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Environmental Disaster: The Impact of Wildfire-Induced Air Pollution on Health Emergencies in California, USA

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The study examines environmental disaster of wildfire in California and its air on human health. The study adopted a descriptive data analysis. The secondary data for analysis was collected from data base of https://www.fire.ca.gov/ . The scope of data collected covered from 2016 to 2024 amounting nine years period. The visual presentation of the data was done in tables and charts. A total of 4,675,113 were total emergences, 70,252 was total wildfire, 23,209,50 was the total acres covered, 203 death recorded and 55,639 structured destroyed. The study concluded that wildfire case has significant prevalence in the past one decade. Wildfire contributes to 1.9 in average of total emergences in US becoming a year occurrence since 2016. There is significant health challenges resulting from air pollution from wildfire and this have contributed to significant health complications and mortality rate. The study recommended that there is need to implement advanced technologies for early wildfire detection and real-time monitoring. There is need to develop targeted air quality alerts and public health advisories to protect vulnerable populations during wildfire seasons and there is need to invest in reforestation, controlled burns, and land management strategies to reduce fuel loads.

Keywords: environment, wildfire, public health, health emergence, air pollution

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1. Introduction

Wildfires are becoming increasingly destructive due to more frequent wildfire incidence, as well as consistent growth in wildfire severity, size, and duration over the last 20 years. This is driven by three primary factors: climate change, historical fire suppression in U.S. forest management, and the expansion of the wildland-urban interface (WUI), or "the zone of transition between unoccupied land and human development". As a result, eight of California's ten largest wildfires have burned within the last decade. Similarly beyond a U.S. context, wildfires in the European Union burned nearly 2 million acres in 2022, about 2.5 times the an Severe wildfires incur well-documented ecological and economic costs. High-severity wildfire events cause long-term species and even ecosystem loss31 as well as contribute sharply to greenhouse gas emissions. The 2018 California Camp Fire killed 85 people, destroyed over 18,000 structures and created $19 billion (inflation-adjusted) in damages. (Atkinson, et al 2014).

Today, federal fire suppression costs total over $2.5 billion a year, in addition to costs borne by state, local, and Tribal governments.35 The total economic cost of wildfire damages nationwide is estimated at "tens to hundreds of billions of dollars" annually.36 Increased attention is now being brought to the social costs of wildfire to human health. Between 2007 and 2018, 99.5% of California's population lived in a county with at minimum one smoke wave, or chronic smoke event. Today, according to a Stanford University study, wildfire-specific PM2.5 pollution has increased to the extent that it has reversed multi-decadal progress in U.S. air quality made under the Clean Air Act. (Appel et al. 2021).

The health costs of wildfire also notably exacerbate social inequalities by most severely impacting populations least able to protect themselves from wildfire and resulting smoke. Projected future risk under current climate scenarios While fire is natural and healthy in fire-adapted landscapes, research shows that anthropogenic climate change contributed to a +172% increase in the area burned in California between 1971 and 2021, and a +320% increase between 1996 and 2021. (BarkJohn, 2021). The Fourth U.S. National Climate Assessment predicts that climate change will result in a tripling in the amount of large wildfires by 2050, And research accordingly projects that over 82 million people will be impacted by smoke waves by mid-century. (Lassman et al, 2023). Building public health resilience to wildfire The California Climate Adaptation Strategy defines resilience as "a state of readiness to face climate risks". (Lassman et al, 2023). Various efforts have been made to build public resilience to wildfire, most notably including public information about smoke and fuel management strategies to decrease wildfire risk. The California Air Resources Board engages in extensive communication campaigns sharing smoke precaution mechanisms with wildland fire-affected communities. (Chen et al, 2022).

Land management strategies to mitigate wildfire risk have also been significantly increased on state and federal levels. Efforts are notably underway to coordinate siloed stakeholders in wildland fire management and public health. The California Wildfire and Forest Resilience Task Force integrates multi-stakeholder efforts at the state level, (Bask et al 2019). Multiple coordinating entities have issued meaningful recommendations for interagency wildfire resilience on the federal level. (Emery, et al, 2021). However, the complexity of public health impacts poses significant challenges for the policy landscape, and many effects are yet unknown. This paper investigates the latest research on the public health impacts of wildland fire in order to identify remaining gaps and propose recommendations for greater health resilience towards a better public health emergencies control in California.

2. Literature Review

One of the years of wildfire in California was in 2020. The largest area burned due to wildfires in California in recorded history and included 5 of the top 7 largest wildfires ever recorded in California. More than 1.7 million hectares burned in 8648 incidents, and 33 people perished as a direct result of the fires (CalFire 2022). The largest fires started in mid-August, clustering across northern California and around the Bay area, which famously turned San Francisco daylight skies into an apocalyptic orange twilight for several days. Because of the large and widespread fires, the state experienced long episodes of elevated fine particulate matter particulate matter with diameter smaller than 2.5 micrometres concentrations (Li et al., 2021).

Exposure to elevated concentrations of PM2.5 is linked to increased respiratory and cardiovascular illnesses and can lead to increased mortality (Atkinson et al. 2014, Brook etal., 2010). Prior research has investigated the effects of recent wildfires on air quality and public health through two primary methodologies. One approach involves employing wildfire emissions and chemical transport models to simulate the contribution of wildfires to PM2.5 levels, as demonstrated by studies conducted by Shi et al. (2019) and Lassman et al. (2023).

The other method utilizes direct measurements obtained from ground-based or satellite observations to map pollutant concentrations and subsequently estimates the portion attributed to wildfires, as seen in research by Wang etal. (2021) and EnayatiAhangar etal. (2022). Shi et al. (2019) specifically examined the impact of wildfires in Southern California in December 2017, utilizing various satellite-based techniques and a chemical transport model to estimate wildfire emissions and their influence on PM2.5 concentrations and population exposure.

The primary physical health risk from wildfire is smoke-induced air pollution. Wildfire smoke contains thousands of compounds, including particulate matter (PM), carbon dioxide, carbon monoxide, nitrogen oxides, complex hydrocarbons, and irritant gases, (Ahangar et al , 2022). These compounds cause varying levels of damage to human health depending on the material burned and its interaction with chemical compounds in the atmosphere, (Gettleman, et al 2022). PM 2.5 exposure The majority of epidemiological research on wildfire smoke has concentrated on its emission of PM2.5, or particulate matter smaller than 2.5 micrometres in diameter, which can easily lodge in the lungs and enter the bloodstream. (Honf et al 2016).

Even brief PM2.5 exposure has been shown to cause spikes in asthma, respiratory symptoms, allergic reactions, strokes, heart attacks, and general hospitalization. Its health effects are not limited to acute wildfire events, however: PM2.5 exposure has been linked to lasting damage to the heart, lungs, liver, kidneys, and the immune system. (Jiang,, 2022). A Harvard University study showed that a minor increase in PM2.5 exposure correlated to an 8% increase in Covid-19 related mortality, (Appel et al , 2021).

While other recent research has shown a correlation between wildfire-associated PM2.5 exposure and the incidence of tuberculosis.57 Smoke pollution exposure is associated with preterm birth and elevated measures of risk if experienced at any point of pregnancy. (Grell et al 2022). Over the long term, PM2.5 exposure has been linked to the exacerbation of Alzheimer’s disease and related dementias, as well as increases in average mortality. (Katsouyanni,, 2019). The World Health Organization (WHO) estimates that PM2.5 exposure results in 7 million premature deaths globally per year. Spikes in PM2.5 exposure from wildfire smoke are becoming increasingly chronic. Research has quantified the contribution of wildfire smoke to ambient PM2.5 exposure in the U.S., showing a 25% average erosion in air quality progress due to increasing wildfire pollution, rising to over 50% across most of the western U.S. (Lassman et al, 2017).

New research is showing that wildland fire-specific PM2.5 interacts differently with the human body than other types of PM2.5 from pollution sources such as vehicular and industrial emissions. (Li et al, 2021). A UC San Diego study found wildfire-specific PM2.5 to be about 10 times more harmful to children’s respiratory health than ambient PM2.5 pollution. (Mandel, et al, 2022). These impacts are attributed to smoke composition: organic matter (such as the wood and forest biomass combusted in wildfires) has high oxidative potential, which is linked to higher levels of inflammation in the body than that caused by other air pollutants. (Grell et al , 2022). Higher levels of inflammation exacerbate the existing respiratory and immunological effects of PM2.5 exposure. (Grell et al , 2022). Research is continuing into the differential impacts of wildland fire-specific PM2.5 on human health. Residential and industrial combustion. As wildfires increasingly affect the wildland-urban interface (WUI), the organic composition of combusted material is often accompanied by burning residential or industrial infrastructure. (Matsui,, 2020). The combustion of residential insulation, appliances, electronics, cars, paints, pesticides, and other materials can release asbestos, heavy metals, and other chemically hazardous substances into wildfire smoke and the water supply. (Sharma et al, 2022). While this chemical pollution is usually more localized to the area burned, its adverse health impacts on firefighters and local communities is of concern. (Wang et al, 2019).

Research into the specific health effects of burning infrastructure on wildfire-affected populations is currently underway. (Shim et al, 2019). Chemical fire retardants In order to meet state flammability standards, many household and consumer products such as mattresses, car interiors, electronics, and carpets are coated in flame retardant chemicals.

Despite their success in slowing point-source ignition, fire retardants' chemical composition has been shown to significantly increase smoke toxicity upon combustion. Polybrominated diphenyl ethers (PBDEs), a common group of fire retardants, have been linked to neurological, reproductive, and cognitive harm, as well as cancer incidence in multiple studies. (Lassman et al, 2023).

Halogenated fire retardants increase the emission of carbon monoxide, hydrogen chloride, and other toxic gases, which are responsible for more fire deaths than combustion itself. The detrimental health effects of fire retardants have been most documented among firefighters, who experience elevated rates of chemical exposure-related cancers — up to six times the national average. (Grell et al 2022). Fire retardant chemicals can also adversely impact public health outside of fire events:

The dry, windy, and hot weather conditions that drive wildfires also facilitate smoke dispersion high into the atmosphere and over large geographic distances. The interaction of smoke particles with atmospheric conditions can alter their chemical composition, exacerbating health impacts on downwind populations. (Lasman et al, 2023). Increases in smoke particle toxicity through oxidation in the atmosphere is a key area for future research. (Grell et al , 2022). The National Oceanic and Atmospheric Association has cataloged wildfire smoke's outsized contribution to the creation of ozone pollution, and is continuing research into the complex properties of smoke dispersion and their cross-populational impact. (Grell et al , 2022).

The health risks of wildfire smoke-induced air pollution follow different distributional patterns than those from other sources of ambient air pollution. (Ahangar et al , 2022). Contrary to other sources of PM2.5 typically concentrated around industrial or vehicular emissions corridors, wildfire smoke disperses widely and affects a much higher proportion of the U.S. population. (Gettleman et al 2019).

When analysed on a census tract level, the highest increases in PM2.5 exposure between 2006 and 2020 have been observed in higher-income and Hispanic populations. Exposure among Black populations has decreased over time, but exposure in Tribal populations has remained by far the highest of all demographic groups. (Grell et al 2022). Beyond broader demographic distribution patterns, wildfire smoke exposure exacerbates structural determinants of health by most harming already-marginalized populations.

Those most vulnerable to increases in air pollution include children, the elderly, the disabled, pregnant people, those with chronic health conditions, outdoor workers, firefighters, Indigenous populations, undocumented populations, incarcerated populations, and unhoused populations. (Lassman, et al 2023). Mediating effects of behavioural responses to wildfire smoke exposure It is important to note that the physical health impacts of wildfire smoke are differentially experienced depending on the ability to afford private measures of protection. Access to protective measures such as air filtration, adequate insulation, and ventilated spaces has the potential to mediate the distributional impacts outlined above. Research by a team at Stanford University found that behavioural responses to smoke exposure, such as Google searches for air filters, were effectively predicted by higher socioeconomic status. (Lassman et al, 2017).

Another study found that medical care-seeking behavior was also impacted by smoke concentration. (Lassman et al, 2023). Emergency department visits during low and moderate smoke days in the study were higher than normal, but declined significantly during extreme smoke days. The starkest declines in seeking medical care were observed for non-respiratory symptoms and injuries, as well as for less-insured populations. This mediation of behavioral responses on the health effects of wildfire adds an element of complexity in epidemiological research on smoke, which often measures emergency department visits as a metric of exposure severity. Economic costs of wildfire smoke exposure, (Grell et al 2022). As a result, the impact from wildfire emissions is believed to be underrepresented in the second week of September, and overall, modelling results suggest that the effects of wildfires on daily PM2.5 presented here are under predicted.

Biomass burning modelled in this study is a major source of atmospheric organic aerosol, typically referred to as brown carbon. Wildfires and brown carbon contribute to the planetary radiative balance and to the formation of secondary organic aerosol, although there are still model limitations in our understanding of the atmospheric transformations of brown carbon (Wong etal. 2019).

Overall, results suggest that wildfires more than doubled the fraction of OM in aerosol, and the overall OM contribution to total PM2.5 during fire events was over 80%.. Psychosocial health impacts of wildfire In addition to the physical health impacts of smoke-induced air pollution, wildfires generate considerable adverse psychosocial effects. Similarly to smoke exposure, these are experienced acutely during catastrophic wildfires, over the long term, and increasingly by populations not directly affected by the wildfire itself. The dispersed and concentrated impacts of wildfires on wellbeing and mental health are detailed in the following sections, (Ahangar et al , 2022).

Societal impacts such as housing loss and displacement are included due to direct links to negative mental health impacts of catastrophic wildfire. Dispersed societal health impacts Wildfires generate dispersed adverse societal impacts in two primary categories besides smoke exposure: exacerbating climate change and disrupting power availability, (Grell et al , 2022).

Wildfires are a significant source of greenhouse gas emissions even as they are driven in large part by climate change.89 Severe fire events produce large amounts of carbon dioxide as well as ozone, the third most potent greenhouse gas, (Katsouyanni,, 2019).

Higher greenhouse gas emissions fuel future wildfire incidence and exacerbate the broader societal impacts of climate change, such as further air quality deterioration and disease incidence. (Gettleman et al, 2023). Wildfires are also notable for disrupting regional power availability. As electric power lines have sparked multiple of California's most destructive fires, preemptive power shutoffs are often employed as a wildfire mitigation measure during high-risk weather events. In 2019, power shutoffs were implemented by California utilities on 27 separate days, some lasting over five days in duration. (Katsouyanni,, 2019).

While they successfully mitigate wildfire incidence, protective power shutoffs also result in a range of public health risks, most notably on populations relying on electricity to power at-home medical equipment. (Grell et al 2022). Other impacts include the loss of refrigeration of medicines, food, and other essential supplies, the loss of electric waste disposal and clean water supply mechanisms, as well as the loss of lighting, especially for populations with disabilities and the elderly. (Honf et al 2016).

Public safety power shutoffs also impact communication infrastructure, limiting residents' ability to go about their daily lives, call for emergency services, or receive evacuation notifications if needed, (wang et al, 2021). Displacement due to the lack of safe and consistent shelter is responsible for high emotional stress, including causing deaths post-fire. (Gettleman, 2022). The destruction of communities results in property loss, employment loss, and the increased incidence of poverty and homelessness. (Wang et al, 2016).

In line with literature on the effects of other natural disasters such as hurricanes, floods, or tornadoes, these impacts disproportionately harm those most vulnerable. The direct societal impacts of wildfires cause extensive detrimental mental health risks similar to other disasters. These include high rates of anxiety, depression, PTSD, and higher rates of suicide. (Lassman et al. 2023). The Camp Fire in 2018, California's deadliest wildfire on record, left thousands of paradise resident's houseless and forced the closure of a community 2 hospital, generating "community-wide posttraumatic stress". (Grell et al, 2022).

Those who survived reported widespread distress, grief, and trauma lasting well after wildfire subsided. People forced to evacuate due to catastrophic fire report multiple types of mental health issues, including anxiety, depression, changes to appetite, and post-traumatic stress. (Katsouyanni,, 2019).

3. Research Method

The study adopted a descriptive data analysis. The secondary data for analysis was collected from data base of https://www.fire.ca.gov/ The scope of data collected covered from 2016 to 2024 amounting nine years period. The visual presentation of the data was done in tables and charts.

4. Data Analysis

4.1

Table 1: Statistical Record of Wildfire in California

Years	Total Emergency	Wildfire	Acre Burned	Confirmed Death	Structure destroyed
2016	472,875	6,954	669,534	6	1,274
2017	433,116	9,270	1,599,640	47	10,868
2018	483,016	7,948	1,975,086	100	24,226
2019	500,518	7,149	277,285	3	703
2020	494,489	8,648	4,304,379	33	11,116
2021	535,819	7,396	2,569,386	3	3,846
2022	554,344	7,477	331,358	9	1,279
2023	595,075	7,386	332,822	4	179
2024	605,861	8,024	1,050,012	1	2,148
Total	4,675,113	70,252	13,109,502	203	55,639

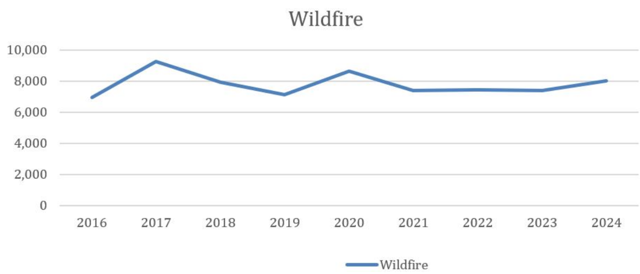
Source: *fire.ca.gov/incidents/ (2024)*

Table 1 above showed data presentation of wildfire in California. Given the data on five categories, there was 472,875 (10.1%) in 2016, a total 433,116 (9.2%) in 2017. A total of 483,016 (10.3%) in 2018. A total of 500,518 (10.7%) in 2019. A total of 494,489 (10.5%) in 2020. A total of 535,819 (11.4%) in 2021. A total of 554,344 (11.8%) in 2022. A total of 595,075 (12.7%) in 2023 and 605,861 (12.9%).

For wildfire, a total of 6,954 incidents was recorded against 472.875 total emergence cases giving (1.4%) in 2016. In 2017, a total of 9,270 was recorded against 433,116 total emergence cases at (2.1%). In 2018, a total of 7,948 incidents were recorded against 483,016 total emergence at (1.6%). In 2019, 7,149 incidents were recorded against 500,518 total emergence at (1.4%). In 2020, 8,648 cases were recorded against 494,489 total emergences at (1.7%). In 2021, a total of 7,396 cases were recorded against 535,819 total emergences at (1.3%). In 2022, a total 7,477 cases were recorded against total emergences of 554,344 at (1.3%). In 2023, a total of 7,386 cases were registered against 595,075 total emergences at (1.2%) and in 2024, a total of 8,024 cases were recorded against 605,861 total emergence at (1.3%). In 2016, a total of 669, 534 acres were burned, 1,599,640 acres were burned in 2017, 1,975,086 acre were burned in 2018, 277,285 acres were burned in 2019, 4,304,379 acres were burned in 2020. In 2021, a total of 2,569,386 acres were burned. In 2022, 331,358 acres were burned. In 2023, 332,822 acres were burned and 1,050,012 were burned in 2024. As regards to deaths resulting from air pollution induced from wildfire, a total of 6 death were recorded in 216, 47 deaths recorded in 2017, 100 deaths recorded in 2018, 3 recorded in 2019, 33 deaths recorded in 2020, 3 deaths recorded in 2021, 9 deaths were recorded in 2022, 4 deaths recorded in 2023 and 1 deaths in 2024. As regards to the structured destroyed from 2016 to 2024, a total of 1,274 buildings were destroyed in 2016, 10,868 buildings destroyed in 2017, 24,226 buildings destroyed in 2018, 703 buildings destroyed in 2019, 11,116buidings were destroyed in 2020, 3,846 buildings were destroyed in 2021, 1,279 buildings were destroyed in 2022, 179 buildings were destroyed in 2023 and 2,148 buildings were destroyed in 2024.

4.2 Trend Analysis

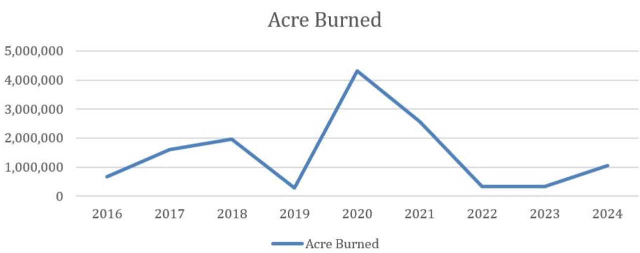
4.2.1 Trend Analysis on Wildfire



Source: *fire.ca.gov/incidents/ (2024)*

Chart 1shiowed that wildfire increased in 2017 from the record of 2016 and dropped in gradually from 2018 t0 2019 and rose up in 2020. The trend indicated that there was fall in the occurrence in 2021 and remained marginal increase from 2022 to 2024.

4.2.2 Trend Analysis on Acre Burned

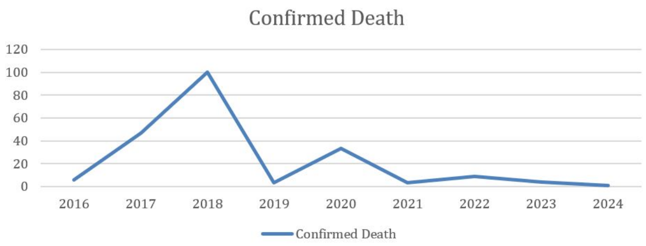


Source: *fire.ca.gov/incidents/ (2024)*

Chart 2 showed that in 2016, the area covered by the wildfire was below 1,000,000 acres and rose up till 2018 and later fall in 2019.

2020 recorded the highest point of wildfire and falls consistently from 2021 to 2022 s it remained marginally in increase.

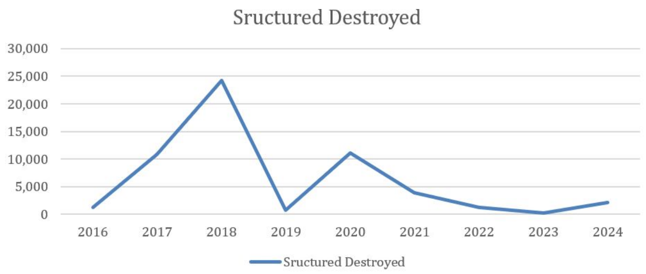
4.2.3 Trend Analysis on Confirmed Death



Source: *fire.ca.gov/incidents/ (2024)*

Chart 3 showed the number of casualty resulting from the wildfire induced air pollution. The chart revealed that death toll rose from 2016 continually to 2018 and fall in 2019 as it marginally rose in 2020 and falls in 2021 as well as remain flat from 2021 to 2024.

4.2.4 Trend Analysis on Structure Destroyed



Source: *fire.ca.gov/incidents/ (2024)*

Chart 4 showed that number of buildings destroyed by wildfire which also have consequence on the lives of the people in California. The chart revealed the highest point of increase in 20219. It rose in 2020 and fall marginally to 2024.

5. Discussion of findings

The result indicated that there is significant cases of wildfire in California from 2016 to 2024. This has consumes significant acres of land totally 43,111 within the period of the study. Wildfires are becoming increasingly destructive due to more frequent wildfire incidence, as well as consistent growth in wildfire severity, size, and duration over the last 20 years. This is driven by three primary factors: climate change, historical fire suppression in U.S. forest management, and the expansion of the wildland-urban interface (WUI), or "the zone of transition between unoccupied land and human development". As a result, eight of California's ten largest wildfires have burned within the last decade. Similarly beyond a U.S. context, wildfires in the European Union burned nearly 2 million acres in 2022, about 2.5 times the an Severe wildfires incur well-documented ecological and economic costs. High-severity wildfire events cause long-term species and even ecosystem loss31 as well as contribute sharply to greenhouse gas emissions, (Shi etal. (2019). As regards to air pollution induced from Wildfire in California, the result indicated that there number of health hazardless is much as a total of 203 deaths were recorded within the nine years of study scope and there were large number of people hospitalized as a result of the air pollution. Exposure to elevated concentrations of PM2.5 is linked to increased respiratory and cardiovascular illnesses and can lead to increased mortality (Atkinson etal. 2014, Brook etal., 2010). Prior research has investigated the effects of recent wildfires on air quality and public health through two primary methodologies. One approach involves employing wildfire emissions and chemical transport models to simulate the contribution of wildfires to PM2.5 levels, as demonstrated by studies conducted by Shi etal. (2019)). These health impacts translate to direct economic costs of wildfire smoke exposure. Wildfire smoke reduced earnings in the U.S. by $125 billion a year (in 2018 dollars) on average between 2007 and 2019. (Lassman etal., 2023).

6. Conclusions

The study concluded that wildfire case has significant prevalence in the past one decade. Wildfire contributes to 1.9 in average of total emergences in US becoming a year occurrence since 2016. There is significant health challenges resulting from air pollution from wildfire and this has contributed to significant health complications and mortality rate.

Recommendations

1. There is need to implement advanced technologies for early wildfire detection and real-time monitoring. This includes satellite surveillance, artificial intelligence-driven predictive modeling, and rapid response teams to reduce wildfire spread and mitigate its impacts.
2. There is need to develop targeted air quality alerts and public health advisories to protect vulnerable populations during wildfire seasons.

Encourage the distribution of protective gear like N95 masks and the establishment of clean air shelters in affected regions.
3. There is need to invest in reforestation, controlled burns, and land management strategies to reduce fuel loads. Increase community education on wildfire prevention, preparedness, and recovery efforts to foster proactive community involvement

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