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The effect of wildfire smoke exposure on student performance: A nationwide study across two decades (2000–2020) and over 40 million students in Brazil

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Highlights

- We conducted a nationwide study of more than 40 million high school students.

- Wildfires were associated with a decrease of 0.33 % in essay.

- Wildfires were associated with a decrease of 0.54 % in general subjects.

Abstract

The impact of wildfire smoke exposure on public health has been extensively studied, yet its potential consequences on academic performance remain relatively unexplored, particularly in the context of fire-prone regions, such as Brazil. We conducted a nationwide study of more than 40 million high school students in Brazil who took the National High School Exam (ENEM) between 2000 and 2020. We used mixed-effects regression models with state-specific random intercepts to examine the associations between the wildfire events and academic performance among Brazilian students. We accounted for multiple covariates, including socioeconomic status, spatiotemporal factors, air pollutants, and weather variables. We also explored the effect modification by exam subject (general subjects and essay), school management (private and public schools), location (urban and rural schools), and time period. Our findings suggest that increased wildfire events are associated with lower academic performance in both essay and general subjects. After adjustments for the covariates, the primary analysis results indicate a negative impact of wildfires on essay writing, with an estimated coefficient of −0.09 (95 % CI: −0.13; −0.05) with 100 wildfire records increase. Similarly, an increase of 100 wildfire records per year corresponded to a decrease of 0.10 (95 % CI: 0.06; 0.11) points for general subjects. This effect on academic performance was associated with a reduction of 0.33 % (95 %CI: 0.31 %; 0.34 %) in essay and 0.54 % (95 %CI: 0.52 %; 0.56 %) in general subjects. Our findings highlight the need for further attention to the influence of wildfire smoke exposure on student academic performance, suggesting that even small associations at the individual level could have broader implications for public health and education policies.

Introduction

Wildfires are a recurring environmental hazard that poses multifaceted challenges to societies worldwide, affecting not only natural ecosystems (Kala, 2023) but also human health and well-being (Sanderfoot et al., 2022). The escalation in wildfire frequency has been linked to declines in average regional air quality and an elevated occurrence of severe air pollution episodes (Liu et al., 2016, Requia et

al., 2019). This could be observed in the recent Canadian wildfires, which created hazardous air conditions in the northeastern United States (Tanne, 2023).

Fine particulate matter ($PM_{2.5}$) is the primary pollutant of public health concern emitted by wildfires. According to the National Emissions Inventory (NEI), in the United States, wildfires contributed to over 20 % of the total $PM_{2.5}$ emissions in 2014 (EPA, 2014). Studies have demonstrated that the chemical composition of $PM_{2.5}$ in wildfire smoke exhibits greater toxicity than that found in $PM_{2.5}$ from other sources (Aguilera et al., 2021, Wegesser et al., 2009). This heightened toxicity has direct implications for acute and chronic health outcomes, encompassing conditions like cardiorespiratory diseases and neurological impairments (Danielsen et al., 2011, Franzi et al., 2011, Hetland et al., 2004, Naeher et al., 2007, Wegesser et al., 2010). Particularly in the context of neurological impairments, emerging evidence suggests that $PM_{2.5}$ in wildfire smoke can exert a negative influence on various facets of cognitive function and brain health, encompassing memory consolidation, attention span, and executive functions (Cleland et al., 2022, Jalaludin et al., 2022, Power et al., 2016).

The relationship between wildfire smoke exposure and cognitive function prompts a closer examination of its potential ramifications within educational contexts. Given that cognitive abilities play a central role in academic achievement, scientists have often considered academic performance as a proxy for cognitive function in environmental health studies. Numerous epidemiological investigations have indicated connections between academic performance and various environmental exposures, including ambient air pollution (Balakrishnan and Tsaneva, 2021, Gardin and Requia, 2023, Mohai et al., 2011), temperature fluctuations (Dong et al., 2023, Mendell and Heath, 2005, Porras-Salazar et al., 2018, Wargocki et al., 2019), and green spaces (Leung et al., 2019; Requia et al., 2022b; Requia and Adams, 2022). However, even with the increasing recognition of the hazardous nature of wildfire-related air pollutants, a substantial gap remains in comprehensive epidemiological research that explores their long-term effects on neurological well-being, particularly in relation to academic performance. To our knowledge, only three studies have investigated the relationship between wildfire smoke exposure and learning outcomes. These studies include one in the United States that utilized standardized test scores as an outcome measure, covering 11,700 American school districts (Wen and Burke, 2022); another in the United States that examined the effects of short-term school closures due to wildfires among students attending 15,738 schools in California, suggesting that the school closures may impact academic performance (Miller and Hui, 2022); and a recent study conducted by our group in Brazil, in which we applied rigorous causal inference methods to estimate the effect of wildfire exposure on the academic performance of high school students across 1571 municipalities between 2009 and 2015, encompassing 8183 high schools (McGrath

et al., 2023). In our ongoing effort to address this literature gap, we conducted the current study to estimate the nationwide association between wildfire smoke exposure and student performance in a large dataset of over 40 million students in Brazil over a 21-year study period (2000–2020).

A significant difference from our previous study can be observed in the extent and level of detail of the data employed. In our prior research (McGrath et al., 2023), we relied on aggregated data from a substantial number of high schools in Brazil, encompassing 8183 institutions. However, in this current study, we have advanced our approach by employing individual student data, a dataset comprising a staggering 40,404,489 students. This shift from school-level aggregation to individual-level data provides a significantly more detailed and comprehensive understanding of the effects of wildfire smoke exposure on student performance, allowing for finer-grained analysis and insights into this critical public health issue.

Section snippets

Student-level academic performance

Data on student-level academic performance was obtained from the National Institute for Educational Research in Brazil, INEP (*Instituto Nacional de Estudos Educacionais Anísio Teixeira*), a governmental agency under the Brazilian Ministry of Education. We collected information from the High School National Exam, known as ENEM (*Exame Nacional do Ensino Médio*), which serves as a crucial university entrance test in Brazil. On average, approximately 4.5 million students take the ENEM annually, …

Results

Our study encompassed a student population of 40,404,489 individuals who participated in the ENEM examination in Brazil between 2000 and 2020. Within this study population, 48.65 % were male, while 51.35 % were female. Among these students, 18.29 % were enrolled in private high schools, while the majority, accounting for 81.71 %, attended public high schools. In terms of school location, the vast majority, specifically 97.85 %, attended high schools situated in urban areas, whereas 2.15 % of …

Discussion

Our study examined the impact of wildfire smoke exposure on the academic performance of students in Brazil. The findings suggest significant associations between increased wildfire events and reduced academic performance. These results underscore the complex challenges posed by wildfire smoke exposure, extending beyond immediate health concerns to affect educational outcomes, especially in fire-prone regions, such as Brazil. We highlight that over the last two decades, Brazil has experienced a …

Strengths and limitations

Our study has some strengths. First, we undertook a nationwide investigation encompassing over 40 million students, spanning a comprehensive 21-year duration from 2000 to 2020. This large sample size of our study endows it with significant statistical robustness. Second, the stratified sub-group analyses allowed us to gain further insights into the variability of the association between air pollution and academic performance based on different characteristics. For example, the impact of air …

Conclusion

Our study highlights the significant impact of wildfire smoke exposure on student academic performance in Brazil, reinforcing the need for proactive public health and environmental policy measures to safeguard the well-being of future generations. The unique environmental context of Brazil serves as a valuable case study, shedding light on the broader implications of wildfire smoke exposure worldwide. …

CRediT authorship contribution statement

Thiago N. Gardin: Writing – original draft, Visualization, Validation, Software, Formal analysis, Data curation. **Weeberb J. Requia:** Writing – review & editing, Validation, Supervision, Software, Resources, Methodology, Funding acquisition, Data curation, Conceptualization. …

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. …

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References (46)

U. Balakrishnan *et al.*

[Air pollution and academic performance: evidence from India](#)

World Dev. (2021)

I. Cobelo *et al.*

[The impact of wildfires on air pollution and health across land use categories in Brazil over a 16-year period](#)

Environ. Res. (2023)

H.R. Dinse *et al.*

[The stress hormone cortisol blocks perceptual learning in humans](#)

Psychoneuroendocrinology (2017)

L.M. Franzi *et al.*

[Why is particulate matter produced by wildfires toxic to lung macrophages?](#)

Toxicol. Appl. Pharm. (2011)

T.N. Gardin *et al.*

Air quality and individual-level academic performance in Brazil: A nationwide study of more than 15 million students between 2000 and 2020

Environ. Res (2023)

R.B. Hetland *et al.*

Release of inflammatory cytokines, cell toxicity and apoptosis in epithelial lung cells after exposure to ambient air particles of different size fractions

Toxicol. Vitr. (2004)

C.P. Kala

Environmental and socioeconomic impacts of forest fires: a call for multilateral cooperation and management interventions

Nat. Hazards Res. (2023)

S. McGrath *et al.*

Wildfire exposure and academic performance in Brazil: a causal inference approach for spatiotemporal data

Sci. Total Environ. (2023)

R. Nelson

US wildfires and mental illness stress health systems

Lancet (2020)

M.C. Power *et al.*

Exposure to air pollution as a potential contributor to cognitive function, cognitive decline, brain imaging, and dementia: a systematic review of epidemiologic research

Neurotoxicology (2016)

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