm caused by fires on hospital admissions and deaths. These findings highlight the urgent need to strengthen healthcare facilities in fire-prone areas to protect people's health better.

## 6 - Concluding Remarks

The investigation into the health impacts of recurrent forest fires in the Brazilian Amazon sheds light on the intricate dynamics among fires, air pollution, and public health. The region's 20 million residents, predominantly in rural areas, face continuous exposure to air pollution from human-driven fires, primarily associated with illegal deforestation and economic activities.

To deal with the potential confounding economic effects of fire activity, precisely because forest fires are linked to economic practices that could positively impact health outcomes, I combine satellite data on fire locations with wind patterns to distinguish upwind from nonupwind fires for each municipality, which allows me to identify the causal impact of fires on health outcomes across all age groups. The identification assumption is that while upwind and nonupwind fires similarly correlate with economic confounders, upwind fires have a more pronounced impact on local air pollution due to the direction the wind was blowing when the fire happened.

The main findings show that upwind fires significantly increase hospital admissions among infants and children, primarily driven by increases in respiratory hospitalizations for infants and children under five and hospital admissions caused by circulatory diseases for children aged 6 to 12. Moreover, I also find that upwind fires increase child and adult mortality rates

The results also highlight the essential role of public healthcare services in mitigating the adverse effects of fires on health outcomes. Municipalities with limited access to community health centers and clinicians within the public healthcare system are shown to bear a more significant burden of fire-induced hospitalizations and mortality, emphasizing the essential role of a robust public healthcare delivery system in addressing the health impacts of climate change.

In conclusion, this research contributes valuable insights into the health effects of recurrent forest fires and underscores the importance of accessible and well-equipped public healthcare systems in safeguarding vulnerable populations. It provides crucial insights to inform the development of impactful policies to address climate change's extensive public health challenges in developing regions.

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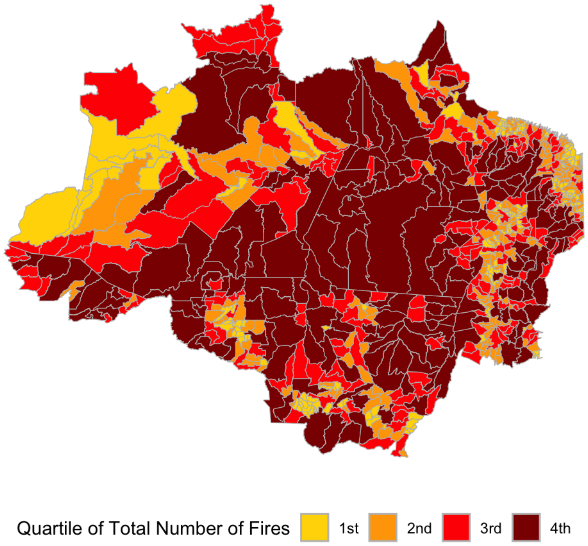
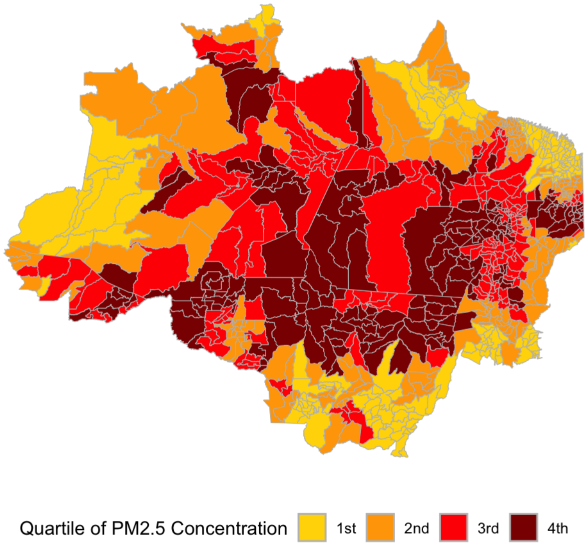
# Figures and Tables

Figure 1: Fires and Air Pollution in the Brazilian Amazon, 2014-2019



(a) Average number of fires per year



(b) Average PM2.5 Concentration (in µg/$m^3$) per year

Notes: Figure 1 displays maps of the average number of fires and PM2.5 concentrations (in µg/$m^3$) per year for all municipalities in the Brazilian Amazon between 2014 and 2019.
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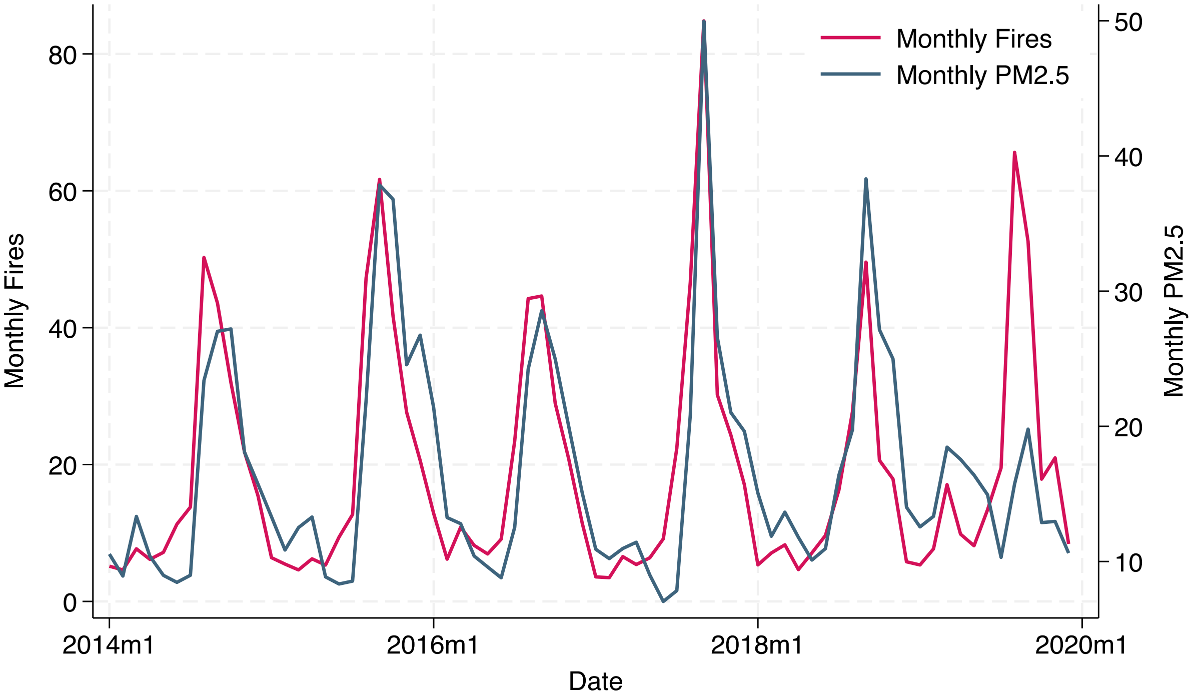
Figure 2: Monthly fires and PM2.5 concentrations in the Brazilian Amazon, 2014-2019



Notes: Figure 2 displays trends in monthly fire counts and PM 2.5 concentrations (in µg/m$^3$) for municipalities in the Brazilian Amazon between 2014 and 2019.
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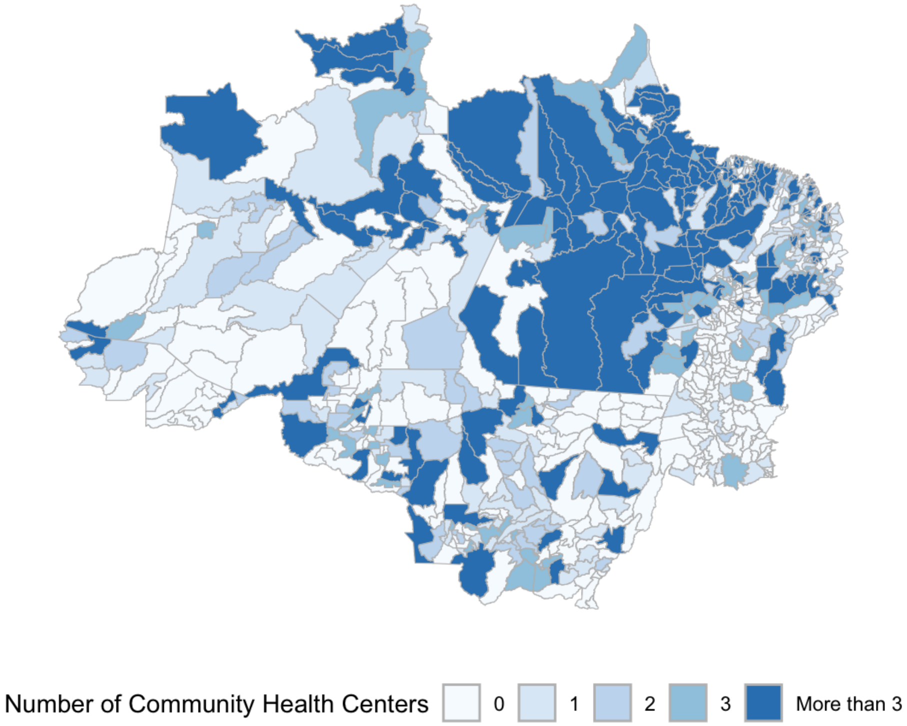
Figure 3: Community Health Centers in the Brazilian Amazon



Notes: Figure 3 displays the map with the number of community health centers in municipalities in the Brazilian Amazon.

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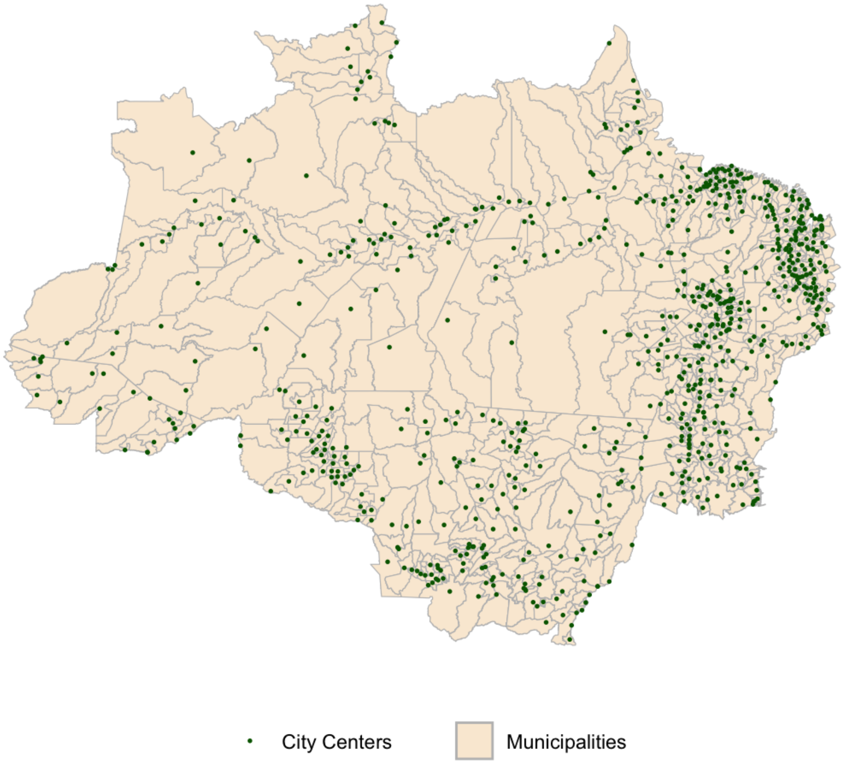
Figure 4: Municipalities and City Centers in the Brazilian Amazon



Notes: Figure 4 displays the map with municipalities and city center locations in the Brazilian Amazon. [Back to Text]

### Table 1: Summary Statistics Brazilian Amazon, 2018-2019

| | Mean | s.d |
|---|---|---|
| **Panel A: Fires, Environmental Outcomes and Socio-Demographics** | | |
| Monthly fires | 7.55 | 26.22 |
| Monthly high-intensity fires | 3.60 | 15.22 |
| Monthly low-intensity fires | 3.93 | 12.02 |
| Monthly high-intensity upwind fires | 0.58 | 3.35 |
| Monthly high-intensity nonupwind fires | 3.02 | 12.97 |
| Monthly PM2.5 concentration (µg/m$^3$) city center | 18.12 | 11.96 |
| Monthly average humidity (%) | 83.18 | 15.33 |
| Monthly cumulative rainfall (*mm*) | 180.30 | 240.20 |
| % Rural | 39.42 | 20.87 |
| **Panel B: Hospital Admissions** | | |
| Monthly hospital admissions rate | 505.54 | 252.62 |
| % Infants | 4.00 | 4.17 |
| % Children 1-5 | 8.97 | 6.62 |
| % Children 6-12 | 6.50 | 5.66 |
| % Teenagers | 7.21 | 5.82 |
| % Adults | 61.96 | 11.77 |
| % Elderly | 14.36 | 9.08 |
| % Respiratory | 10.36 | 8.00 |
| % Respiratory Infants | 29.47 | 30.48 |
| % Respiratory Children 1-5 | 33.26 | 27.28 |
| % Respiratory Children 6-12 | 22.93 | 24.91 |
| % Respiratory Teenagers | 5.48 | 12.68 |
| % Respiratory Adults | 4.77 | 5.99 |
| % Respiratory Elderly | 17.41 | 18.46 |
| % Circulatory | 6.13 | 5.82 |
| % Circulatory Infants | 0.89 | 6.25 |
| % Circulatory Children 1-5 | 0.89 | 5.45 |
| % Circulatory Children 6-12 | 0.89 | 5.47 |
| % Circulatory Teenagers | 0.73 | 4.61 |
| % Circulatory Adults | 4.75 | 6.14 |
| % Circulatory Elderly | 20.61 | 19.86 |
| **Panel C: Mortality** | | |
| Monthly deaths rate | 43.93 | 25.03 |
| % Infants | 5.62 | 12.03 |
| % Children 1-5 | 1.85 | 6.87 |
| % Children 6-12 | 0.79 | 4.52 |
| % Teenagers | 1.35 | 6.03 |
| % Adults | 37.14 | 25.17 |
| % Elderly | 54.24 | 26.22 |
| **Panel D: Supply of Public Healthcare Services** | | |
| % Without community healthcare center | 39.56 | 48.90 |
| Number of doctors working on public healthcare system | 396 | 1,424 |
| Number of clinical doctors working on public healthcare system | 10 | 46 |
| Number of public hospital beds | 52 | 193 |
| **Observations** | 18,504 | |

Notes: Table 1 presents summary statistics at the municipality and month/year level in the Brazilian Amazon between 2018 and 2019.

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### Table 2: Effects of high-intensity fires on air pollution

| | **Fine Particulate Matter (PM2.5)** | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| **Panel A: All fires** | | | | |
| Monthly fires | 0.1055*** | 0.0911*** | | |
| | (0.0140) | (0.0138) | | |
| **Panel B: Differentiating upwind and nonupwind fires** | | | | |
| Monthly upwind fires | | | 0.2646*** | 0.2407*** |
| | | | (0.0656) | (0.0607) |
| Monthly nonupwind fires | | | 0.0747*** | 0.0621*** |
| | | | (0.0156) | (0.0158) |
| Dependent Variable Mean | 18.12 | 18.12 | 18.12 | 18.12 |
| Observations | 18,528 | 18,528 | 18,528 | 18,528 |
| R-squared | 0.5391 | 0.5793 | 0.5403 | 0.5804 |
| Municipality and Month/Year Fixed Effects | Yes | Yes | Yes | Yes |
| Weather Controls | No | Yes | No | Yes |

Notes: Table 2 shows the effects of monthly high-intensity fires on monthly fine particulate matter (PM2.5) concentrations (in µg/m$^3$) 50km around municipalities' city centers. Weather controls include monthly average temperature, humidity and cumulative rainfall. Robust standard errors in parentheses are clustered at the municipality level.

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**Table 3: Effects of high-intensity fires on hospitalizations for different age groups**

| | **Full sample** | | **Infants** | | **Children 1-5** | | **Children 6-12** | | **Teenagers** | | **Adults** | | **Elderly** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) |
| **Panel A: All fires** | | | | | | | | | | | | | | |
| Monthly fires | 0.0023 | | -0.0118 | | -0.0153 | | 0.0122 | | 0.0176 | | -0.0223 | | 0.0103 | |
| | (0.0642) | | (0.0087) | | (0.0200) | | (0.0122) | | (0.0117) | | (0.0412) | | (0.0156) | |
| **Panel B: Differentiating upwind and nonupwind fires** | | | | | | | | | | | | | | |
| Monthly upwind fires | | 0.7869** | | 0.0887** | | 0.1438* | | 0.1071* | | 0.0906 | | 0.3054 | | 0.1211 |
| | | (0.3431) | | (0.0366) | | (0.0850) | | (0.0575) | | (0.0587) | | (0.2348) | | (0.0801) |
| Monthly nonupwind fires | | -0.1502 | | -0.0313** | | -0.0462 | | -0.0062 | | 0.0034 | | -0.0860 | | -0.0112 |
| | | (0.0917) | | (0.0122) | | (0.0318) | | (0.0190) | | (0.0144) | | (0.0604) | | (0.0234) |
| Dependent variable mean | 505.54 | | 21.08 | | 48.84 | | 34.36 | | 35.67 | | 308.29 | | 73.62 | |
| Observations | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 |
| R-squared | 0.7546 | 0.7546 | 0.3981 | 0.3982 | 0.5735 | 0.5736 | 0.4580 | 0.4581 | 0.4150 | 0.4150 | 0.6952 | 0.6953 | 0.5816 | 0.5817 |
| Municipality and Month/Year Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Weather Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

Notes: Table 3 shows the effects of monthly high-intensity fires on monthly hospital admission rates for different age groups. Panel A uses the total number of monthly fires, and Panel B differentiates upwind from nonupwind fires. Weather controls include monthly average temperature, humidity and cumulative rainfall. Robust standard errors in parentheses are clustered at the municipality level.

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**Table 4: Effects of high-intensity fires on monthly respiratory hospitalizations for different age groups**

| | Full sample | | Infants | | Children 1-5 | | Children 6-12 | | Teenagers | | Adults | | Elderly | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) |
| **Panel A: All fires** | | | | | | | | | | | | | | |
| Monthly fires | -0.0266 | | -0.0114** | | -0.0199* | | -0.0018 | | -0.0012 | | -0.0044 | | 0.0012 | |
| | (0.0196) | | (0.0055) | | (0.0118) | | (0.0055) | | (0.0023) | | (0.0066) | | (0.0065) | |
| **Panel B: Differentiating upwind and nonupwind fires** | | | | | | | | | | | | | | |
| Monthly upwind fires | | 0.0635 | | 0.0626*** | | 0.0741 | | 0.0180 | | 0.0025 | | -0.0036 | | -0.0301 |
| | | (0.0780) | | (0.0240) | | (0.0457) | | (0.0241) | | (0.0104) | | (0.0289) | | (0.0297) |
| Monthly nonupwind fires | | -0.0442 | | -0.0259*** | | -0.0383** | | -0.0056 | | -0.0019 | | -0.0045 | | 0.0073 |
| | | (0.0270) | | (0.0086) | | (0.0189) | | (0.0073) | | (0.0034) | | (0.0087) | | (0.0093) |
| Dependent variable mean | 57.39 | | 6.37 | | 17.30 | | 8.24 | | 1.99 | | 16.31 | | 13.38 | |
| Observations | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 |
| R-squared | 0.6278 | 0.6279 | 0.3143 | 0.3146 | 0.4824 | 0.4825 | 0.4186 | 0.4186 | 0.2980 | 0.2981 | 0.5254 | 0.5254 | 0.3495 | 0.3495 |
| Municipality and Month/Year Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Weather Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

Notes: Table 4 shows the effects of monthly high-intensity fires on monthly respiratory hospitalizations for different age groups. Panel A uses the total number of monthly fires, and Panel B differentiates upwind from nonupwind fires. Weather controls include monthly average temperature, humidity and cumulative rainfall. Robust standard errors in parentheses are clustered at the municipality level.
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**Table 5: Effects of high-intensity fires on monthly circulatory hospitalizations for different age groups**

| | Full sample | | Infants | | Children 1-5 | | Children 6-12 | | Teenagers | | Adults | | Elderly | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) |
| **Panel A: All fires** | | | | | | | | | | | | | | |
| Monthly fires | -0.0117 | | -0.0003 | | -0.0006 | | -0.0008 | | -0.0009 | | -0.0080 | | -0.0013 | |
| | (0.0099) | | (0.0004) | | (0.0006) | | (0.0008) | | (0.0012) | | (0.0067) | | (0.0073) | |
| **Panel B: Differentiating upwind and nonupwind fires** | | | | | | | | | | | | | | |
| Monthly upwind fires | | 0.0445 | | 0.0003 | | -0.0014 | | 0.0112* | | 0.0033 | | 0.0123 | | 0.0180 |
| | | (0.0521) | | (0.0015) | | (0.0025) | | (0.0067) | | (0.0044) | | (0.0394) | | (0.0338) |
| Monthly nonupwind fires | | -0.0226 | | -0.0004 | | -0.0005 | | -0.0032** | | -0.0017* | | -0.0120 | | -0.0050 |
| | | (0.0138) | | (0.0005) | | (0.0009) | | (0.0016) | | (0.0009) | | (0.0099) | | (0.0109) |
| Dependent variable mean | 31.72 | | 0.17 | | 0.36 | | 0.27 | | 0.26 | | 15.23 | | 15.54 | |
| Observations | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 | 18,504 |
| R-squared | 0.4773 | 0.4773 | 0.0711 | 0.0711 | 0.0699 | 0.0699 | 0.0534 | 0.0538 | 0.0517 | 0.0517 | 0.3327 | 0.3327 | 0.3959 | 0.3959 |
| Municipality and Month/Year Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Weather Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

Notes: Table 5 shows the effects of monthly high-intensity fires on monthly circulatory hospitalizations for different age groups. Panel A uses the total number of monthly fires, and Panel B differentiates upwind from nonupwind fires. Weather controls include monthly average temperature, humidity and cumulative rainfall. Robust standard errors in parentheses are clustered at the municipality level.

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**Table 6: Effects of high-intensity fires on monthly deaths for different age groups**

| | Full sample | | Infants | | Children 1-5 | | Children 6-12 | | Teenagers | | Adults | | Elderly | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) |
| **Panel A: All fires** | | | | | | | | | | | | | | |
| Monthly fires | -0.0016 | | -0.0059** | | -0.0016 | | -0.0003 | | -0.0000 | | 0.0077 | | -0.0023 | |
| | (0.0107) | | (0.0025) | | (0.0015) | | (0.0006) | | (0.0014) | | (0.0066) | | (0.0079) | |
| Monthly lagged fires | -0.0107 | | -0.0035 | | -0.0009 | | -0.0017** | | 0.0010 | | -0.0087 | | 0.0011 | |
| | (0.0150) | | (0.0025) | | (0.0021) | | (0.0008) | | (0.0020) | | (0.0082) | | (0.0098) | |
| **Panel B: Differentiating upwind and nonupwind fires** | | | | | | | | | | | | | | |
| Monthly upwind fires | | -0.0019 | | -0.0161 | | 0.0034 | | -0.0011 | | 0.0030 | | 0.0369 | | -0.0310 |
| | | (0.0585) | | (0.0135) | | (0.0065) | | (0.0034) | | (0.0065) | | (0.0373) | | (0.0353) |
| Monthly nonupwind fires | | -0.0014 | | -0.0039 | | -0.0026 | | -0.0001 | | -0.0007 | | 0.0021 | | 0.0034 |
| | | (0.0170) | | (0.0039) | | (0.0023) | | (0.0010) | | (0.0023) | | (0.0092) | | (0.0107) |
| Monthly lagged upwind fires | | 0.0850 | | -0.0110 | | 0.0144* | | -0.0040 | | -0.0052 | | 0.0870** | | 0.0131 |
| | | (0.0585) | | (0.0119) | | (0.0076) | | (0.0031) | | (0.0080) | | (0.0341) | | (0.0412) |
| Monthly lagged nonupwind fires | | -0.0293 | | -0.0021 | | -0.0039* | | -0.0013 | | 0.0022 | | -0.0268*** | | -0.0017 |
| | | (0.0188) | | (0.0032) | | (0.0023) | | (0.0013) | | (0.0035) | | (0.0102) | | (0.0128) |
| Dependent variable mean | 43.93 | | 2.31 | | 0.77 | | 0.33 | | 0.58 | | 16.33 | | 24.01 | |
| Observations | 17,733 | 17,733 | 17,733 | 17,733 | 17,733 | 17,733 | 17,733 | 17,733 | 17,733 | 17,733 | 17,733 | 17,733 | 17,733 | 17,733 |
| R-squared | 0.1902 | 0.1903 | 0.1406 | 0.1406 | 0.1285 | 0.1287 | 0.0610 | 0.0610 | 0.0547 | 0.0548 | 0.1171 | 0.1175 | 0.1793 | 0.1793 |
| Municipality and Month/Year Fixed Effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Weather Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

Notes: Table 6 shows the effects of monthly high-intensity fires on monthly deaths for different age groups. Panel A uses the total number of monthly fires, and Panel B differentiates upwind from nonupwind fires. Weather controls include monthly average temperature, humidity and cumulative rainfall. Robust standard errors in parentheses are clustered at the municipality level.

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**Table 7: Heterogeneous effects of high-intensity fires on hospitalizations by age group w.r.t number of community health centers**

| | **Full sample**<br>(1) | **Infants**<br>(2) | **Children 1-5**<br>(3) | **Children 6-12**<br>(4) | **Teenagers**<br>(5) | **Adults**<br>(6) | **Elderly**<br>(7) |
|---|---|---|---|---|---|---|---|
| **Panel A: Few Community Health Centers** | | | | | | | |
| Monthly upwind fires | 1.4930*** | 0.1240* | 0.2625* | 0.2322*** | 0.1294 | 0.7542* | 0.0820 |
| | (0.5496) | (0.0683) | (0.1349) | (0.0879) | (0.1081) | (0.4082) | (0.1369) |
| Monthly nonupwind fires | -0.2412* | -0.0268 | -0.0790 | -0.0399 | 0.0169 | -0.1279 | -0.0127 |
| | (0.1366) | (0.0204) | (0.0503) | (0.0305) | (0.0203) | (0.0912) | (0.0329) |
| Dependent Variable Mean | 466.15 | 18.88 | 41.59 | 29.91 | 31.61 | 287.92 | 70.08 |
| Observations | 9,240 | 9,240 | 9,240 | 9,240 | 9,240 | 9,240 | 9,240 |
| R-squared | 0.6949 | 0.3092 | 0.4792 | 0.3340 | 0.3277 | 0.6329 | 0.4978 |
| **Panel B: Many Community Health Centers** | | | | | | | |
| Monthly upwind fires | 0.2586 | 0.0560 | 0.0398 | 0.0089 | 0.0730 | -0.0185 | 0.1455 |
| | (0.4279) | (0.0409) | (0.0978) | (0.0787) | (0.0654) | (0.2693) | (0.0994) |
| Monthly nonupwind fires | -0.0418 | -0.0335** | -0.0079 | 0.0285 | -0.0114 | -0.0336 | -0.0083 |
| | (0.1106) | (0.0131) | (0.0298) | (0.0230) | (0.0194) | (0.0775) | (0.0336) |
| Dependent Variable Mean | 544.82 | 23.27 | 56.06 | 38.80 | 39.72 | 328.60 | 77.16 |
| Observations | 9,264 | 9,264 | 9,264 | 9,264 | 9,264 | 9,264 | 9,264 |
| R-squared | 0.7861 | 0.4627 | 0.6161 | 0.5512 | 0.4764 | 0.7351 | 0.6589 |

Notes: Table 7 shows the heterogeneous effects of monthly upwind and nonupwind fires on monthly hospital admissions for different age groups depending on the number of community health centers. Municipalities with few community health centers are defined as places with the number of health centers per capita below the median for the region. Municipalities with many community health centers are defined as places with the number of health centers per capita above the median for the region. Weather controls include monthly average temperature, humidity and cumulative rainfall. Robust standard errors in parentheses are clustered at the municipality level.

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## Table 8: Heterogeneous effects of high-intensity fires on respiratory hospitalizations for infants and children w.r.t number of community health centers

| | **Infants**<br>(1) | **Children 1-5**<br>(2) | **Children 6-12**<br>(3) |
|---|---|---|---|
| **Panel A: Few Community Health Centers** | | | |
| Monthly upwind fires | 0.0968** | 0.1365* | 0.0583 |
| | (0.0402) | (0.0744) | (0.0358) |
| Monthly nonupwind fires | -0.0406*** | -0.0658** | -0.0193* |
| | (0.0141) | (0.0303) | (0.0103) |
| Dependent Variable Mean | 5.43 | 14.82 | 7.20 |
| Observations | 9,240 | 9,240 | 9,240 |
| R-squared | 0.2394 | 0.3886 | 0.2994 |
| **Panel B: Many Community Health Centers** | | | |
| Monthly upwind fires | 0.0253 | 0.0161 | 0.0199 |
| | (0.0224) | (0.0477) | (0.0349) |
| Monthly nonupwind fires | -0.0142** | -0.0174 | -0.0043 |
| | (0.0072) | (0.0154) | (0.0128) |
| Dependent Variable Mean | 7.50 | 20.58 | 10.27 |
| Observations | 9,264 | 9,264 | 9,264 |
| R-squared | 0.3723 | 0.5358 | 0.4843 |

Notes: Table 8 shows the heterogeneous effects of monthly upwind and nonupwind fires on monthly respiratory hospitalizations for infants and children, depending on the number of community health centers. Municipalities with few community health centers are defined as places with the number of health centers per capita below the median for the region. Municipalities with many community health centers are defined as places with the number of health centers per capita above the median for the region. Weather controls include monthly average temperature, humidity and cumulative rainfall. Robust standard errors in parentheses are clustered at the municipality level.

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## Table 9: Heterogeneous effects of high-intensity fires on circulatory hospitalizations for children w.r.t number of community health centers

| | **Children 6-12** |
|---|---|
| **Panel A: Few Community Health Centers** | |
| Monthly upwind fires | 0.0283* |
| | (0.0147) |
| Monthly nonupwind fires | -0.0079*** |
| | (0.0028) |
| Dependent Variable Mean | 0.28 |
| Observations | 9,240 |
| R-squared | 0.0519 |
| **Panel B: Many Community Health Centers** | |
| Monthly upwind fires | 0.0005 |
| | (0.0018) |
| Monthly nonupwind fires | -0.0000 |
| | (0.0009) |
| Dependent Variable Mean | 0.27 |
| Observations | 9,264 |
| R-squared | 0.0582 |

Notes: Table 9 shows the heterogeneous effects of monthly upwind and nonupwind fires on monthly circulatory hospitalizations for children aged between 6 and 12, depending on the number of community health centers. Municipalities with few community health centers are defined as places with the number of health centers per capita below the median for the region. Municipalities with many community health centers are defined as places with the number of health centers per capita above the median for the region. Weather controls include monthly average temperature, humidity and cumulative rainfall. Robust standard errors in parentheses are clustered at the municipality level.

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**Table 10: Heterogeneous effects of high-intensity fires on monthly deaths w.r.t number of community health centers**

| | **Full sample**<br>(1) | **Infants**<br>(2) | **Children 1-5**<br>(3) | **Children 6-12**<br>(4) | **Teenagers**<br>(5) | **Adults**<br>(6) | **Elderly**<br>(7) |
|---|---|---|---|---|---|---|---|
| **Panel A: Few Community Health Centers** | | | | | | | |
| Monthly upwind fires | -0.0000 | -0.0155 | -0.0015 | -0.0030 | -0.0056 | 0.1105 | -0.0923 |
| | (0.1014) | (0.0221) | (0.0086) | (0.0045) | (0.0090) | (0.0679) | (0.0656) |
| Monthly nonupwind fires | -0.0221 | -0.0094 | -0.0012 | 0.0009 | -0.0038 | -0.0047 | -0.0041 |
| | (0.0244) | (0.0057) | (0.0031) | (0.0012) | (0.0032) | (0.0140) | (0.0157) |
| Monthly lagged upwind fires | 0.1378 | -0.0008 | 0.0245* | -0.0044 | -0.0039 | 0.1148* | 0.0213 |
| | (0.1063) | (0.0175) | (0.0125) | (0.0050) | (0.0159) | (0.0628) | (0.0769) |
| Monthly lagged nonupwind fires | -0.0211 | -0.0020 | -0.0089*** | 0.0001 | 0.0065 | -0.0391** | 0.0161 |
| | (0.0298) | (0.0051) | (0.0026) | (0.0021) | (0.0063) | (0.0160) | (0.0215) |
| Dependent Variable Mean | 45.40 | 2.20 | 0.71 | 0.30 | 0.58 | 16.80 | 25.20 |
| Observations | 8,855 | 8,855 | 8,855 | 8,855 | 8,855 | 8,855 | 8,855 |
| R-squared | 0.1529 | 0.1078 | 0.1162 | 0.0481 | 0.0476 | 0.0988 | 0.1475 |
| **Panel B: Many Community Health Centers** | | | | | | | |
| Monthly upwind fires | -0.0200 | -0.0192 | 0.0056 | 0.0008 | 0.0081 | -0.0209 | 0.0046 |
| | (0.0677) | (0.0171) | (0.0094) | (0.0051) | (0.0095) | (0.0377) | (0.0404) |
| Monthly nonupwind fires | 0.0242 | 0.0019 | -0.0034 | -0.0013 | 0.0030 | 0.0100 | 0.0138 |
| | (0.0206) | (0.0054) | (0.0034) | (0.0016) | (0.0031) | (0.0112) | (0.0135) |
| Monthly lagged upwind fires | 0.0464 | -0.0188 | 0.0045 | -0.0026 | -0.0047 | 0.0598* | 0.0130 |
| | (0.0612) | (0.0157) | (0.0085) | (0.0040) | (0.0050) | (0.0343) | (0.0424) |
| Monthly lagged nonupwind fires | -0.0393* | -0.0026 | 0.0015 | -0.0029** | -0.0025 | -0.0135 | -0.0217 |
| | (0.0236) | (0.0035) | (0.0032) | (0.0013) | (0.0016) | (0.0108) | (0.0145) |
| Dependent Variable Mean | 42.46 | 2.43 | 0.83 | 0.36 | 0.58 | 15.86 | 22.82 |
| Observations | 8,878 | 8,878 | 8,878 | 8,878 | 8,878 | 8,878 | 8,878 |
| R-squared | 0.2465 | 0.1821 | 0.1476 | 0.0775 | 0.0706 | 0.1477 | 0.2282 |

Notes: Table 10 shows the heterogeneous effects of monthly upwind and nonupwind fires on monthly deaths for different age groups depending on the number of community health centers. Municipalities with few community health centers are defined as places with the number of health centers per capita below the median for the region. Municipalities with many community health centers are defined as places with the number of health centers per capita above the median for the region.

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## Table 11: Heterogeneous effects of high-intensity fires on monthly deaths for children and adults w.r.t number of clinical doctors

| | **Children 1-5**<br>(1) | **Adults**<br>(2) |
|---|---|---|
| **Panel A: Few Clinicians** | | |
| Monthly upwind fires | 0.0045 | 0.0857 |
| | (0.0097) | (0.0720) |
| Monthly nonupwind fires | -0.0000 | -0.0098 |
| | (0.0032) | (0.0126) |
| Monthly lagged upwind fires | 0.0301** | 0.1525** |
| | (0.0126) | (0.0593) |
| Monthly lagged nonupwind fires | -0.0099*** | -0.0517*** |
| | (0.0017) | (0.0140) |
| Dependent Variable Mean | 0.74 | 15.07 |
| Observations | 8,855 | 8,855 |
| R-squared | 0.0824 | 0.1156 |
| **Panel B: Many Clinicians** | | |
| Monthly upwind fires | 0.0008 | -0.0018 |
| | (0.0087) | (0.0385) |
| Monthly nonupwind fires | -0.0041 | 0.0136 |
| | (0.0034) | (0.0120) |
| Monthly lagged upwind fires | 0.0048 | 0.0452 |
| | (0.0087) | (0.0386) |
| Monthly lagged nonupwind fires | 0.0008 | -0.0070 |
| | (0.0036) | (0.0119) |
| Dependent Variable Mean | 0.80 | 17.58 |
| Observations | 8,878 | 8,878 |
| R-squared | 0.1683 | 0.1083 |

Notes: Table 11 shows the heterogeneous effects of monthly upwind and nonupwind fires on monthly deaths for children under five and adults, depending on the number of clinical doctors. Municipalities with few clinicians are defined as places with the per capita number of clinicians within the public healthcare system below the median for the region. Municipalities with many clinicians are defined as places with the per capita number of clinicians within the public healthcare system above the median for the region.

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# Appendix

**Table A1: Effects of high-intensity fires on air pollution using different degrees to define upwind and nonupwind fires**

| | Particulate Matter (PM2.5) | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| **All fires** | | | | | |
| Monthly fires | 0.0911***<br>(0.0138) | | | | |
| **Differentiating upwind and nonupwind fires using 30 degrees** | | | | | |
| Monthly upwind fires | | 0.2568***<br>(0.0662) | | | |
| Monthly nonupwind fires | | 0.0639***<br>(0.0155) | | | |
| **Differentiating upwind and nonupwind fires using 35 degrees** | | | | | |
| Monthly upwind fires | | | 0.2407***<br>(0.0607) | | |
| Monthly nonupwind fires | | | 0.0621***<br>(0.0158) | | |
| **Differentiating upwind and nonupwind fires using 40 degrees** | | | | | |
| Monthly upwind fires | | | | 0.2334***<br>(0.0576) | |
| Monthly nonupwind fires | | | | 0.0584***<br>(0.0162) | |
| **Differentiating upwind and nonupwind fires using 45 degrees** | | | | | |
| Monthly upwind fires | | | | | 0.2117***<br>(0.0519) |
| Monthly nonupwind fires | | | | | 0.0588***<br>(0.0168) |
| Observations | 18,528 | 18,528 | 18,528 | 18,528 | 18,528 |
| R-squared | 0.5793 | 0.5804 | 0.5804 | 0.5805 | 0.5804 |
| Municipality and Month/Year Effects | Yes | Yes | Yes | Yes | Yes |
| Weather Controls | Yes | Yes | Yes | Yes | Yes |

Notes: Table A1 shows the effects of high-intensity fires on average monthly air pollution 50km around municipalities' city centers using different degrees to define upwind and nonupwind fires. Weather controls include monthly average temperature, humidity and cumulative rainfall. Robust standard errors in parentheses are clustered at the municipality level.

## Table A2: Effects of high-intensity fires on air pollution using INPE's data on PM2.5

| | Particulate Matter (PM2.5) | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| **Panel A: All fires** | | | | |
| Monthly fires | 0.3519*** | 0.3423*** | | |
| | (0.0325) | (0.0326) | | |
| **Panel B: Differentiating upwind and nonupwind fires** | | | | |
| Monthly upwind fires | | | 0.5883*** | 0.5755*** |
| | | | (0.1339) | (0.1331) |
| Monthly nonupwind fires | | | 0.3062*** | 0.2970*** |
| | | | (0.0450) | (0.0449) |
| Observations | 18,528 | 18,528 | 18,528 | 18,528 |
| R-squared | 0.4424 | 0.4488 | 0.4448 | 0.4511 |
| Municipality and Month/Year Fixed Effects | Yes | Yes | Yes | Yes |
| Weather Controls | No | Yes | No | Yes |

Notes: Table A2 shows the effects of monthly high-intensity fires on monthly fine particulate matter (PM2.5) concentrations (in µg/m$^3$) using air pollution data at the municipality level. Weather controls include monthly average temperature, humidity and cumulative rainfall. Robust standard errors in parentheses are clustered at the municipality level.

## Table A3: Heterogeneous effects of high-intensity fires on respiratory hospitalizations for infants and children w.r.t presence of community health centers

| | **Infants**<br>(1) | **Children 1-5**<br>(2) | **Children 6-12**<br>(3) |
|---|---|---|---|
| **Panel A: No Community Health Center** | | | |
| Monthly upwind fires | 0.1046** | 0.1209 | 0.0618 |
| | (0.0426) | (0.0770) | (0.0400) |
| Monthly nonupwind fires | -0.0503*** | -0.0796** | -0.0172 |
| | (0.0155) | (0.0337) | (0.0118) |
| Observations | 7,320 | 7,320 | 7,320 |
| R-squared | 0.2191 | 0.3659 | 0.2774 |
| **Panel B: With Community Health Center** | | | |
| Monthly upwind fires | 0.0244 | 0.0295 | 0.0208 |
| | (0.0209) | (0.0431) | (0.0323) |
| Monthly nonupwind fires | -0.0092 | -0.0104 | -0.0059 |
| | (0.0066) | (0.0146) | (0.0111) |
| Observations | 11,184 | 11,184 | 11,184 |
| R-squared | 0.3718 | 0.5288 | 0.4786 |

Notes: Table A3 shows the heterogeneous effects of monthly upwind and nonupwind fires on monthly respiratory hospitalizations for infants and children, depending on the presence of community health centers. Weather controls include monthly average temperature, humidity and cumulative rainfall. Robust standard errors in parentheses are clustered at the municipality level.

## Table A4: Heterogeneous effects of high-intensity fires on circulatory hospitalizations for children aged 6 to 12 w.r.t presence of community health centers

| | **Children 6-12** |
|---|---|
| **Panel A: No Community Health Center** | |
| Monthly upwind fires | 0.0158* |
| | (0.0087) |
| Monthly nonupwind fires | -0.0044** |
| | (0.0017) |
| Observations | 7,320 |
| R-squared | 0.0496 |
| **Panel B: With Community Health Center** | |
| Monthly upwind fires | 0.0008 |
| | (0.0013) |
| Monthly nonupwind fires | -0.0001 |
| | (0.0003) |
| Observations | 11,184 |
| R-squared | 0.0568 |

Notes: Table A4 shows the heterogeneous effects of monthly upwind and nonupwind fires on monthly circulatory hospitalizations for children aged between 6 and 12, depending on the presence of community health centers. Weather controls include monthly average temperature, humidity and cumulative rainfall. Robust standard errors in parentheses are clustered at the municipality level.

### Table A5: Heterogeneous effects of high-intensity fires on respiratory hospitalizations for infants and children w.r.t number of clinical doctors

| | **Infants**<br>(1) | **Children 1-5**<br>(2) | **Children 6-12**<br>(3) |
|---|---|---|---|
| **Panel A: Few Clinicians** | | | |
| Monthly upwind fires | 0.0814* | 0.1167 | 0.0404 |
| | (0.0473) | (0.0943) | (0.0429) |
| Monthly nonupwind fires | -0.0330* | -0.0585 | -0.0068 |
| | (0.0174) | (0.0357) | (0.0147) |
| Observations | 9,240 | 9,240 | 9,240 |
| R-squared | 0.3161 | 0.5055 | 0.4579 |
| **Panel B: Many Clinicians** | | | |
| Monthly upwind fires | 0.0478** | 0.0478 | 0.0292 |
| | (0.0220) | (0.0410) | (0.0324) |
| Monthly nonupwind fires | -0.0272*** | -0.0363*** | -0.0193** |
| | (0.0066) | (0.0135) | (0.0090) |
| Observations | 9,264 | 9,264 | 9,264 |
| R-squared | 0.3149 | 0.4587 | 0.3658 |

Notes: Table A5 shows the heterogeneous effects of monthly upwind and nonupwind fires on respiratory hospitalizations for infants and children depending on the number of clinical doctors. Municipalities with few clinicians are defined as places with the per capita number of clinicians within the public healthcare system below the median for the region. Municipalities with many clinicians are defined as places with the per capita number of clinicians within the public healthcare system above the median for the region. Weather controls include monthly average temperature, humidity and cumulative rainfall. Robust standard errors in parentheses are clustered at the municipality level.

## Table A6: Heterogeneous effects of high-intensity fires on circulatory hospitalizations for children aged 6 to 12 w.r.t number of clinical doctors

| | **Children 6-12** |
|---|---|
| **Panel A: Few Clinicians** | |
| Monthly upwind fires | 0.0305*<br>(0.0163) |
| Monthly nonupwind fires | -0.0076**<br>(0.0034) |
| Observations | 9,240 |
| R-squared | 0.0518 |
| **Panel B: Many Clinicians** | |
| Monthly upwind fires | 0.0001<br>(0.0021) |
| Monthly nonupwind fires | -0.0001<br>(0.0008) |
| Observations | 9,264 |
| R-squared | 0.0609 |

Notes: Table A6 shows the heterogeneous effects of monthly upwind and nonupwind fires on circulatory hospitalizations for children aged between 6 and 12, depending on the number of clinical doctors. Municipalities with few clinicians are defined as places with the per capita number of clinicians within the public healthcare system below the median for the region. Municipalities with many clinicians are defined as places with the per capita number of clinicians within the public healthcare system above the median for the region. Weather controls include monthly average temperature, humidity and cumulative rainfall. Robust standard errors in parentheses are clustered at the municipality level.

## Table A7: Heterogeneous effects of high-intensity fires on adult mortality w.r.t number of public hospital beds

| | **Adults** |
|---|---|
| **Panel A: Few Hospital Beds** | |
| Monthly upwind fires | 0.0799 |
| | (0.0679) |
| Monthly nonupwind fires | 0.0030 |
| | (0.0150) |
| Monthly lagged upwind fires | 0.2061*** |
| | (0.0590) |
| Monthly lagged nonupwind fires | -0.0493*** |
| | (0.0125) |
| Observations | 8,855 |
| R-squared | 0.1030 |
| **Panel B: Many Hospital Beds** | |
| Monthly upwind fires | 0.0199 |
| | (0.0429) |
| Monthly nonupwind fires | -0.0017 |
| | (0.0113) |
| Monthly lagged upwind fires | 0.0171 |
| | (0.0434) |
| Monthly lagged nonupwind fires | -0.0113 |
| | (0.0168) |
| Observations | 8,878 |
| R-squared | 0.1429 |

Notes: Table A7 shows the heterogeneous effects of monthly upwind and nonupwind fires on adult mortality depending on the number of public hospital beds. Municipalities with hospital beds are defined as places with the per capita number of hospital beds within the public healthcare system below the median for the region. Municipalities with many hospital beds are defined as places with the per capita number of hospital beds within the public healthcare system above the median for the region. Weather controls include monthly average temperature, humidity and cumulative rainfall. Robust standard errors in parentheses are clustered at the municipality level.

## Table A8: Heterogeneous effects of high-intensity fires on adult mortality w.r.t number of public clinical hospital beds

| | **Adults** |
|---|---|
| **Panel A: Few Clinical Hospital Beds** | |
| Monthly upwind fires | 0.0677 |
| | (0.0647) |
| Monthly nonupwind fires | 0.0061 |
| | (0.0154) |
| Monthly lagged upwind fires | 0.1844*** |
| | (0.0619) |
| Monthly lagged nonupwind fires | -0.0425*** |
| | (0.0127) |
| Observations | 8,855 |
| R-squared | 0.1077 |
| **Panel B: Many Clinical Hospital Beds** | |
| Monthly upwind fires | 0.0221 |
| | (0.0443) |
| Monthly nonupwind fires | -0.0020 |
| | (0.0112) |
| Monthly lagged upwind fires | 0.0243 |
| | (0.0445) |
| Monthly lagged nonupwind fires | -0.0155 |
| | (0.0166) |
| Observations | 8,878 |
| R-squared | 0.1337 |

Notes: Table A8 shows the heterogeneous effects of monthly upwind and nonupwind fires on adult mortality depending on the number of public clinical hospital beds. Municipalities with few clinical hospital beds are defined as places with the per capita number of clinical hospital beds within the public healthcare system below the median for the region. Municipalities with many clinical hospital beds are defined as places with the per capita number of clinical hospital beds within the public healthcare system above the median for the region. Weather controls include monthly average temperature, humidity and cumulative rainfall. Robust standard errors in parentheses are clustered at the municipality level.

## Table A9: Heterogeneous effects of high-intensity fires on adult mortality w.r.t number of general hospitals

| | **Adults** |
|---|---|
| **Panel A: Few General Hospitals** | |
| Monthly upwind fires | 0.0841 |
| | (0.0672) |
| Monthly nonupwind fires | 0.0068 |
| | (0.0161) |
| Monthly lagged upwind fires | 0.1060** |
| | (0.0532) |
| Monthly lagged nonupwind fires | -0.0524*** |
| | (0.0130) |
| Observations | 8,855 |
| R-squared | 0.0915 |
| **Panel B: Many General Hospitals** | |
| Monthly upwind fires | 0.0047 |
| | (0.0463) |
| Monthly nonupwind fires | 0.0031 |
| | (0.0119) |
| Monthly lagged upwind fires | 0.0574 |
| | (0.0492) |
| Monthly lagged nonupwind fires | -0.0113 |
| | (0.0161) |
| Observations | 8,878 |
| R-squared | 0.1661 |

Notes: Table A9 shows the heterogeneous effects of monthly upwind and nonupwind fires on adult mortality depending on the number of general hospitals. Municipalities with few general hospitals are defined as places with a per capita number of general hospitals below the median for the region. Municipalities with many general hospitals are defined as places with a per capita number of general hospitals above the median for the region. Weather controls include monthly average temperature, humidity and cumulative rainfall. Robust standard errors in parentheses are clustered at the municipality level.

### Table A10: Heterogeneous effects of high-intensity fires on adult mortality w.r.t presence of general hospitals

| | **Adults** |
|---|---|
| **Panel A: No General Hospital** | |
| Monthly upwind fires | 0.1086 |
| | (0.1350) |
| Monthly nonupwind fires | 0.0092 |
| | (0.0270) |
| Monthly lagged upwind fires | 0.1980** |
| | (0.0911) |
| Monthly lagged nonupwind fires | -0.0783*** |
| | (0.0206) |
| Observations | 6,256 |
| R-squared | 0.0798 |
| **Panel B: With General Hospital** | |
| Monthly upwind fires | 0.0148 |
| | (0.0358) |
| Monthly nonupwind fires | 0.0029 |
| | (0.0090) |
| Monthly lagged upwind fires | 0.0422 |
| | (0.0380) |
| Monthly lagged nonupwind fires | -0.0109 |
| | (0.0125) |
| Observations | 11,477 |
| R-squared | 0.1774 |

Notes: Table A10 shows the heterogeneous effects of monthly upwind and nonupwind fires on adult mortality depending on the presence of general hospitals. Weather controls include monthly average temperature, humidity and cumulative rainfall. Robust standard errors in parentheses are clustered at the municipality level.