



Human and planetary health on fire

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Wildfires are increasing globally, with several recent catastrophic wildfires linked to climate change. Here, we consider the negative impact of the toxic contaminants arising from these fires on the immune system, with a focus on how wildfire pollution can exacerbate inflammatory diseases.

Wildfires are increasing in both frequency and severity around the world, and this has been linked to mismanagement, global warming and the loss of biodiversity and natural habitats. These fires have numerous pathological effects, either directly owing to the fire and smoke-related air pollution, or indirectly owing to subsequent water and soil pollution as well as from the stress and trauma associated with displacement, loss of property and loss of life. Acute and chronic illnesses can result in humans, often arising from the activation of inflammatory pathways or DNA damage responses, leading to respiratory and cardiovascular diseases, cancer, mental health issues and preterm birth in infants.

Increasing prevalence of wildfires

From 1979 to 2022, fire seasons lengthened across 25.3% of the Earth's vegetated surface, resulting in an 18.7% increase in the mean length of the global fire season¹. Recent years have seen deadly wildfires in the Amazon rainforest, Australian bush and Siberian and Californian wildlands. Record-breaking wildfires that occurred in Turkey, Greece, Russia and California in 2021 were linked to climate change. Wildfires cause significant air pollution, loss of water, loss of wildlife and loss of human lives, and these fires increase greenhouse gas emissions, further exacerbating climate change. As climate change increases the likelihood of catastrophic fires occurring, this leads to a vicious circle of ever-escalating wildfires and global warming¹.

Wildfire smoke can travel thousands of miles, potentially resulting in widespread adverse health impacts. The area actually burned is often relatively small compared with the total area that a wildfire may impact. For example, the smoke from a 10,000-hectare wildfire could affect people living in an area 10 to 15 times larger, impacting people who have never even seen the flames². Studies of wildfire smoke and its health effects are limited in comparison to the literature on ambient air pollution, but have shown both short-term and long-term negative health effects from wildfire smoke exposure. A longitudinal study conducted in Brazil showed that a 10 µg/m³ increase in wildfire-related PM_{2.5} (particulate matter, 2.5 microns or smaller in size) was associated with a 1.7%

increase in all-cause hospital admissions, a 5% increase in respiratory hospital admissions and a 1.1% increase in cardiovascular hospital admissions between 0 to 1 days after the exposure. Estimates from studies in 749 cities across 43 countries suggest that wildfire smoke and air pollution cause over 33,000 deaths annually with an increased risk of all-cause mortality.

Immune dysfunction and health effects

The impact of a wildfire on human mortality and morbidity depends on the size and speed of the fire, human proximity to the fire, and whether the population has advanced warning to evacuate. Potential negative effects of wildfire on human health are depicted in FIG. 1. The risk associated with exposure to wildfire smoke appears to vary with age, generally being higher in pregnant individuals and children, decreasing in young adults, and increasing again in middle-age through to old age, as the prevalence of heart, lung and metabolic disease increases. Key immune pathways are reported to be modified in animals and humans after wildfire smoke exposure, even days to weeks later. For example, exposure to wildfire smoke and pollution has been associated with activation of arylhydrocarbon receptor, Toll-like receptor and NF-κB signalling, as well as with the upregulation of pro-inflammatory cytokines and reactive oxygen species³⁻⁵. Fire fighters exposed to wildfires show increased pulmonary and systemic inflammation, and serum taken from fire fighters 12 hours after exposure has increased IL-6 and IL-12 and decreased IL-10 (REFS.^{6,7}).

Wildfire smoke can contain carbon dioxide, carbon monoxide, PM, complex hydrocarbons, nitrogen oxides, trace minerals, and several other toxic and carcinogenic compounds. The health impacts of wildfire smoke vary depending on the size of the PM, the fuel source, the chemical makeup, and the combustion characteristics of the smoke. Fine and ultrafine particles are small enough to reach pulmonary alveoli and access the bloodstream, thus aggravating both the respiratory and cardiovascular systems.

Importantly, wildfire smoke has been shown to disrupt epithelial barriers⁸. This may contribute to many chronic non-communicable diseases as proposed by the

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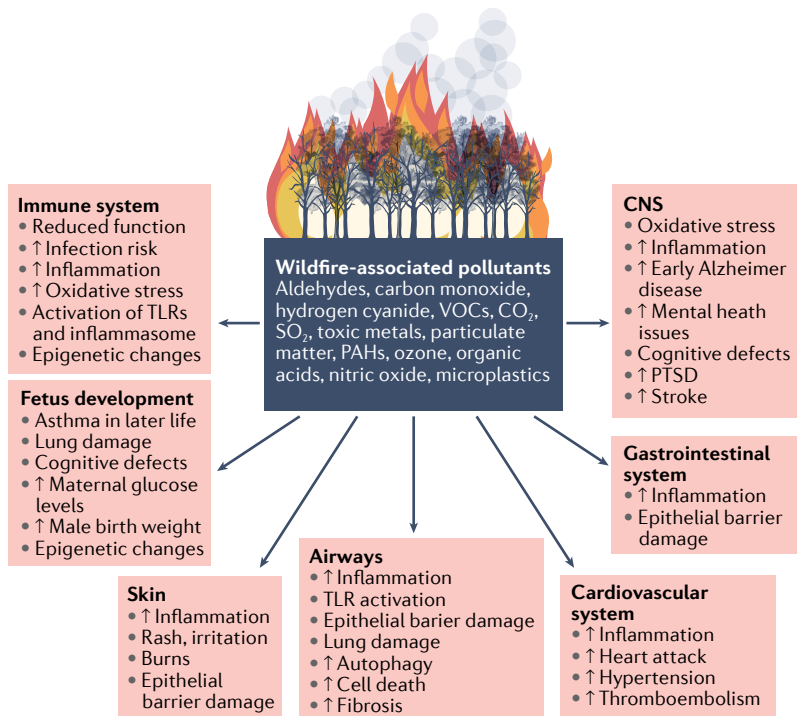


Fig. 1 | **Toxic substances and environmental contaminants generated by wildfires and their effects on the immune system, other organs and fetus.** PAHs, polycyclic aromatic hydrocarbons; PTSD, post-traumatic stress disorder; TLR, Toll-like receptor; VOCs, volatile organic compounds.

epithelial barrier hypothesis, which posits that the disturbance of epithelial barriers by environmental toxins can lead to tissue inflammation and microbial dysbiosis that contribute to the initiation and exacerbation of many non-communicable diseases⁹.

A recent study showed that increases in PM_{2.5} pollution due to wildfires can also exacerbate mortality and morbidity from infectious disease¹⁰. The study found that wildfire smoke amplified the negative effect of exposure to PM_{2.5} on COVID-19 cases and deaths for up to four weeks after the exposure. This study provided evidence that wildfires and airborne infectious diseases can be a disastrous combination, likely due to disruption of immune and lung epithelial barrier function by exposure to wildfire pollution.

Future directions

As scientists and researchers, we should focus on key priorities for research on wildfires and health, specifically on both the acute and chronic changes seen in the immune system, other affected organs and fetus. It will be important to define the long-term effects caused by epigenetic changes in wildfire-exposed cohorts compared with control cohorts. Research on plants, animals and humans to determine how wildfire smoke affects the health of all species is essential. Additionally, research on previously devastated areas to determine the ecological effects of wildfires as well as their effects on long-term

land use, and on water and soil pollution will be vital. To this end, new technologies using personal devices, satellites and innovative methods to examine big data by artificial intelligence are currently being developed¹. In addition, modelling of the cumulative effects (such as longitudinal assessments over a lifespan or studies of epigenetic effects) and combinatorial effects (for example, on the collective impact of heat stress, wildfire smoke and infection) will facilitate a better understanding of how exposure to wildfire smoke affects the immune system. Mental health, displacement, psychological and sociological studies can also be combined with measurement of clinical outcomes. These types of studies will enable better policy writing and benchmarking.

Wildfires have a massive and ever-increasing impact on many living species, including humans. Their contribution to global warming and climate change is increasing, and the size of the affected lands is expected to grow in the coming years. Unfortunately, research and funding in this area are limited, and mitigation strategies are still universally lacking. Public awareness continues to grow as more and more of the globe is affected by wildfires. We suggest several solutions at the individual, local and global level, including educating public health professionals and government and fire management officials about the health hazards associated with wildfires and improving land-use management. Resiliency and capacity building, especially in vulnerable communities, will be needed now and in the future as we develop solutions to improve public health. There is an urgent need to mitigate and adapt to climate change, which has led to many of the environmental features contributing to wildfires. Importantly, countries and states must not only meet but exceed their commitments under the Paris Agreement to reduce global warming and limit the destructive impact of wildfires.

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Competing interests

The authors declare no competing interests.