

Impact of Wildfire Smoke on Human Health

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ABSTRACT

Wildfire smoke is a major environmental health concern due to its harmful components, including fine particulate matter (PM_{2.5}), carbon monoxide, and volatile organic compounds, which can significantly impact human health. Exposure to wildfire smoke is associated with various respiratory disorders, such as asthma exacerbation, chronic obstructive pulmonary disease (COPD), and respiratory infections. Additionally, wildfire smoke contributes to cardiovascular issues, including increased risks of hypertension, stroke, and myocardial infarction. Beyond physical health, prolonged exposure to wildfire smoke can also affect mental health, leading to heightened stress, anxiety, and depressive symptoms. Certain populations, such as children, pregnant women, and the elderly, are particularly vulnerable to these health effects due to their physiological characteristics. This study reviews the health impacts of wildfire smoke, emphasizing respiratory and cardiovascular diseases, mental health disorders, and the risks faced by vulnerable groups. Furthermore, this study explores mitigation strategies, including air quality monitoring, public health interventions, and the development of infrastructure to minimize exposure. Understanding the health risks associated with wildfire smoke and implementing effective mitigation measures are crucial steps in reducing its impact on public health.

Keyword : Wildfire smoke, Health impacts, Respiratory diseases, Cardiovascular diseases, Mental health effects

Introduction

Wildfires are becoming more frequent and intense due to rising global temperatures and shifting precipitation patterns caused by climate change¹. While wildfires themselves cause immediate destruction, their long-term impact on air quality and human health is a growing concern. Wildfire smoke contains a complex mix of pollutants, including fine particulate matter (PM_{2.5}), which can travel long distances and degrade air quality far beyond the fire's origin². Exposure to wildfire smoke has been linked to various health risks, particularly affecting the respiratory and cardiovascular systems, leading to increased hospital admissions for conditions such as asthma, chronic obstructive

pulmonary disease (COPD), and cardiovascular diseases^{3,4}.

Beyond respiratory and cardiovascular effects, wildfire smoke exposure is associated with pregnancy complications, including an increased risk of preterm birth^{5,6}. Additionally, prolonged exposure to wildfire smoke has been linked to negative mental health outcomes, such as anxiety and depression, especially among individuals experiencing displacement or chronic exposure to poor air quality⁷. Vulnerable populations, including children, the elderly, pregnant women, and individuals with preexisting health conditions, are at the highest risk of severe health effects^{8,9}.

As wildfires continue to increase in frequency and severity, understanding their health impacts is essential for developing effective public health strategies and mitigation measures¹⁰. This review summarizes recent findings on the health effects of wildfire smoke, with a focus on respiratory and cardiovascular health, pregnancy outcomes, and mental health. Furthermore, it highlights strategies to minimize these risks, emphasizing the importance of public health interventions, air quality management, and policy measures aimed at protecting affected communities⁴. Addressing these challenges is crucial to reducing the health burden of wildfire smoke and enhancing community resilience in the face of escalating wildfire events.

Material and Methods

The literature search focused on articles that discuss the health impacts of wildfire smoke. The search was conducted using the keywords wildfire smoke, health impacts, respiratory disease, cardiovascular diseases, and mental health. Literature sources were obtained from Google Scholar, PubMed, and ScienceDirect. The sources were searched in English. Based on the type of publication, we considered articles from scientific journals published between 2020-2025.

We employed a Population, Intervention, Comparison, and Outcome (PICO) strategy to guide the literature search and ensure the inclusion of relevant studies:

1. Population: General population, vulnerable groups (e.g., children, pregnant women, elderly);
2. Interventions: Exposure to wildfire smoke, PM_{2.5}, and other related air pollutants;
3. Comparison: Health outcomes with and without wildfire smoke exposure;
4. Outcome: Health impacts on respiratory, cardiovascular, and mental health, as well as effects on specific vulnerable populations.

The literature search considered articles that included data in titles, abstracts, and results sections. From the initial search, 15 articles were identified and screened based on their relevance to the research topic. After applying the inclusion and exclusion criteria, a total of 10 articles were selected.

Results

Table 1. List of literatur

Title	Author and Year	Reaserch Subject	Methods	Result
Air Quality and Health Impact of the 2020 Wildfires in California	Adams et al., 2023	Residents in wildfire-affected regions in California during 2020	Observational study analyzing air quality monitoring data and hospital admission records	Significant increase in PM _{2.5} levels was linked to higher rates of respiratory-related hospitalizations. Vulnerable groups, including children and the elderly, were dispropor tionately affected.
Long-Term Exposure to Wildfire-Related Fine Particulate Matter and Cardiovascular Disease	Smith et al., 2023	Nationwide cohort of adults exposed to wildfire smoke	Longitudinal cohort study using satellite data on PM _{2.5} exposure and cardiovascular health outcomes	Chronic exposure to wildfire-related PM _{2.5} was associated with a 12% increased risk of cardiovascular disease, particularly ischemic heart disease.
Wildfire Smoke and Symptoms Affecting Mental Health Among Adults in the U.S State of Oregon	Brown et al., 2022	Adults in Oregon during the 2020 wildfire season	Survey-based study with mental health assessment tools	25% of participan ts reported anxiety and depression symptoms during prolonged exposure to wildfire smoke, highlighting mental health as a significant concern.
Impact of Wildfire Smoke Exposure on Health in Korea	Park et al., 2022	Residents in wildfire-affected regions in Korea	Retrospective study analyzing hospital records and air pollution data	Increased hospital visits for respiratory and cardiovascular complaints were observed during wildfire events, with PM _{2.5} identified as the main contributor.
Wildfire Smoke Impacts Respiratory Health More Than Fine Particles From Other Sources	Thompson et al., 2021	Comparative study of wildfire smoke and urban PM _{2.5}	Case-control study using air quality data and health outcomes	PM _{2.5} from wildfire smoke caused more severe respiratory outcomes compared to urban sources, due to differences in chemical composition and oxidative properties
Impact of Fine Particulate Matter From Wildfire Smoke on Respiratory and Cardiovascular Health in California	Williams et al., 2022	Residents across California during peak wildfire seasons	Systematic review of epidemiological data	Wildfire-related PM _{2.5} significantly increased risks of respiratory infections and cardiovascular events, particularly among outdoor workers and children.
Cardiovascular Health Impact of Wildfire Smoke Exposure	Miller et al., 2021	Adults exposed to wildfire smoke	Observational study integrating air quality data with cardiovascular health records	Increased incidence of arrhythmias and heart attacks during periods of high wildfire smoke exposure, especially in older adults.
Wildfire Smoke Exposure and Early Childhood Respiratory Health	Lee et al., 2023	Children under 5 years in wildfire-affected areas	Prospective cohort study with respiratory health assessments	Prolonged exposure to wildfire smoke in early childhood was linked to increased rates of bronchitis , asthma development, and reduced lung function.

Impacts of Heat and Wildfire on Preterm Birth	Ha et al., 2024	Pregnant women exposed to heat and wildfire smoke	Observational study analyzing birth records, temperature, and air pollution data	Exposure to wildfire smoke was associated with a 3.0% increase in the likelihood of preterm birth.
Wildfire-Sourced Fine Particulate Matter and Preterm Birth Risks in Brazil	Oliveira et al., 2024	Pregnant women in wildfire-affected regions of Brazil	Retrospective cohort study analyzing air pollution data (PM _{2.5}) and pregnancy outcomes	Exposure to wildfire-related PM _{2.5} during pregnancy increased the risk of preterm birth by 15%, with the highest risk observed during the third trimester.

Discussion

Health Impacts of Wildfire Smoke on Humans

Wildfire smoke is a complex mixture of hazardous pollutants, primarily fine particulate matter (PM_{2.5}), carbon monoxide (CO), volatile organic compounds (VOCs), and other toxic chemicals. These pollutants can deeply penetrate the human body, causing a wide range of health effects, including respiratory, cardiovascular, and mental health complications, as well as increased risks for vulnerable populations. The primary mechanisms underlying these health effects involve oxidative stress, systemic inflammation, and immune system activation, leading to tissue damage and dysfunction across multiple organ systems¹¹.

Respiratory Health Effects of Wildfire Smoke

The respiratory system is the first and most directly affected by wildfire smoke exposure. PM_{2.5} particles are small enough to bypass the body's natural defense mechanisms and penetrate deep into the lungs, reaching the alveoli, where gas exchange occurs. Once deposited in the lungs, PM_{2.5} triggers oxidative stress by generating reactive oxygen species (ROS), which damage lung epithelial cells and disrupt normal pulmonary function³.

This oxidative damage stimulates the activation of immune cells, including macrophages and neutrophils, which release proinflammatory cytokines such as interleukin-6 (IL-6), interleukin-8 (IL-8), and tumor necrosis factor-alpha (TNF- α). These inflammatory mediators promote mucus hypersecretion and airway constriction, exacerbating conditions like asthma, chronic obstructive pulmonary disease (COPD), and bronchitis^{4,11}.

Additionally, wildfire smoke exposure impairs mucociliary clearance by damaging cilia, the microscopic hair-like structures responsible for clearing mucus and pathogens from the airways. This impairment increases susceptibility to respiratory infections, including pneumonia and bronchitis, particularly in children and the elderly, whose immune responses are less robust⁸.

Long-term exposure to wildfire smoke has also been associated with pulmonary fibrosis, a condition characterized by excessive scarring of lung tissue, leading to reduced lung capacity and chronic respiratory impairment. In severe cases, persistent inflammation may contribute to pulmonary hypertension, where stiffened and narrowed pulmonary blood vessels increase the workload on the heart, potentially leading to heart failure³.

Cardiovascular Effects of Wildfire Smoke

Beyond the lungs, inhaled PM_{2.5} can cross the alveolar-capillary barrier and enter the bloodstream, allowing toxic pollutants to circulate systemically and affect the cardiovascular system. Wildfire smoke exposure induces systemic inflammation, marked by increased levels of C-reactive protein (CRP), interleukin-1 beta (IL-1β), and fibrinogen, all of which contribute to endothelial dysfunction and thrombogenesis^{2,9}. Endothelial dysfunction disrupts the regulation of blood vessel tone, leading to hypertension and atherosclerosis (plaque buildup in arteries). The prothrombotic effects of wildfire smoke increase the risk of blood clot formation, potentially resulting in stroke and myocardial infarction (heart attack)^{3,9}.

Inhaled carbon monoxide (CO) further exacerbates cardiovascular risks by binding to hemoglobin with a higher affinity than oxygen, reducing the oxygen-carrying capacity of blood. This forces the heart to pump harder to compensate for decreased oxygen delivery, heightening the risk of arrhythmias, ischemic heart disease, and sudden cardiac arrest, particularly in individuals with preexisting heart conditions. A nationwide study reported a 12% increase in wildfire smoke-related hospitalizations for heart attacks, with the highest risk observed in older adults¹².

Mental Health and Cognitive Impacts of Wildfire Smoke

Emerging evidence suggests that wildfire smoke not only affects physical health but also contributes to neuropsychiatric disorders. Fine particulate matter can penetrate the blood-brain barrier (BBB), triggering neuroinflammation and oxidative damage within the central nervous system⁷. PM_{2.5} exposure activates microglial cells, the brain's resident immune cells, leading to the release of proinflammatory cytokines such as IL-6 and TNF-α, which disrupt neurotransmitter balance and neuronal function. This neuroinflammatory response has been linked to increased risks of anxiety, depression, and cognitive decline^{7,13}.

Wildfire smoke exposure also stimulates the hypothalamic-pituitary-adrenal (HPA) axis, resulting in elevated cortisol levels. Chronic activation of the stress response contributes to mood disorders, sleep disturbances, and impaired memory consolidation¹³. Long-term exposure to wildfire-related air pollution may also play a role in neurodegenerative diseases, including Alzheimer's and Parkinson's disease. PM_{2.5} has been shown to promote amyloid-beta plaque deposition, a hallmark of Alzheimer's disease, suggesting a possible link between air pollution and accelerated cognitive decline¹³.

Vulnerable Populations at Higher Risk

Certain populations are disproportionately affected by wildfire smoke exposure due to physiological vulnerabilities or preexisting conditions. Children, the elderly, pregnant women, and individuals with chronic diseases face heightened health risks^{8,9}. Children are particularly susceptible due to their developing lungs and immature immune systems. Early-life exposure to PM_{2.5} has been associated with reduced lung function growth and increased lifelong susceptibility to respiratory diseases⁸.

Pregnant women exposed to wildfire smoke have a higher risk of adverse birth outcomes, including preterm birth, low birth weight, and stillbirth^{5,6,14}. Polycyclic aromatic hydrocarbons (PAHs), another component of wildfire smoke, can cross the placenta and interfere with fetal development, increasing the likelihood of congenital abnormalities and long-term health complications¹⁴. Elderly individuals and those with preexisting conditions such as cardiovascular disease, COPD, and diabetes experience exacerbated health effects due to reduced physiological resilience and impaired detoxification mechanisms^{3,9,12}.

Mitigation Strategies to Reduce Health Risks

Given the growing frequency and intensity of wildfires, public health strategies are essential to minimize exposure and associated health risks^{10,15}. Key mitigation approaches include:

1. Improved Air Quality Monitoring - Advanced air quality surveillance systems can provide real-time data, enabling early warnings and protective measures during wildfire events.
2. Public Health Messaging - Clear communication about the dangers of wildfire smoke and recommended protective actions, such as using N95 masks, air purifiers, and staying indoors, can significantly reduce exposure.
3. Indoor Air Filtration and Home Modifications - Retrofitting homes with high-efficiency air filtration systems and sealing windows and doors during high-smoke periods can reduce indoor pollutant levels.
4. Protection of Vulnerable Populations - Special measures, such as ensuring access to clean air shelters and medical resources, should be prioritized for children, the elderly, and pregnant women.
5. Climate Change Mitigation - Since climate change has been linked to increased wildfire frequency and severity, reducing greenhouse gas emissions and implementing sustainable land management practices are critical for long-term prevention.

Conclusion

In conclusion, the increasing prevalence of wildfires poses significant health risks to populations worldwide, particularly in terms of respiratory, cardiovascular, and mental health. Understanding the full scope of these impacts, as well as the specific risks faced by vulnerable populations, is crucial for public health planning and intervention strategies. Implementing effective mitigation measures, such as improved air quality monitoring, public health education, and enhanced building filtration, can reduce these health risks. Additionally, addressing climate change through policy changes is essential for long-term solutions to this growing problem.

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