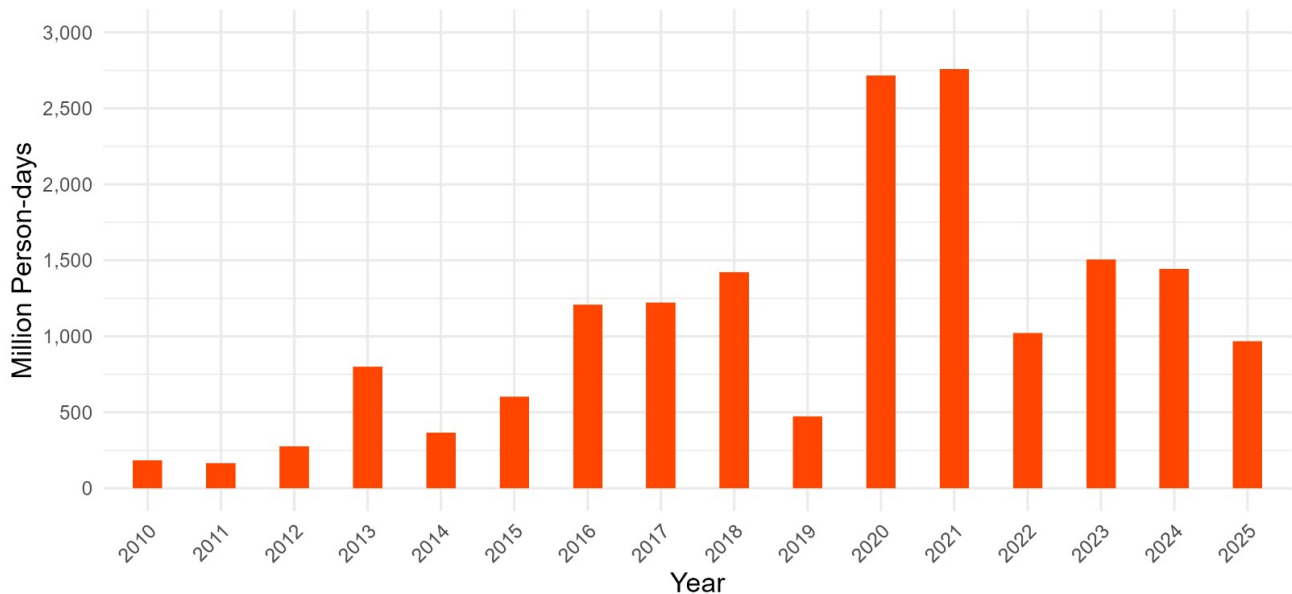


5.3 Wildfire Smoke and Human Health

Wildfire smoke has become an increasingly important climate-related hazard to air quality and public health in California. Climate change contributes to more frequent, intense, and severe wildfires, causing regions across the state to experience longer-lasting smoke impacts that extend far beyond the fire perimeter. Because wildfire smoke affects populations across broad geographic areas and contributes to the state's growing burden of climate-related illness, this indicator examines two complementary measures: a smoke metric, which tracks population impacts from wildfire smoke and related fine particulate matter exposure, and a health metric, which tracks associated respiratory health impacts over time. Together, these metrics provide a more complete picture of the statewide impacts of wildfire smoke.

Figure 5.3.1. Statewide Population Impacts from Wildfire Smoke, 2010-2025.

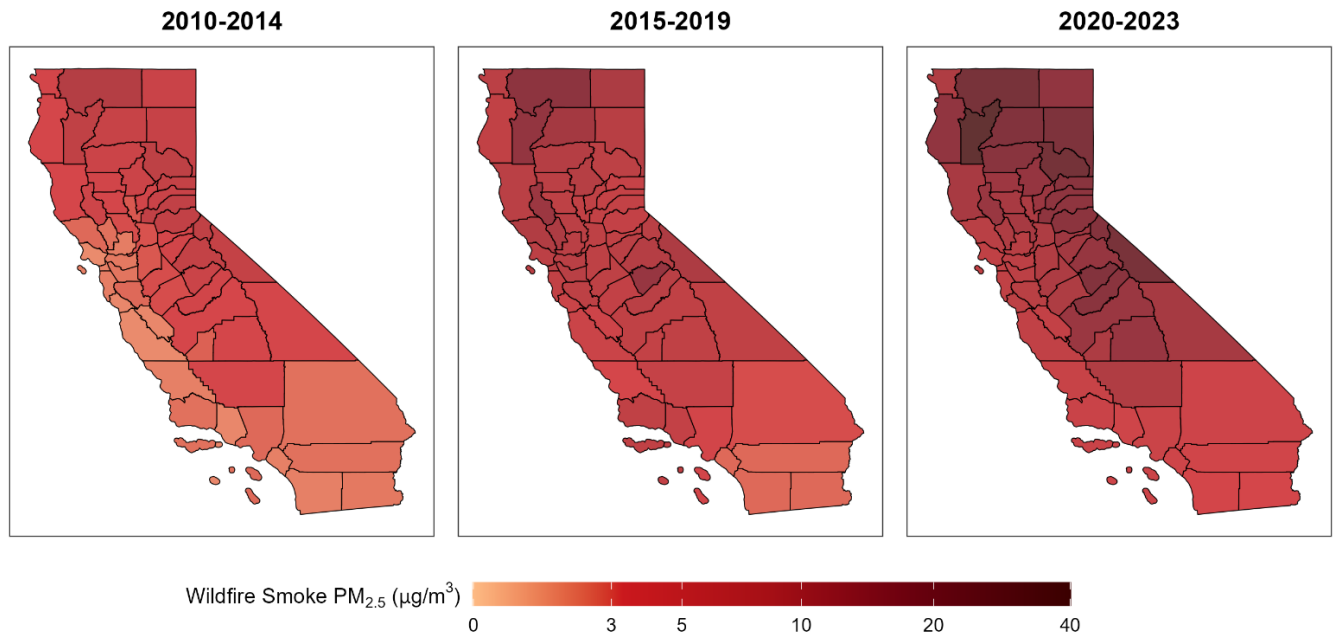


This graph shows annual “person-days” of wildfire smoke, which represents the estimated number of people living in California in areas where smoke plumes were present, multiplied by the number of days plumes were present, for each year from 2010-2025. Estimates are based on the presence of smoke plumes over populated areas and may not reflect smoke impacts at ground-level where people breathe. Source: CDPH (2026), NOAA Hazard Mapping System, U.S. Census Bureau Centers of Population¹

¹ California Department of Public Health (CDPH), Environmental Health Investigations Branch;



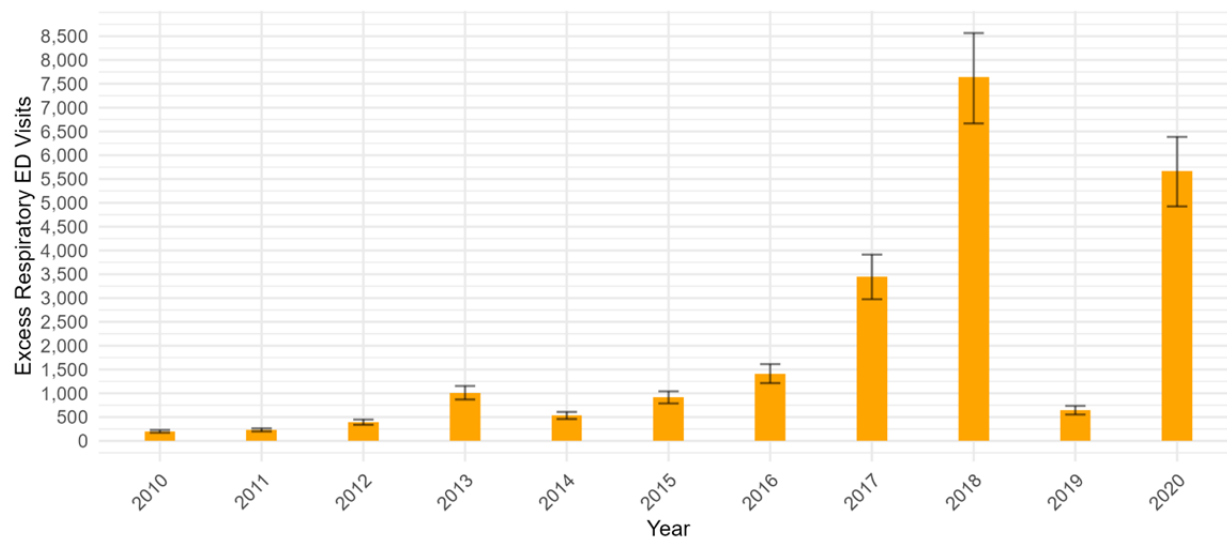
Figure 5.3.2. Average Annual Wildfire Smoke $PM_{2.5}$ Concentrations by County, 2010-2014, 2015-2019, and 2020-2023.



The maps show county-level average annual wildfire-specific $PM_{2.5}$ (WF- $PM_{2.5}$; fine particulate matter specifically attributed to wildfire smoke emissions) in micrograms per cubic meter ($\mu g/m^3$), based on daily average estimates. County averages are summarized as 5-year averages for 2010-2014 and 2015-2019, and as a 4-year average for 2020-2023. Source: Childs et al. (2025) Updated v2.0 preprint data, made available through the Stanford Environmental Change and Human Outcomes Lab.



Figure 5.3.3. Statewide Wildfire Smoke PM_{2.5}-Attributable Respiratory Emergency Department (ED) Visits, 2010-2020.



Total Excess Respiratory ED Visits (2010-2020): 22,096 (95% CI: 19,161-24,953)

This graph presents the estimated number of annual respiratory-related ED visits that were associated with WF-PM_{2.5} exposure during a wildfire seasonal period (May-November) from 2010-2020. The “attributable number” represents the estimated excess number of respiratory ED visits beyond what would have been expected had there been no WF-PM_{2.5}. The 95% confidence interval (CI) represents the degree of uncertainty around the estimate. Source: Analysis by the California Department of Public Health (CDPH) (2026), Environmental Health Investigations Branch

What does the indicator show?

Smoke metric

Population impacts from wildfire smoke in California have risen substantially since 2010 (**Figure 5.3.1**). From 2010–2014, annual person-days of smoke were relatively low (168–800 million). By the mid-to-late 2010s, annual person-days increased to 475 million–1.4 billion. The highest annual person-days occurred in 2020 and 2021, when record-breaking wildfires led to unprecedented smoke impacts across the state, reaching approximately 2.7 billion person-days in each year. During 2022-2025, when wildfire activity was less severe, annual person-days of smoke remained elevated above pre-2015 levels, ranging from approximately 968 million to 1.5 billion.



Average annual concentrations of wildfire smoke $\text{PM}_{2.5}$ (WF- $\text{PM}_{2.5}$), or fine particulate matter less than 2.5 microns in diameter derived from wildfire smoke emissions, have also increased, both in the magnitude of concentrations and in geographic extent (**Figure 5.3.2**). During 2010-2014, the highest average annual concentrations were limited primarily to the northern and eastern parts of the state, while WF- $\text{PM}_{2.5}$ remained relatively low (below $3.0 \mu\text{g}/\text{m}^3$) across much of California. During 2015-2019, over half of California counties experienced annual average WF- $\text{PM}_{2.5}$ concentrations of 3.5 to $6.0 \mu\text{g}/\text{m}^3$ (52%), while some counties in the northern region reached concentrations up to $11.4 \mu\text{g}/\text{m}^3$. During 2020-2023, annual average WF- $\text{PM}_{2.5}$ concentrations increased substantially, reflecting the severe smoke impacts of 2020 and 2021. Several highly impacted counties, particularly in the northern and eastern regions, including Mono, Siskiyou, Plumas, and Trinity, experienced annual average WF- $\text{PM}_{2.5}$ concentrations above $24.0 \mu\text{g}/\text{m}^3$, with Trinity County reaching $40.0 \mu\text{g}/\text{m}^3$.

Health metric

Across wildfire seasons (May-November) from 2010-2020, an estimated 22,096 excess respiratory emergency department (ED) visits (95% CI: 19,161-24,953) were attributable to WF- $\text{PM}_{2.5}$ exposure (**Figure 5.3.3**). Annual excess respiratory ED visits increased over time, from about 200 in 2010 to over 5,500 in more recent years. The largest increases occurred in 2017, 2018, and 2020, during severe wildfire seasons that included major fires such as the Thomas Fire, Camp Fire, and August Complex Fire. In 2020, the estimated number of WF- $\text{PM}_{2.5}$ attributable respiratory ED visits (5,667) was lower than in 2018, likely reflecting the sharp decline in ED utilization during the onset of the COVID-19 pandemic. Overall, the upward trend in WF- $\text{PM}_{2.5}$ attributable respiratory ED visits indicates that wildfire smoke became an increasing contributor to the statewide respiratory health burden over time, particularly during years with more severe smoke impacts.

Why is this indicator important?

Smoke Metric

Wildfire smoke is an increasingly important air quality concern in California. As the frequency, intensity, and duration of wildfire smoke events has increased, smoke



emissions have begun to offset improvements in air quality achieved over past decades (Deng et al., 2026; Jaffe et al., 2026; Jaffe et al., 2020). Recent research suggests that wildfire smoke now contributes up to 50% of ambient fine particulate matter (PM_{2.5}) in the western U.S., underscoring its growing influence on regional air quality (Burke et al., 2022). Wildfire smoke has become an increasingly important driver of harmful PM_{2.5} pollution exposure in California and is no longer limited to isolated air quality events during the most severe fire seasons.

Wildfire smoke is a complex mixture of fine particles and gases, and its composition can vary depending on the types of vegetation or material burned, fire behavior and intensity, and weather conditions. PM_{2.5} is the most studied component of wildfire smoke and among the most harmful to health, because these particles can remain in the air for extended periods and travel long distances. PM_{2.5} can penetrate deep into the lungs, enter the bloodstream, and affect the heart and other organs. Wildfire smoke also contains other hazardous pollutants, including carbon monoxide, nitrogen oxides, volatile organic compounds, polycyclic aromatic hydrocarbons, and metals. Some of these pollutants, such as benzene and formaldehyde, are known carcinogens.

In addition to smoke generated from burned vegetation, fires that burn in the wildland-urban interface (WUI) – areas where built structures and developed landscapes intermix with wildland vegetation – can produce a more complex mixture of toxic pollutants from building materials, household products, vehicles, and other synthetic sources. These emissions can create more hazardous air pollution than smoke from wildfires that burn primarily vegetation. A recent analysis reported that large wildfires that burned more structures produced smoke containing toxic heavy metals such as lead and zinc (CARB, 2021).

More generally, wildfire smoke can infiltrate indoor environments like schools, workplaces, and homes, affecting the air people breathe indoors. Smoke can enter through doors, windows, ventilation systems, or other openings if not properly sealed, contributing to unhealthy indoor air. As people spend most of their time indoors, smoke that infiltrates buildings can become an important source of smoke exposure during wildfire events, especially when sheltering indoors (Liang et al., 2021).



Wildfire smoke can also interact with other air pollutants and climate-related exposures. Across the western U.S., smoke emissions have been associated with increasing co-occurrence of hazardous PM_{2.5} and ground-level ozone concentrations, particularly during summer months when strong UV light and higher temperatures can promote ozone formation (Kalashnikov et al., 2022). Over the last two decades, these overlapping events have contributed to greater population exposure to multiple harmful air pollutants (Kalashnikov et al., 2022).

As wildfire seasons become longer and more severe, wildfire smoke is also increasingly co-occurring with extreme heat, which is also becoming more frequent in California (see the *Extreme Heat Events* chapter). When wildfire smoke and extreme heat occur at the same time, this compound climate hazard may pose greater health risks than either exposure alone (Chen et al., 2024a; Jones-Ngo et al., 2025a; Rahman et al., 2022). These co-occurring exposures also create additional challenges related to cooling, air filtration, and other resources used to reduce smoke and heat exposure. In 2020, extreme heat and high concentrations of wildfire-related PM_{2.5} co-occurred at least once across 68% of California's land area, occurring an average of 2.5 times across affected areas. An estimated 16.5 million people, or 42% of the state's population, were exposed to at least one such compound event (Rosenthal et al., 2022).

Health Metric

Exposure to wildfire smoke is an increasingly important contributor to respiratory-related morbidity, as well as other adverse health impacts that are experienced disproportionately across populations and regions of the state. Epidemiologic and toxicological studies of wildfire smoke-related health effects have focused primarily on wildfire smoke PM_{2.5}, while less is known about the health effects associated with gaseous components of wildfire smoke (Chen et al., 2021; Chen et al., 2024b; Kim et al., 2018). Some studies also suggest that wildfire smoke PM_{2.5} may pose greater adverse health effects than PM_{2.5} from other ambient sources due to its complex pollutant mixture and toxicity (Aguilera et al., 2021). The strongest and most consistent evidence on the health effects of wildfire smoke relates to short-term respiratory outcomes associated with exposure on the day of a smoke event and over the following several days (Gould et al., 2024; Reid et al., 2016). Wildfire smoke has been associated with asthma exacerbation, reduced lung function,



chronic obstructive pulmonary disease, pneumonia, and heart conditions, such as congestive heart failure and cardiac events (Cascio, 2018; US EPA, 2019). Evidence for cardiovascular-related impacts has been reported, although findings are generally less consistent compared to respiratory outcomes (Chen et al., 2021; Reid et al., 2016; Thilakaratne et al., 2023). These health impacts are often tracked and studied using healthcare utilization data, such as emergency department visits and hospitalizations, as well as other health indicators that allow researchers to quantify how the health burden of wildfire smoke changes over time and across populations.

Evidence is expanding beyond respiratory and cardiovascular-related health effects and increasingly includes adverse birth outcomes, cognitive and neurodegenerative effects, premature mortality, and mental health effects, including anxiety, depression, psychotic episodes, and suicidal behavior (Cleland et al., 2022; Connolly et al., 2024; Eisenman and Galway, 2022; Elser et al., 2025; Heft-Neal et al., 2022; Jung et al., 2025; Ma et al., 2024; Qiu et al., 2025; Zhu et al., 2024). However, research on health effects beyond acute impacts remains limited and continues to develop with advancements in data availability and methodological approaches.

Concerns are growing about the health effects of repeated and long-term wildfire smoke exposure (Casey et al., 2024; Hao et al., 2026; Jin et al., 2025; Schwarz et al., 2025). More frequent multi-day smoke events and shorter intervals between events (recovery periods) may limit the ability of communities to fully recover between periods of hazardous air quality (Jones-Ngo et al., 2025b). Emerging evidence also suggests that repeated and long-term wildfire smoke exposure may contribute to chronic diseases such as diabetes, dementia, and stroke, as well as all-cause and cause-specific mortality (Connolly et al., 2024; Elser et al., 2025; Hao et al., 2026; Ma et al., 2024; Zhang et al., 2026). Additional research is needed to better understand how these changing exposure patterns may affect long-term health.

Some populations and communities may be more affected by wildfire smoke than others. Identifying who is most affected and where public health impacts are most severe is important for prioritizing public health actions and protective resources across the state. Infants, children, older adults, pregnant people, individuals with pre-existing health



conditions, unhoused populations, outdoor workers, wildland firefighters, and communities facing environmental, socioeconomic, and racial inequities may be disproportionately affected by wildfire smoke (Cascio, 2018; Casey et al., 2024; Gould et al., 2024). These unequal health burdens reflect differences in both exposure and vulnerability to wildfire smoke, which are influenced by the conditions in which people live and work. Current evidence indicates that several populations experience disproportionate exposure to wildfire smoke; studies have also reported differential health effects across sociodemographic groups, although this evidence remains less consistent (Casey et al., 2024; Heaney et al., 2022; Kondo et al., 2019; Reid et al., 2016; Stowell et al., 2025).

Tribal Connection 5.3.1

California Native American Tribes also face disproportionate impacts due to the legacy of genocide and forced relocation, which continues to perpetuate health and economic inequities today. For example, a member of the Big Pine Paiute Tribe in the Owens Valley writes: *“As our people no longer travel to the mountains to live during the hotter summer months, they are routinely exposed to higher temperatures in the summer. Summer is typically dry and windy, with exposure to smog from tourist vehicles and smoke from California wildfires. During the 2020 fire season, residents of the Owens Valley were forced to remain indoors for many months straight. It should be noted that during this time there was little wind, which allowed the smoke to settle over the town of Big Pine; many people commented about how unusual it was. Not all households own air conditioners or swamp coolers, so many people are left in houses that are too hot to safely occupy.”* (Big Pine, 2026)

Assessing the health burden of wildfire smoke provides critical information to support emergency preparedness and response, strengthen adaptive capacity, and reduce population exposure during smoke events. Mitigating smoke-related health impacts requires timely smoke and health data, accessible public health communications, and expanded access to protective resources. Improved data can support situational



awareness and inform state and local response activities, while clear, actionable, culturally and linguistically appropriate guidance delivered through multiple channels can help communities take recommended protective actions. More equitable access to resources such as Clean Air Centers, N95 respirators, and portable air cleaners can further support efforts to reduce smoke exposure.

What factors influence this indicator?

Several factors contribute to wildfire smoke exposure and related health impacts across California, including wildfire activity and smoke intensity, geographic and community characteristics, health inequities, access to protective resources, individual protective behaviors, and other contextual factors that may affect emergency department utilization or healthcare-seeking behavior.

Wildfire Activity and Smoke Intensity

Wildfire smoke-related PM_{2.5} concentrations vary widely across California due to differences in the characteristics of landscape fires and the specific conditions that influence how smoke is generated, transported, and experienced by communities in different regions of the state year to year. The location and size of a wildfire, the intensity of the burning, the types of vegetation and materials burned, how dry (or moist) the vegetation is, and the rate at which an area burns all influence the amount of WF-PM_{2.5} emitted into the atmosphere (Reid et al., 2016). Fires that are larger, more intense, and longer-lasting are often due to hotter and drier burn conditions, or accumulated vegetation, and typically generate higher WF-PM_{2.5} emissions and wider geographic impacts (Williamson et al., 2016).

Meteorological and topographic characteristics, including wind speed and direction, temperature, humidity, and atmospheric inversions, further influence how smoke is transported and dispersed (Jaffe et al., 2020). In regions of California prone to temperature inversions, such as the Central Valley and mountain basins, smoke can remain trapped at ground-level for extended periods, increasing the duration of population exposure (Gao et al., 2023). Additionally, as smoke disperses in the atmosphere, its chemical composition and toxicity can transform through interactions with other pollutants, contributing to both regional and compositional differences in pollution



mixtures (Altshuler, 2020; Jaffe et al., 2020). Together, these factors contribute to significant geographic and seasonal variations in WF-PM_{2.5} concentrations across the state.

Geographic and Community Characteristics

Geographic and community characteristics influence both population exposure and vulnerability to wildfire smoke across California. Rural and more remote communities often face disproportionate smoke impacts due to their proximity to wildfire-prone areas. These regions may also face additional vulnerabilities that affect adaptive capacity, such as longer travel times to seek healthcare services, fewer local resources to mitigate smoke exposure, or limited access to timely information during smoke events. As wildfire activity intensifies and expands across the state, fires occurring in WUI areas may increasingly affect more densely populated communities (Alshehri et al., 2023; Krasovich Southworth et al., 2025). Similarly, changing patterns in California's population growth, mobility, and migration, such as expanded development in WUI areas, may further contribute to geographic variations in wildfire smoke exposure and related health impacts by changing where people and housing are located relative to wildfire activity.

In addition, community characteristics such as age distribution, underlying health status, occupational conditions such as outdoor or emergency response work, and housing conditions can contribute to differences in wildfire smoke exposure and associated health outcomes (D'Evelyn et al., 2022; Do et al., 2024). Communities with a higher prevalence of chronic conditions such as asthma, heart disease, or diabetes may experience greater wildfire smoke-related health impacts (Reid et al., 2023; Liu et al., 2015). Together, these characteristics influence population-level and regional variations in wildfire smoke exposure and health impacts and point to important inequities in community capacity to prepare for and respond to smoke events.

Health Inequities, Access to Resources, and Protective Actions

Health inequities are often reflected in social determinants of health, such as income, education, occupation or workplace conditions, access to healthcare, and housing quality, which shape both vulnerability and the ability to mitigate exposure to wildfire smoke (Kramer et al., 2023; Weheba et al., 2024). These inequities are rooted in historical and ongoing environmental injustice, housing, and land use policies that concentrate social



and environmental burdens in specific neighborhoods and populations across California, contributing to greater smoke and health impacts (Casey et al., 2024; D'Evelyn et al., 2022; Jung et al., 2024; Lane et al., 2022).

For many of these communities, wildfire smoke can act as a threat multiplier, adding to existing environmental burdens, including poor air quality, multiple sources of pollution, low housing quality, and other environmental hazards further compounded by frequent smoke events (Davies et al., 2018; Reid et al., 2023). These overlapping burdens can increase vulnerability during smoke events, particularly for communities and individuals that already face barriers in managing underlying health conditions or accessing protective resources such as air conditioning, indoor air filtration, well-sealed indoor environments, or other health-protective resources (Jaffe et al., 2020).

Individual behavioral responses and protective actions during wildfire smoke events influence the extent of exposure and risk of health impacts (Burke et al., 2022). People may evacuate, temporarily relocate, reduce outdoor activity, wear N95 respirators, use indoor air filtration, or take other actions to reduce exposure to smoke. However, the ability to adopt these health-protective behaviors varies across communities in California and may be limited by the inequities and resource constraints described above.

Interpretation of Emergency Department (ED) Utilization in 2020

The WF-PM_{2.5}-attributable respiratory burden estimated for 2020 should be interpreted in the context of significant changes in healthcare utilization patterns and pandemic-related behaviors during the COVID-19 pandemic. The ED visit data showed a substantial decline in respiratory ED visits from all causes during 2020, reflecting reduced utilization and general avoidance of healthcare services during the early period of the pandemic. Moreover, widespread adoption of health-protective behaviors, such as spending more time indoors, masking, and using indoor air filtration, may have altered the conditions under which respiratory health impacts attributable to wildfire smoke were estimated. In addition, changes in COVID-19-specific ICD-10 coding practices during this period may have influenced how respiratory ED visits were recorded or classified in administrative health data. Consequently, these pandemic-related factors complicated direct



comparisons between 2020 and earlier wildfire seasons and limited the ability to fully characterize the wildfire smoke-attributable respiratory burden for 2020.

Technical considerations

Data sources

Smoke Metrics

Population impacts from wildfire smoke were estimated using daily smoke plume data from the National Oceanic and Atmospheric Administration (NOAA) Hazard Mapping System (HMS) Smoke Product and population data from the U.S. Census Bureau Centers of Population by Block Group. HMS is a satellite-based smoke product that maps the spatial extent of visible smoke plumes across North America over 24-hour periods. Block group centers of population from the 2010 Census were used for 2010-2019, and 2020 Census centers of population were used for 2020-2025.

Annual person-days of smoke were estimated using HMS smoke polygons, which were intersected with block group centers of population to identify areas and populations potentially impacted by smoke each day. For each year, population counts in smoke-affected areas were multiplied by the total number of days smoke was detected. Person-days were then summed across all impacted areas to estimate total annual person-days of smoke across California.

Daily wildfire-specific PM_{2.5} concentrations were obtained from high-resolution wildfire smoke PM_{2.5} datasets by Childs et al. The health impact assessment used the Childs et al. (2022) dataset, which provides modeled daily (24-hour average) concentrations of fine particulate matter derived specifically from wildfire smoke across the contiguous United States from 2006 to 2020. WF-PM_{2.5} concentrations were estimated using a data fusion and machine-learning modeling framework that integrates ground-based air quality monitoring data, satellite observations, smoke dispersion modeling, and meteorological data. Daily WF-PM_{2.5} estimates were generated at a 10-km gridded resolution and subsequently downscaled to the ZIP Code Tabulation Area (ZCTA) level using population- and area-of-intersection-weighted averaging.

The county-level WF-PM_{2.5} concentrations shown in [Figure 5.3.2](#) were estimated using the updated v2.0 preprint dataset from Childs et al. (2025), which extends the period



through 2023. Daily WF-PM_{2.5} estimates were extracted for California ZCTAs from 2010-2023 and aggregated to the county level. County-level daily estimates were then averaged annually and summarized for the 2010-2014, 2015-2019, and 2020-2023 periods.

Health Metric

Statewide emergency department (ED) visit records were obtained from the California Department of Health Care Access and Information (HCAI), which maintains administrative records of all ED visit encounters in California. Respiratory-related ED visits were identified using principal diagnosis codes from the *International Statistical Classification of Diseases, Ninth and Tenth Revisions* (ICD-9 and ICD-10), with respiratory diseases defined using diagnosis codes 460-519 (ICD-9) and J00-J99 (ICD-10). Daily ED visit counts were aggregated to the ZCTA level for each May-November period from 2010-2020 and restricted to encounters with a residential ZIP code in California. The daily ED visit counts were then linked with the WF-PM_{2.5} data by residential ZIP code and date.

A health impact assessment framework was used to estimate the excess number of respiratory ED visits attributable to WF-PM_{2.5} exposure in California from 2010-2020 (Gasparrini & Leone, 2014). This assessment used a previously published health effect estimate, which represents the association between short-term WF-PM_{2.5} exposure and respiratory-related ED visits, and applied the corresponding concentration-response function (CRF) to calculate the population-level health burden attributable to wildfire smoke. The CRF describes how changes in daily WF-PM_{2.5} concentrations relate to corresponding changes in respiratory ED visits.

Specifically, a published health effect estimate from Stowell et al. (2025) was used. This health effect estimate reflects the cumulative change in risk of respiratory-related ED visits over seven days following WF-PM_{2.5} exposure in California (2012-2019). For this indicator, the cumulative 7-day risk estimate was converted into a CRF that reflects the proportional change in respiratory ED visit risk per $\mu\text{g}/\text{m}^3$ increase in WF-PM_{2.5}. The wildfire season was defined as the period from May through November each year, as this



exposure window captures the months when wildfire activity and WF-PM_{2.5} concentrations are most common in California.

The attributable number, or the estimated number of respiratory ED visits associated with wildfire smoke was calculated to compare wildfire smoke-attributed respiratory impacts across years. Daily ZCTA-level WF-PM_{2.5} estimates were used to assign exposure values to corresponding ED visit counts by residential ZIP code and date. WF-PM_{2.5} attributable ED visits were estimated for each ZCTA-day in which WF-PM_{2.5} concentrations were above 0 µg/m³. These ZCTA-day estimates were then summed across all impacted days within each year to quantify the number of respiratory ED visits associated with wildfire smoke during each May-November wildfire season from 2010-2020.

A concentration limit of 100 µg/m³ was applied to reduce the potential for overestimation at very high WF-PM_{2.5} concentrations. For any ZCTA-day in which WF-PM_{2.5} exceeded 100 µg/m³, concentrations were set to 100 µg/m³ before estimating the WF-PM_{2.5} attributable number of ED visits (affecting <1% of data). This approach attempted to adjust daily attributable ED visit estimates that may be disproportionately affected by a small portion of ZCTA-days with severe smoke impacts, particularly in 2017, 2018, and 2020, when several areas of California experienced extreme levels of WF-PM_{2.5}. By excluding exposures above 100 µg/m³, this indicator provides more conservative estimates of wildfire smoke-attributable respiratory health impacts during the most severe smoke events.

Metric Formula:

$$\text{Attributable Number} = \text{Observed ED Visits} \times \left(1 - \frac{1}{RR_{\Delta WF-PM_{2.5}}}\right)$$

Where:

Observed ED Visits = the total number of respiratory ED visits from all causes for a given ZCTA-day

RR = the relative risk associated with the WF-PM_{2.5} concentration on that ZCTA-day, based on the concentration-response relationship reported in Stowell et al. (2025)

$\Delta WF-PM_{2.5}$ = the WF-PM_{2.5} concentration on that ZCTA-day, relative to a counterfactual of no wildfire smoke exposure (WF-PM_{2.5} = 0)



Strengths and limitations

Smoke Metric

The HMS Smoke Product is publicly available, updated daily, and covers all of North America, providing consistent and timely observations of smoke plume detections derived from satellite imagery and validated by human analysts. HMS is valuable for producing geographically relevant indicators of fire-related smoke plumes for characterizing smoke impacts across space and time. However, HMS smoke detections should be interpreted as an indicator of potential population exposure rather than a direct measure of ground-level air quality conditions or individual-level exposure. While HMS detects visible smoke in the atmosphere, it cannot determine the height of smoke plumes or whether smoke was near ground level where people breathe. Satellite-based smoke detections can also be influenced by cloud cover, daylight availability, and the timing of observations over a given area. Smoke plumes can shift rapidly and may not be fully captured by detections, which may impact the coverage and accuracy of HMS data.

Person-days of smoke should also be interpreted within this context. This metric is based on residential population locations and does not account for mobility, evacuation, time spent indoors, use of air filtration, or other protective measures. Additionally, because person-days are calculated by multiplying smoke days by number of people in an affected area, the metric gives greater weight to smoke events occurring in more densely populated areas and may understate impacts in less populated rural areas that may experience more frequent smoke but contribute fewer total person-days.

The WF-PM_{2.5} exposure metric is derived from modeled daily ZCTA-level estimates of wildfire-specific PM_{2.5}. The model provides fine-scale estimates of wildfire smoke intensity across California, particularly in areas where stationary monitors or air quality sensors are sparse or unavailable. This allows wildfire-specific PM_{2.5} concentrations to be characterized across space and time in ways that would not be possible using monitoring data alone. Although the model is well validated and demonstrated strong performance, WF-PM_{2.5} estimates may be less certain at very high concentrations, which may introduce exposure measurement error in high-impact locations. The WF-PM_{2.5} estimates reflect wildfire-derived PM_{2.5} only and do not account for potential exposure to other pollutants, co-pollutant mixtures, or co-occurring exposures such as extreme heat and wildfire



smoke, all of which may modify respiratory-related health effects associated with WF-PM_{2.5} exposure.

Health Metric

The health indicator applied a well-validated health impact assessment approach using a peer-reviewed, California-specific health effect estimate that reflects the cumulative respiratory effects of wildfire smoke over a seven-day exposure period. The indicator also used established data sources, consistent with those applied in Stowell et al. (2025), to integrate modeled WF-PM_{2.5} estimates with statewide emergency department data, providing strong generalizability across the 2010-2020 study period.

The use of respiratory ED visit encounters (identified by ICD-9/10 diagnostics codes), a well-established health outcome in air quality and wildfire smoke health studies, provided a valid and standardized measure of respiratory impacts at the population-level. The health data captured more than five million respiratory ED visits over an 11-year period, enabling the characterization of statewide trends in wildfire smoke-related health impacts across more than a decade of wildfire seasons in California. Lastly, the characterization of population-level health impacts using the attributable number provides a clear and interpretable measure of estimated wildfire smoke-related health impacts in California.

However, the health indicator is based on administrative emergency department visit data, and therefore only captured respiratory health events that resulted in an ED visit encounter. This excludes urgent care visits, outpatient care, hospital admissions, and subclinical respiratory symptoms that may have also resulted from wildfire smoke exposure. The indicator does not include differences in health impacts by age, race-ethnicity, sex or gender identity, socioeconomic status, health status, or other factors that may result in disproportionate health impacts among specific subpopulations. Finally, behavioral responses to smoke and health-protective actions, such as mask use, indoor air filtration, access to clean air spaces, and other adaptive strategies, are not captured in the available data, though may substantially protect individuals from exposure and associated health outcomes. Taken together, these strengths and limitations provide important context for interpreting the smoke and health indicators presented in this chapter.



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