

Impact of Wildfire Smoke Waves on Asthma Emergencies in Children: Insights Into the Pediatric Subpopulations Most Vulnerable to the Threat of Climate Change

Real-world data shows asthma exacerbations rose 95% for Hispanic/Latino children in the San Francisco Bay Area during the most destructive wildfire in California history; children living in regions with less home ownership and education had a 51% and 45% greater risk of asthma-related ED visits, respectively.

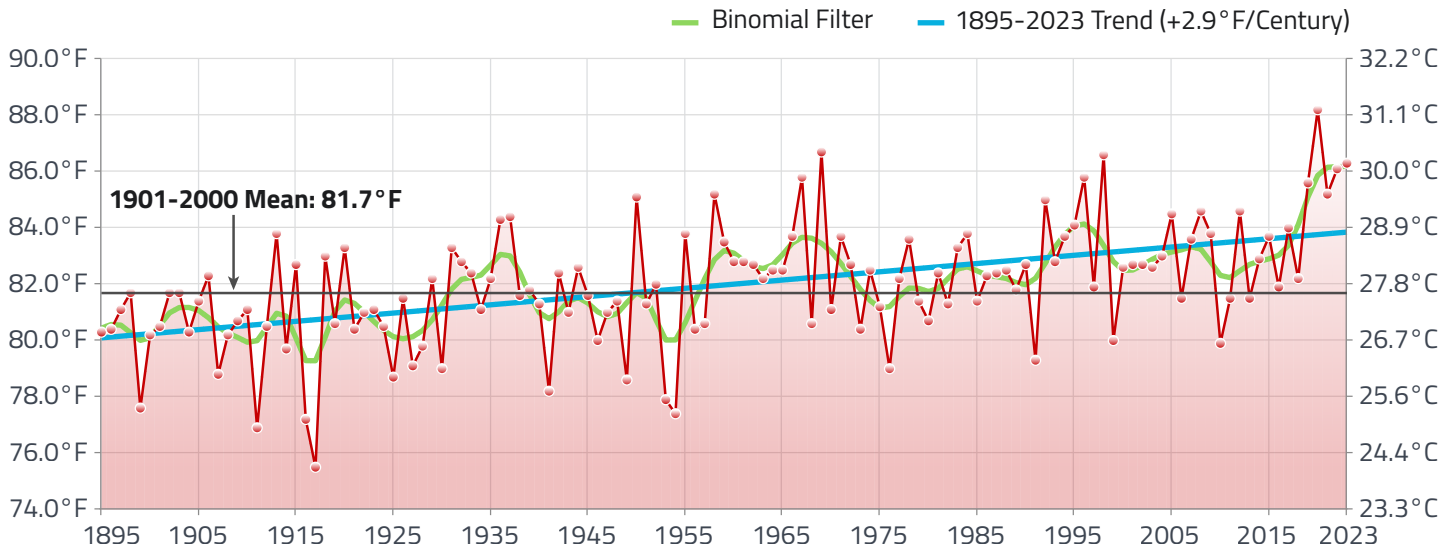
KEY FINDINGS:

- **General impact on pediatric asthma emergencies:** For asthma-related emergencies in children, the wildfire smoke wave was associated with a 76% increase in the daily rate of asthma exacerbations and a 27% increase in the rate of daily asthma-related ED visits.
- **Racial disparities:** Wildfire-associated increases in the daily rate of asthma exacerbations were highest among Hispanic/Latino (+95%), Asian American and Pacific Islander (+75%), and African American (+63%) children.
- **Relationship between regional poverty, home ownership, education, and asthma-related ED visits:** Children living in regions with less home ownership and education had a 51% and 45% greater risk of asthma-related ED visits, respectively. Children residing in regions with the highest poverty levels had a 38% greater risk of asthma-related ED visits.

EXECUTIVE SUMMARY:

Over the past several decades, the extent and frequency of wildfires have concomitantly increased with our warming climate, particularly in regions prone to wildfires like the western U.S. Each year, the U.S. experiences [approximately 73,000 wildfires](#), which burn an average of 7 million acres of private, state, and federal land. Recent increases in both the [severity and frequency](#) of these fires have raised significant concerns about the influence of climate change and the associated economic and health impacts of these events. In California, which often takes the top spot for most wildfires and acres burned per state, the most destructive wildfire in its history occurred in Butte County in 2018, with smoke waves affecting the San Francisco Bay Area and surrounding counties. The total impact of the fire was wide-reaching, totaling over \$16 billion in economic losses and taking the lives of 85 civilians.

ALAMEDA COUNTY, CALIFORNIA, MAXIMUM TEMPERATURE



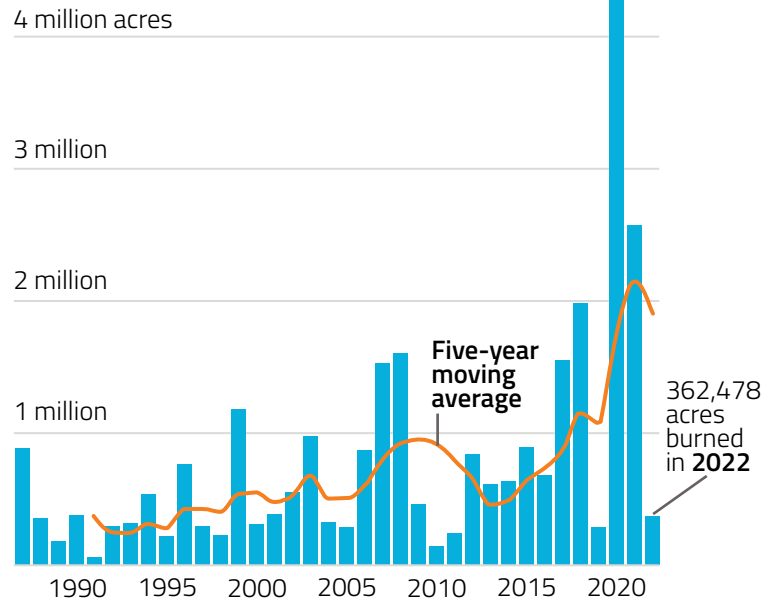
Source: National Interagency Fire Center

Even in communities far from the immediate damage of the fires themselves, wildfire smoke has been directly linked to poor air quality that can lead to [significant health effects](#), often in the form of respiratory ailments. Research tracking the health effects of wildfire smoke in California between 2012 and 2018 found that each additional day of wildfire smoke led to more than 12 hospitalizations for respiratory or circulatory issues, resulting in an average annual cost of roughly \$192 million.

Though the effects of ambient air pollution on respiratory health outcomes in children have been well-established in the literature, much less is known about the impact of wildfire-associated air pollution on childhood asthma. Despite reports of worse respiratory health outcomes for adults exposed to wildfire smoke (Reid et al., 2016) and recent evidence indicating that particulate matter from wildfire smoke has a greater impact on respiratory health than fine particulates from other sources (Aguilera et al., 2021), there is a paucity of studies focused on examining the effects of wildfire smoke in children (Holm et al., 2021).

To provide insight into this issue, we examined the impact of wildfire-associated air pollution on pediatric asthma, the most prevalent childhood illness, and uncovered real-world evidence of the effects of wildfire smoke waves on asthma emergencies in children. Our analysis included approximately 1.6 million pediatric asthma patients living in regions of California affected by the wildfire smoke wave in 2018. Tracking of both asthma-related ED visits and asthma exacerbations during the 14-day wildfire smoke-wave period showed a 76% overall increase in pediatric asthma exacerbations and a 27% increase in asthma-related ED visits. These increases were even more pronounced in the Hispanic/Latino population and among children living in regions with lower economic security, less home ownership, and lower education. (This research was originally presented at Stanford University's Center for Excellence in Pulmonary Biology's 2023 Symposium on Climate Change and Child Respiratory Health.)

ACRES BURNED BY WILDFIRES IN CALIFORNIA



Source: California Department of Forestry and Fire Protection, or CalFire
New York Times, 2022



METHODOLOGY:

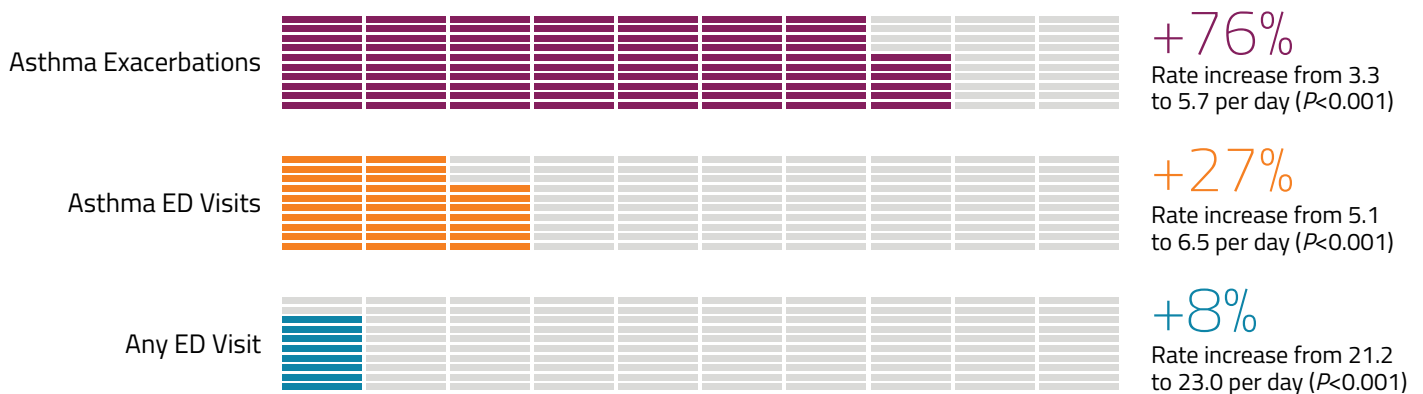
Powered by Komodo's Healthcare Map™, which tracks the healthcare journeys of more than 330 million patients in the U.S., we employed Komodo's suite of analytics to identify 1.6 million pediatric asthma patients living in the San Francisco Bay Area and nearby counties affected by the 2018 wildfire in Northern California, the most destructive wildfire in California history. To generate a comprehensive dataset of health, race, air pollution as indicated by PM2.5 (particulate matter <2.5 μm in diameter), and social determinants of health (i.e., zip-level home ownership, poverty, and education) for patients affected by the 2018 wildfire, health data from our Healthcare Map was linked to population data from the American Community Survey (ACS; 2018, 5yr), the U.S. Census, and the EPA Air Quality System's daily PM2.5 at the zip level. Patients <18 years old with ≥2 asthma encounters in 2018 were included in this study. The main outcome measures are asthma exacerbations (defined as encounters in which an asthma diagnosis occurred within 1 day of systemic steroid administration) and asthma-related ED visits (defined as ED encounters with an asthma diagnosis occurring within 1 day). To assess the impact of exposure to a wildfire smoke wave on the respiratory health of children with asthma, daily rates of asthma-related ED visits and exacerbations during the 14-day wildfire smoke-wave period were compared to the rates that occurred during a period of equal length (14 days) and within the same season (1 month prior), during which no wildfires and associated elevations in PM2.5 were observed.

To examine whether there were differential effects of smoke-wave exposure by race, the same analysis was performed for the pediatric asthma cohort segmented by race/ethnicity. In addition, we examined whether regional factors modified the effect of a wildfire smoke wave on cohorts of children segmented by tertiles of the following zip-level variables: mean home ownership, percentage of the population without a high school diploma, proportion of the population living below the poverty line, and average annual daily PM2.5 levels. All outcome measures were compared to baseline rates during the non-smoke-wave period via a two-sample Poisson equivalence test, with *P* values of <0.05 indicating significance.

KEY FINDINGS:

Pediatric asthma exacerbations increased 76% during the smoke wave: Over the 14 days following the onset of the 2018 Northern California wildfire, children in areas affected by the smoke wave experienced a 76% increase in asthma exacerbations and a 27% increase in asthma-related ED visits.

INCREASED RISK OF EMERGENCY HEALTH EVENTS IN CHILDREN EXPOSED TO WILDFIRE SMOKE WAVE



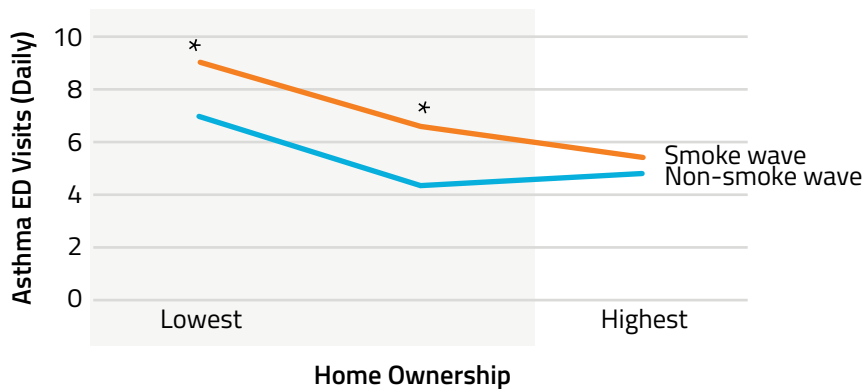
Risk of asthma exacerbation during the smoke wave was highest in the Hispanic/Latino population: When stratified by race and ethnicity, the increase in asthma exacerbation rates was highest among Hispanic/Latino (+95%), followed by Asian American and Pacific Islander (+75%) and Black/African American (+63%) children. Among White children, asthma exacerbations increased by 55%.

RACIAL DIFFERENCES IN THE RISK OF ASTHMA EXACERBATIONS IN CHILDREN EXPOSED TO WILDFIRE SMOKE WAVE



Effects of the smoke wave on asthma-related ED visits were highest in regions with less home ownership, lower education, and greater poverty: Children living in regions with reduced home ownership had an increased risk for asthma-related ED visits of up to 51% when compared to the overall population in the affected area. Regions with the highest proportion of residents who did not have a high school diploma had a 45% greater risk of asthma-related ED visits, and regions with the highest poverty levels had a 38% greater risk of asthma-related ED visits.

EFFECT OF SMOKE WAVE ON ASTHMA ED VISITS EFFECT MODIFICATION† BY REGIONAL HOME OWNERSHIP

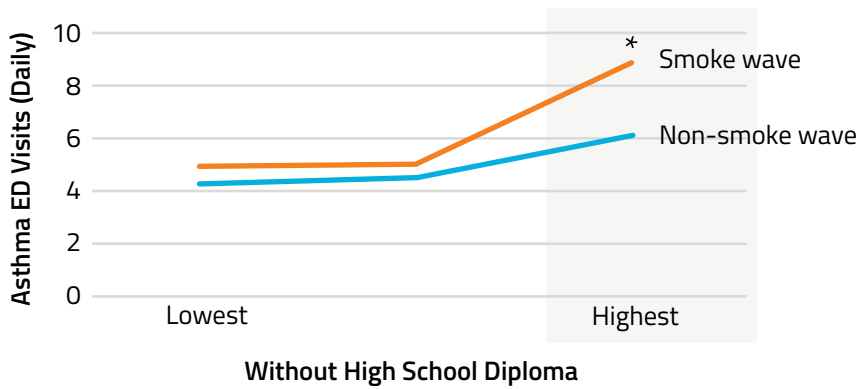


Regions with LESS home ownership
29%-51%
 GREATER risk for asthma ED visits
 * $P < 0.01$

†Effect modification by tertiles of zip-level poverty



**EFFECT OF SMOKE WAVE ON ASTHMA ED VISITS
EFFECT MODIFICATION[†] BY REGIONAL EDUCATION (HIGH SCHOOL DIPLOMA)**



Regions with the HIGHEST proportion of residents without HS diploma

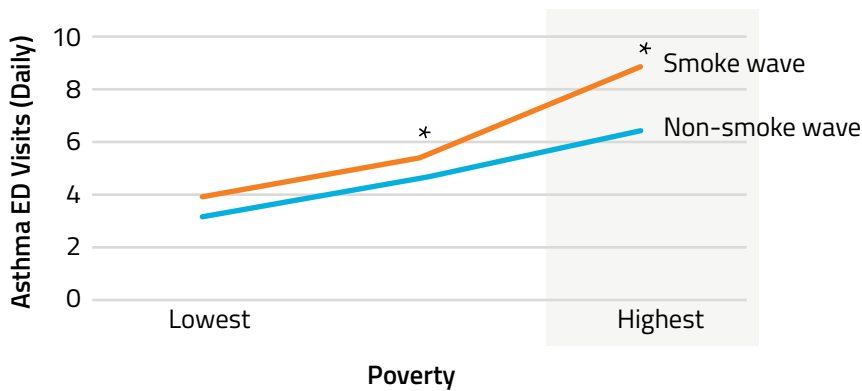
45%

GREATER risk for asthma ED visits

* $P < 0.001$

[†]Effect modification by tertiles of zip-level poverty

**EFFECT OF SMOKE WAVE ON ASTHMA ED VISIT
EFFECT MODIFICATION[†] BY REGIONAL POVERTY**



Regions with the MOST poverty

38%

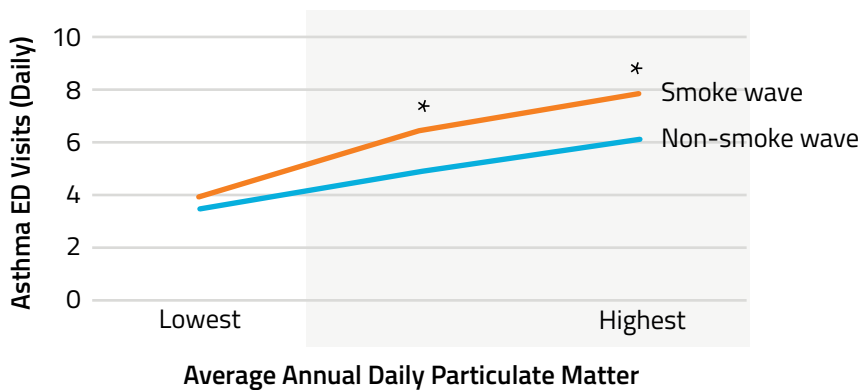
GREATER risk for asthma ED visits

* $P < 0.01$

[†]Effect modification by tertiles of zip-level poverty

Children living in regions with higher average daily particulate matter exposure had an increased risk of asthma-related ED visits: These children were 29% to 32% more likely to experience asthma-related ED visits during the wildfire smoke wave.

**EFFECT OF SMOKE WAVE ON ASTHMA ED VISITS
EFFECT MODIFICATION[†] BY REGIONAL DAILY PARTICULATE MATTER EXPOSURE**



Regions with MORE average daily particulate matter exposure

29% - 32%

GREATER risk for asthma ED visits

* $P < 0.001$

[†]Effect modification by tertiles of zip-level poverty



DISCUSSION:

In this study, we present real-world evidence of the effects of a wildfire smoke wave on pediatric asthma emergencies and show that there are racial disparities in its impact on asthma exacerbations. Furthermore, we show that a relationship exists between regional factors (i.e., area-level poverty, home ownership, and education) and an increased risk of asthma-related ED visits during a wildfire smoke wave. Irrespective of race/ethnicity, these regional factors modified the effect of a wildfire smoke wave on asthma-related ED visits in children, with the worst outcomes observed in regions with the highest poverty, lowest home ownership, and the least proportion of residents with a high school diploma. Moreover, we observed an increased risk of asthma-related ED visits for children living in regions with the highest chronic particulate matter exposure. Importantly, we found that the distribution of racial/ethnic subgroups with the worst outcomes during a wildfire smoke wave was consistent with the regions where the highest effects were observed, suggesting that area-level poverty, housing instability, and lower education may explain the observed racial disparities in asthma exacerbations during a wildfire smoke wave.

By identifying the specific characteristics of populations most affected in a wildfire-prone region, we have highlighted opportunities to mitigate adverse outcomes as climate change threatens to increase exposure to wildfire smoke.

Strengths and Limitations

To our knowledge, this is the largest cohort of children for which the respiratory health risks of wildfire smoke have been examined in the San Francisco Bay Area. However, this study has the following limitations. First, we employed the zip3 of patients' home addresses to estimate the area-level — rather than patient-level — values of home ownership, poverty, education, and chronic particulate matter exposure. Moreover, the area-level examination of affected regions within the 14-day smoke-wave period did not include time lags that account for different levels of particulate matter exposure, which can vary within the same region based on hyperlocal wind currents, topographical features, and distance from the wildfire epicenter. Finally, this work estimated the wildfire smoke wave time window based on spatiotemporal measurements of one air pollutant (PM_{2.5}); the measurements of two other wildfire-associated pollutants (i.e., ozone and carbon monoxide) that have been shown to impact health were not included in estimates of the window of exposure to wildfire-associated air pollution.

Conclusions

In this study, we show evidence of the subpopulations of children most affected by wildfire-associated air pollution and present a data-driven approach to identifying addressable areas of vulnerability that are potential targets for interventions that aim to protect children from the increasingly adverse consequences of climate change as it threatens to increase the extent and frequency of wildfires. Specifically, the results of this study highlight the need for proactive strategies to address disparities in education, poverty, and home ownership that are associated with the increased risk of adverse outcomes for children exposed to wildfire smoke:

- County-level allocation of protective equipment (e.g., N95 masks), clean-air shelters, and portable air filters to regions known to have higher poverty and less home ownership
- Development of community-based multilingual education resources aimed to educate residents about the health risks of wildfire smoke and opportunities to mitigate them
- A re-examination of air-quality standards to account for the cumulative effects of different particulate matter exposures (chronic low level, acute high level, or acute on chronic) on the health of children

The results of this study raise critical questions about whether racial, socioeconomic, and educational disparities make certain populations more vulnerable to the consequences of climate change. They also suggest that prioritizing policies that address these disparities is an important part of developing the infrastructure to reduce the impact of climate change on respiratory health. Further research (with a specific focus on the pediatric population) is required to understand the long-term impact of acute exposure to a wildfire smoke wave on respiratory health and whether targeted interventions to address the disparities we've identified can prevent adverse outcomes for our most vulnerable children.



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About Komodo Health

Komodo Health is a technology platform company creating the new standard for real-world data and analytics by pairing the industry's most complete view of patient encounters with enterprise software and machine learning to connect the dots between individual patient journeys and large-scale health outcomes. Across Life Sciences, payers, providers, and developers, Komodo helps its customers unearth patient-centric insights at scale — marrying clinical data with advanced algorithms and AI-powered software solutions to inform decision-making, close gaps in care, address disease burden, and help enterprises create a more cost-effective, value-driven healthcare system. For more information, visit [Komodohealth.com](https://komodohealth.com).

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