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SHORT RESEARCH AND DISCUSSION ARTICLE

A population under smoke: fire events trigger severe air pollution in Portugal

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Abstract
Our short communication aims to shed light on the critical health implications of the severe forest fires that occurred in Portugal in September 2024, highlighting the immediate surge in hospitalizations, the increase in mortality rates, and the long-term consequences for public health. Additionally, we emphasize the urgent need for updated public policies and air quality management strategies to effectively mitigate such crises in the future.

Keywords Forest fires · Air pollution · Public health · Air quality management · Climate crisis

Short communication

Portugal has faced a series of severe forest fires since 2002, with a significant intensification of events in the last 8 years, driven by rising temperatures and prolonged droughts linked to climate change (Senande-Rivera et al. 2025). One of the most tragic incidents occurred in 2017 in Pedrógão Grande, located in the central region of Portugal, where 66 individuals lost their lives, 47 of whom were trapped on a road surrounded by flames with no means of escape (Ribeiro et al. 2020). The 2017 fires prompted reassessing the forest management strategy for fire prevention. However, many felt the measures were insufficient and advocated more comprehensive approaches. Rural areas cover 92% of mainland Portugal, and inadequate forest management along with widespread eucalyptus, contribute to the country's history of wildfires, causing major economic and ecological losses. Earlier, the devastating fires of 2003, triggered by intense heatwaves, tragically claimed 21 lives (Trigo et al. 2006; Varela 2006; Tarín-Carrasco et al. 2021). This period coincided with a major heatwave that affected much of Europe during the first two weeks of August, with temperatures peaking on August 1 st, particularly in southern Portugal. Record highs were set, reaching the maximum of 47.3 °C in Amaraleja and the minimum of 30.1 °C in Portalegre (Ribeiro and Coutinho 2007), marking a significant escalation in both temperatures and pollutant levels, further intensifying the strain on public health systems and the environment. The Portuguese National Health Observatory reported a 43% rise in deaths from July 30 th to August 15 th, 2003 (Calado et al. 2004), compared to the seasonal average. Concerningly, these events are becoming more frequent, driven mainly by rising temperatures and the absence of effective predictive models and mitigation policies. These occurrences highlight the growing threat of climate change, as extreme heat and drought increasingly lead to fatal outcomes.

In addition to the tragic loss of lives, the health impacts of these fires extend far beyond the immediate fatalities. Increased hospital admissions and mortality from cardiovascular and respiratory diseases, linked to air pollution

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from the fires, are widely reported (Molina-Terrén et al. 2019; James et al. 2020; Tarín-Carrasco et al. 2021). The healthcare system faces the dual challenge of managing the acute surge in cases during fire events while addressing the long-term chronic health consequences that follow further straining resources. These subsequent chronic health impacts are often overlooked in global assessments of wildfire consequences.

Furthermore, beyond the immediate public health impacts, forest fires in Portugal have long-term ecological consequences, threatening biodiversity, increasing soil erosion and hindering ecosystem recovery. The destruction of carbon sinks exacerbates climate change, creating a vicious cycle where rising temperatures fuel more fires, releasing even greater amounts of carbon into the atmosphere.

Unfortunately, September 2024 witnessed severe wildfires across central and northern Portugal, with around 150,000 hectares burned and 450 active fires (Observador 2024). This dramatically boosted air pollutant levels, including NO_2, CO and particulates, primarily PM_{10} and $PM_{2.5}$, particulate matter with an aerodynamic diameter of less than 10 µm and 2.5 µm, respectively. We selected the 12 air quality monitoring stations based on their proximity to areas most affected by the September 2024 fires, which were primarily concentrated in northern and center of Portugal (Fig. 1). Although Portuguese network includes additional stations, those in surrounding regions did not show significant variations in pollutant concentrations during the study period and were therefore excluded from the analysis. This focused approach allowed us to capture the most relevant data related to the fire impact. Analysis of 12 air quality monitoring stations (Qualar 2024) showed daily PM_{10} averages ranging from 143 to 583 µg/m^3 and $PM_{2.5}$ levels between 115 and 180 µg/m^3, respectively 3.2- to 13-fold and 7.7- to 12-fold higher than World Health Organization (WHO) air quality guidelines 24-h average exposure (World Health Organization 2021). Maximum daily values were even more alarming, with PM_{10} peaking 2159 µg/m^3 and $PM_{2.5}$ 412 µg/m^3 at a station located northwest of Albergaria-a-Velha, the most affected city. These figures far exceed WHO air quality standards and the air quality legislation in Portugal (Decreto-Lei no 47/2017, de 10 de maio), as can be seen in Fig. 2. These fires directly

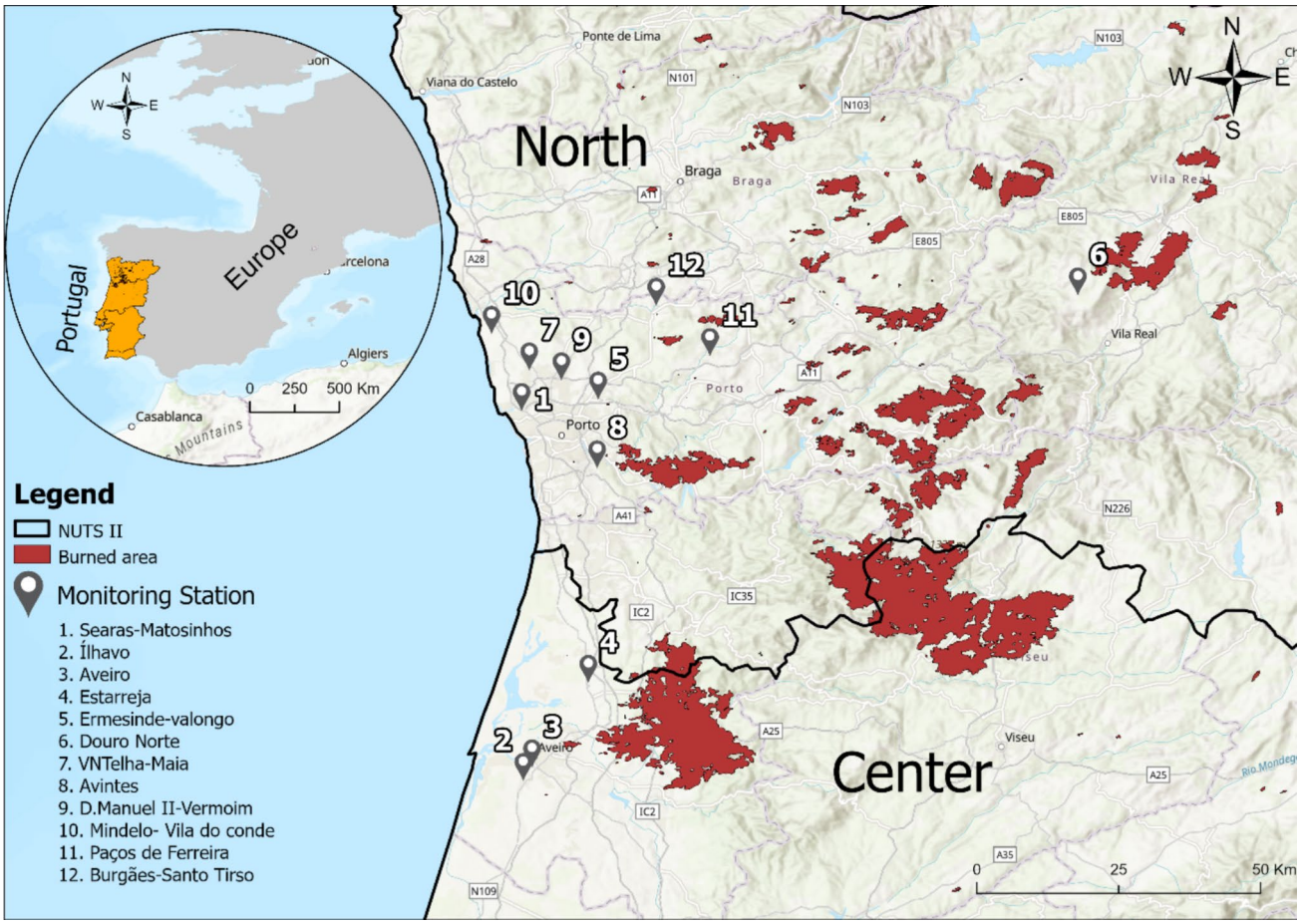

Fig. 1 The analyzed air quality monitoring stations and burned areas. The map was generated using ArcGIS Pro

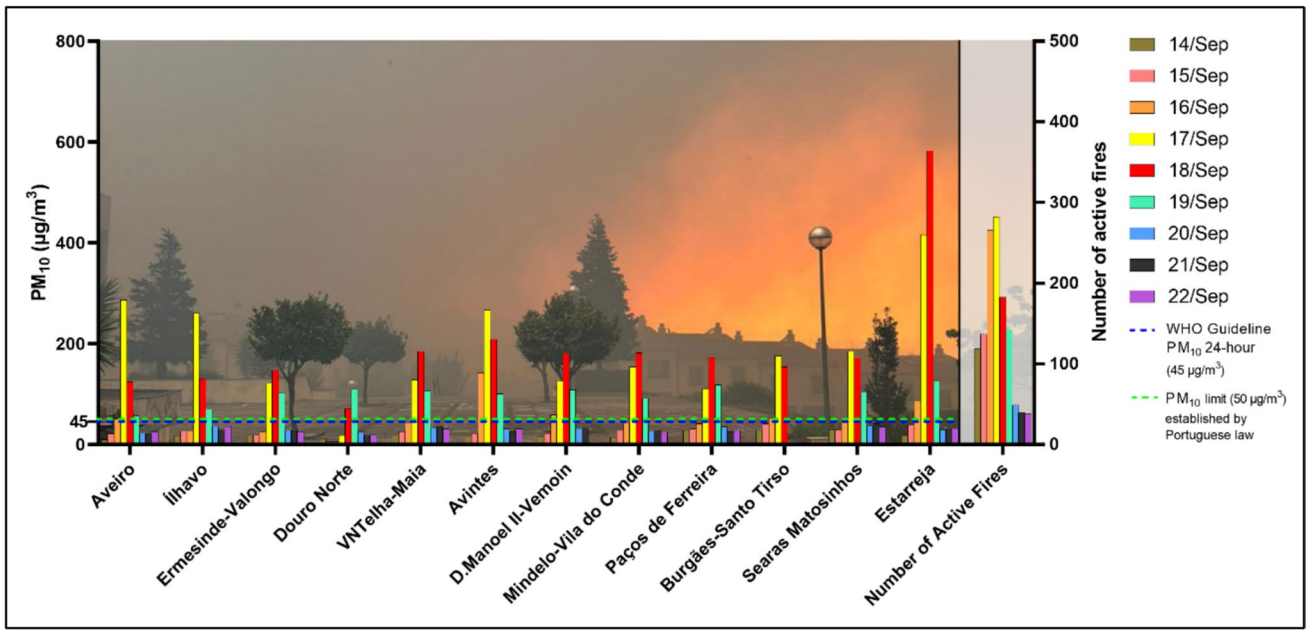

Fig. 2 PM_{10} average concentration (µg/m^3) and active fires from September 14 th to 22nd 2024. The background photograph was taken on September 17 th, 2024, captured by Sofia Ramos in the district of Gondomar, located in the metropolitan area of Porto, northern Portugal, and visually illustrates the severe atmospheric conditions caused by the fires. Data on PM_{10} concentration elaborated by the authors based on https://qualar.apambiente.pt/ (consulted on September 23rd 2024) (QUALAR 2024). Data on number of active fires elaborated by the authors based on https://fogos.pt/estatisticas (consulted on September 21.st 2024) (Fires 2024)

resulted in 9 deaths and injured 175 people, including both firefighters and civilians (Observador, 2024). However, the effects of short-term exposure to pollutants extend beyond the immediate aftermath, with impacts observed for up to 14 days following exposure to the elevated levels of air pollution caused by the fires (Yu et al. 2022). For comparison, an analysis of total daily mortality in northern Portugal during September for the years 2023 and 2024 revealed a statistically significant increase in mortality from September 16 th to 21 st, 2024, with an average increase of 9.3 deaths and a total increase of 56 deaths over this period (unpaired *T*-test analysis; *p*-value = 0.03), coinciding with the peak days of the fires. We utilized air quality monitoring data from the Portuguese agency Qualar, which provides daily measurements of key air pollutants. Similarly, daily mortality data were obtained from Statistics Portugal, while the number of active fires was sourced from Portuguese fire surveillance records.

Moreover, the need for protective public policies highlights the critical importance of accurate air quality assessments to develop effective protocols that prevent health injury. The absence of timely data hampers the creation of Health Impact Assessment (HIA) models, which are essential for building predictive frameworks to minimize the health impacts of air pollution, especially during extreme events like forest fires. Besides the impacts discussed in this brief communication, wildfire smoke exposure has been associated with significant mental health burdens, including anxiety, depression, and post-traumatic stress disorders (Eisenman and Galway 2022; Oerther et al. 2024), emphasizing the urgency of preparedness strategies. Given that extreme weather events are becoming more frequent and intense due to the current global climate crisis, strengthening the resilience of health care systems is crucial to ensuring an adequate response to upcoming emergencies.

Climate change is intensifying extreme weather events, leading to more frequent and severe wildfires (Stevens-Rumman et al. 2018; NASA 2025), particularly in temperate regions like Southern Europe, the western United States, and southeastern Australia. The Los Angeles wildfire of January 2025 exemplifies how rising temperatures, prolonged droughts, and shifting precipitation patterns create highly flammable conditions (Burki 2025). These factors, combined with human-induced land-use changes and increased fuel loads, underscore the growing wildfire risk driven by climate change.

Recent fire events underscore the urgent need to enhance forest management practices and develop robust national-level monitoring systems to mitigate climate change impacts. Actionable steps include implementing comprehensive crisis management plans that account for disturbance risks, strengthening early-warning systems through satellite and sensor-based monitoring, and regularly evaluating firefighting protocols. Together, these measures can foster proactive

conservation efforts and inform strategic environmental responses. Future research should focus on improving predictive models that integrate environmental and health data, as well as evaluating the effectiveness of early warning systems and mitigation strategies. Effective and well-designed strategies based on integrative efforts of the environmental and health sectors can significantly reduce the health burden and economic costs associated with critical air pollution episodes and promote community resilience.

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Data availability Raw data is available from the corresponding author upon reasonable request.

Declarations

Ethical approval Not applicable.

Consent to participate Not applicable.

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Competing interests The authors declare no competing interests.

References

Burki, Talha. "Wildfires in southern California: concerns for lung health." The Lancet Respiratory Medicine (2025). https://doi.org/10.1016/S2213-2600(25)00016-5

Calado R, Nogueira PJ, Catarino J, Paixão EDJ, Botelho J, Carreira M, Falcão JM (2004) The heat wave of August 2003 and its effects on mortality among the Portuguese population. Revista Portuguesa De Saúde Pública 22(2):7–20 ((in Portuguese))

Eisenman DP, Galway LP (2022) The mental health and well-being effects of wildfire smoke: a scoping review. BMC Public Health 22(1):2274. https://doi.org/10.1186/s12889-022-14662-z

Fires. Platform for monitoring and alerting rural fires in real time in Portugal. National Emergency and Civil Protection Authority. https://fogos.pt/estatisticas (consulted on September 21, 2024) (in Portuguese)

James SL, Lucchesi LR, Bisignano C, Castle CD, Dingels ZV, Fox JT, Hamilton EB, Henry NJ, McCracken D, Roberts NLS, Sylte DO, Ahmadi A, Ahmed MB, Alahdab F, Alipour V, Andualem Z, Antonio CAT, Arabloo J, Badiye AD, Bagherzadeh M, Banstola A, Bärnighausen TW, Barzegar A, Bayati M, Bhaumik S, Bijani A, Bukhman G, Carvalho F, Crowe CS, Dalal K, Daryani A, Nasab MD, Do HT, Do HP, Endries AY, Fernandes E, Filip I, Fischer F, Fukumoto T, Gebremedhin KBB, Gebremeskel GG, Gilani SA, Haagsma JA, Hamidi S, Hostiuc S, Househ M, Igumbor EU, Ilesanmi OS, Irvani SSN, Jayatilleke AU, Kahsay A, Kapoor N, Kasaeian A, Khader YS, Khalil IA, Khan EA, Khazaee-Pool M, Kokubo Y, Lopez AD, Madadin M, Majdan M, Maled V, Malekzadeh R, Manafi N, Manafi A, Mangalam S, Massenburg BB, Meles HG, Menezes RG, Meretoja TJ, Miazgowski B, Miller TR, Mohammadian-Hafshejani A, Mohammadpourhodki R, Morrison SD, Negoi I, Nguyen TH, Nguyen SH, Nguyen CT, Nixon MR, Olagunju AT, Olagunju TO, Padubidri JR, Polinder S, Rabiee N, Rabiee M, Radfar A, Rahimi-Movaghar V, Rawaf S, Rawaf DL, Rezapour A, Rickard J, Roro EM, Roy N, Safari-Faramani R, Salamati P, Samy AM, Satpathy M, Sawhney M, Schwebel DC, Senthilkumaran S, Sepanlou SG, Shigematsu M, Soheili A, Stokes MA, Tohidinik HR, Tran BX, Valdez PR, Wijeratne T, Yisma E, Zaidi Z, Zamani M, Zhang ZJ, Hay SI, Mokdad AH (2020) Epidemiology of injuries from fire, heat and hot substances: global, regional and national morbidity and mortality estimates from the Global Burden of Disease 2017 study. Inj Prev 26(Supp 1):i36–i45. https://doi.org/10.1136/injuryprev-2019-043299

Molina-Terrén DM, Xanthopoulos G, Diakakis M, Ribeiro L, Caballero D, Delogu GM, Viegas DX, Silva CA, Cardil A (2019) Analysis of forest fire fatalities in southern Europe: Spain, Portugal, Greece and Sardinia (Italy). Int J Wildland Fire 28(2):85–98. https://doi.org/10.1071/WF18004

NASA. National Aeronautics and Space Administration (2025). Wildfires and Climate Change. https://science.nasa.gov/wildfires-and-climate-change/ (consulted on March 07, 2024).

Observador. Fires. The most critical period ends this Monday and is marked by the fires that killed 9 people. https://observador.pt/2024/09/30/incendios-epoca-mais-critica-termina-esta-segunda-feira-e-fica-marcada-pelos-fogos-que-mataram-9-pessoas/ (consulted on September 30, 2024) (in Portuguese)

Oerther S, Manspeaker S, Wix A, Oerther D, Marsit C (2024) The effects of wildfires on the mental and physical health of school-age children in north america: a scoping review. J Child Adolesc Psychiatr Nurs 37(4):e70002. https://doi.org/10.1111/jcap.70002

QUALAR. Information on Air Quality. https://qualar.apambiente.pt/. Data on PM_{10} and $PM_{2.5}$ average and maximum concentration elaborated by the authors based on https://qualar.apambiente.pt/. 2024 (consulted on September 23, 2024)

Ribeiro C, Coutinho M (2007) Application of TAPM to predict photochemical air pollution over Portugal. Air Pollution XV 1:25–33

Ribeiro LM, Rodrigues A, Lucas D, Viegas DX (2020) The impact on structures of the Pedrógão Grande fire complex in June 2017 (Portugal). Fire 3(4):57. https://doi.org/10.3390/fire3040057

Senande-Rivera M, Insua-Costa D, Miguez-Macho G (2025) Climate change aggravated wildfire behaviour in the Iberian Peninsula in recent years. NPJ Clim Atmos Sci 8(1):19. https://doi.org/10.1038/s41612-025-00906-3

Stevens-Rumann CS, Kemp KB, Higuera PE, Harvey BJ, Rother MT, Donato DC, Morgan P, Veblen TT (2018) Evidence for declining forest resilience to wildfires under climate change. Ecol Lett 21(2):243–252. https://doi.org/10.1111/ele.12889

Tarín-Carrasco P, Augusto S, Palacios-Peña L, Ratola N, Jiménez-Guerrero P (2021) Impact of large wildfires on PM 10 levels and human mortality in Portugal. Nat Hazard 21(9):2867–2880. https://doi.org/10.5194/nhess-21-2867-2021

Trigo RM, Pereira JM, Pereira MG, Mota B, Calado TJ, Dacamara CC, Santo FE (2006) Atmospheric conditions associated with the exceptional fire season of 2003 in Portugal. Int J Climatol 26(13):1741–1758

Varela MC (2006) The deep roots of the 2003 forest fires in Portugal. International Forest Fire News (IFFN) 35:2–22

World Health Organization. (2021). WHO global air quality guidelines: particulate matter (PM2. 5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization. https://www.who.int/publications/i/item/9789240034228

Yu P, Xu R, Li S, Yue X, Chen G, Ye T, Coêlho MS, Saldiva PH, Sim MR, Abramson MJ, Guo Y (2022) Exposure to wildfire-related PM2 5 and site-specific cancer mortality in Brazil from 2010 to 2016: a retrospective study. PLoS medicine. 19(9):e1004103. https://doi.org/10.1038/s41467-022-35326-x