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Wildfire-induced pollution and its short-term impact on COVID-19 cases and mortality in California

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Abstract

Globally, wildfires have seen remarkable increase in duration and size and have become a health hazard. In addition to vegetation and habitat destruction, rapid release of smoke, dust and gaseous pollutants in the atmosphere contributes to its short and long-term detrimental effects. Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) has emerged as a public health concern worldwide that primarily target lungs and respiratory tract, akin to air pollutants. Studies from our lab and others have demonstrated association between air pollution and COVID-19 infection and mortality rates. However, current knowledge on the impact of wildfire-mediated sudden outburst of air pollutants on COVID-19 is limited. In this study, we examined the association of air pollutants and COVID-19 during wildfires burned during August-October 2020 in California, United States. We observed an increase in the tropospheric pollutants including aerosols (particulate matter [PM]), carbon monoxide (CO) and nitrogen dioxide (NO2) by approximately 150%, 100% and 20%, respectively, in 2020 compared to the 2019. Except ozone (O3), similar proportion of increment was noticed during the peak wildfire period (August 16 – September 15, 2020) in the ground PM2.5, CO, and NO2 levels at Fresno, Los Angeles, Sacramento, San Diego and San Francisco, cities with largest active wildfire area. We identified three different spikes in the concentrations of PM2.5, and CO for the cities examined clearly suggesting wildfire-induced surge in air pollution. Fresno and Sacramento showed increment in the ground PM2.5, CO and NO2 levels, while San Diego recorded highest change rate in NO2 levels. Interestingly, we observed a similar pattern of higher COVID-19 cases and mortalities in the cities with adverse air pollution caused by wildfires. These findings provide a logical rationale to strategize public health policies for future impact of COVID-19 on humans residing in geographic locations susceptible to sudden increase in local air pollution.

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1. Introduction

In the past decades, the world has witnessed widespread impact of anthropogenic activities on climate changes in the form of extreme, unprecedented and detrimental weather conditions that are considered a threat to human existence (Abatzoglou and Williams, 2016; Fazel-Rastgar, 2020). Prolonged warm and dry weather is becoming a global phenomenon and has contributed to numerous record-breaking wildfires in the recent years destroying wildlife habitat, vegetation, livestock, displacing millions of residents and above all costs thousands of human lives (Westerling, 2016). In addition, historic heat waves and sudden outpouring of atmospheric pollutants to local environment are secondary effects of wildfires that further complicate...
their containment and amplify their adverse health effects well beyond the local geographic region (Holm et al., 2021). Understanding the spatiotemporal effects of wildfires on tropospheric and ground air pollutants and their impact on the human health is critical to inform local environmental policies to mitigate human cost of natural disasters (Davis et al., 2017; Tomshin and Solovyev, 2021). Numerous studies have reported global increase in wildfire frequency and extended duration in the recent years (North et al., 2015; Doerr and Santin, 2016). Approximately 30–46 million km², ~4% of the total land surface, burned every year signifying its profound impact of greenhouse gas release (Johnston et al., 2012). Wildfires release substantial amount of pollutants into the atmosphere each year, influencing weather, climate, and air quality, which attributed to an average of 339,000 deaths annually (Johnston et al., 2012). Global economic damage from wildfires over the period of 1984–2014 amounted to an average of US $2677 million annually (Doerr and Santin, 2016). While direct impact of wildfires is detrimental yet short-term, its secondary and long-term effects as such accelerated flooding, soil erosion, mass movement and pollution of water bodies further adds to the global economic burden (Santin and Doerr, 2016; Martin, 2016).

Wildfires generate various pollutants including particulate matter (PM) and gases (including CO, NO2 and O3) that enters into atmosphere and pose a great risk to human health. PM2.5 is the major component of wildfire smoke that affects public health (Gupta et al., 2018; Liu et al., 2015) and a short-term exposure to PM2.5 leads to severe health outcomes (Deryugina et al., 2019). By virtue of its small size compared with other coarse particulate matter, PM2.5 can reach deeper into the respiratory system to cause long-term health problems (Kim et al., 2015). Burke et al., (2021) showed that 25% of the PM2.5 is contributed by wildfires alone and at some places up to 50%. The CORINAIR-1990 inventory reveals that 0.2% of the NO2 emissions, 0.5% of the non-methane volatile organic compounds, 0.4% of the NH4 emissions and 1.9% of the CO emissions are contributed by wildfires, which in turn, adversely affect the human health (EMEP/CORINAIR, 2002). Patients with chronic respiratory disease are susceptible to COVID-19 infection and exhibit severe clinical manifestations that may lead to death (O’Horo et al., 2021; Beltramo et al., 2021). Recent studies have shown association between increased air pollution and severe COVID-19 illness, health outcomes and mortality. A study by Pozzer et al., (2020) shows the relationship between particle pollution and COVID-19 mortality worldwide which concludes that 15% of the deaths throughout the world due to COVID-19 may be associated to long-term exposure to air pollution. The particulate matters like PM2.5 and PM10 have direct association with the increasing number of respiratory diseases (pneumonia) and hospital admissions (Lelieveld et al., 2015; Wonjun et al., 2017; Zanobetti and Woolhead, 2010; Cheng et al., 2019; Sun and Sung, 2020). Nitrogen dioxide (NO2) is an important air pollutant and its higher atmospheric concentrations may cause increased toxicity to respiratory systems and mortality (Faustini et al., 2014). NO2 is also linked with several other diseases such as diabetes, hypertension and heart related diseases (Maawa et al., 2020). Similarly, short-term exposure to ozone (O3) in combination with other atmospheric factors could be linked with the initiation and transmission of COVID-19 (Adhikari and Yin, 2020).

In the recent decades, the US has seen surge in wildfires days and size (NIFC, 2021). National Interagency Fire Center data shows that 2.83 million hectares of land burns in the US every year and 4.09 million hectares of land was under wildfire during 2020 (NIFC, 2021). The area under wildfires in the US during the last ten years has increased by 195% (NIFC, 2021). The US witnessed worst wildfire season on record from February 15 – December 31, 2020 during which 9917 fire spots were reported. These wildfires burnt 1.77 million hectares of land, which accounted for almost 4% of the total land area and on August 18, 2020, it was declared a national disaster (Cal Fire, 2020). The wildfires were at their peak during the month of August releasing large amount of pollution into the atmosphere, which coincided with the surge in COVID-19 cases and mortalities (Meo et al., 2020).

We and others have shown the impact of COVID-19 lockdown on air pollutants and the association with virus infection and mortality globally (Naqvi et al., 2020; Naqvi et al., 2021a; Naqvi et al., 2021b; Gautam, 2021c; Cole et al., 2020; Travaglio et al., 2021). Numerous studies have reported decreased air pollution during COVID-19 lockdown period when people stayed at home due to reduced anthropogenic activities (Gautam et al., 2020, Gautam et al., 2020a, Gautam et al., 2020b; Cheiani and Gautam, 2021; Ambade et al., 2021; Gautam et al., 2021a; Gautam, 2021b; Naqvi et al., 2020; Naqvi et al., 2021a; Gautam et al., 2021d). Respiratory manifestations of COVID-19 are further complicated by natural disaster-induced air pollution (Copat et al., 2020; Villeneuve & Goldberg, 2020). Increasing range and intensity of wildfires across the globe has further complicated global response to contain virus. However, the association between wildfire-induced pollution and COVID-19 is poorly studied. Whether the local wildfires contribute to the air pollution and exacerbate COVID-19 infection and mortalities remain understudied. Here, we assessed the impact of California wildfires on tropospheric and ground air pollutants during July–October 2020 and its correlation with COVID-19 cases and mortalities in five cities viz., Fresno, Los Angeles, Sacramento, San Diego and San Francisco with largest wildfire area.

2. Material and methods

2.1. Satellite-derived tropospheric air pollutant levels

The remote sensing data product Sentinel 5P Tropospheric Monitoring Instrument (TROPOMI) is widely used for air quality applications (Veefkind et al., 2012). Satellite datasets are becoming easier to extract through Google Earth Engine platform to monitor the changes in tropospheric pollutants. Accordingly, we extracted the Absorbing Aerosol Index (AAI), column number density of carbon monoxide (CO), nitrogen dioxide (NO2) and Ozone (O3) in mol/m² for July 16 – October 15, 2019 and 2020 from the United States Geological Survey portal (USGS: https://lpdaac.usgs.gov/products/mcd19a2v006/). A series of wildfires burned during February 15 – December 31, 2020 in California. However, it was important to find out the peak period of wildfire and its association with COVID-19. Based on the California wildfire information, we decided to classify the wildfire periods in three categories viz., (i) onset: July 16 – August 15, (ii) peak: August 16 – September 15 (Sannigrahi et al., 2020) also considered peak period as wildfire days and (iii) slowdown: September 15 – October 16, 2020. The average values of tropospheric aerosol Index, CO, NO2 and O3 units in mol/m² except aerosol index for the whole California under the classified periods in 2020 were assessed and compared with corresponding period of 2019.

2.2. Daily ground air pollutants and COVID-19 cases and mortalities

Next, we identified the Californian cities severely affected by wildfires and with the highest COVID-19 morbidity and mortalities rates in the state. After careful assessment of the wildfire and COVID-19 datasets, we selected Fresno, Los Angeles, Sacramento, San Diego and San Francisco cities, where both the crisis were ongoing. The daily median of ground air pollutants viz., PM2.5, O3, NO2 (in µg/m³) and CO (in ppm) were obtained from different
websites (California Air Pollution: Air Quality Index-AQI, 2020 and Environmental Protection Agency - EPA, USA, 2020). A few data points of some pollutants were missing from the datasets used in this study. We addressed this issue by using median values one-week before and after the missing point, a widely accepted approach (Cokluk and Kayri, 2011; Gopal et al., 2019). Later, we assessed the trends and patterns along with their association with daily COVID-19 cases and deaths (Worldometer, 2020; COVID-19 Live Tracker Johns Hopkins, 2020) in each city under the classified periods of wildfire.

3. Results and discussion

3.1. Wildfires contributed to a sudden outburst of tropospheric pollutants in California

California wildfires were catastrophic and created environmental disaster in the midst of the ongoing pandemic. We asked whether wildfires burned during August to October 2020 in California, the most populated state in US, contributed to temporal changes in air pollutants. To this end, average values of various tropospheric pollutants viz., aerosols, carbon monoxide (CO), NO2, and O3 were examined during three phases of wildfires: onset (July 16 – August 15), peak (August 16-September 15) and slowdown (September 16 – October 15, 2020) and the corresponding period in 2019. Our results show that tropospheric absorbing aerosol index (AAI) concentration were almost similar throughout the time periods in 2019 (Fig. 1a-c) where the extracted average values were in negative (Fig. 1d). Before the onset of wildfire in 2020, few yellow color patches (close to index score 0) were observed in the southern part of California, suggesting similar tropospheric aerosol levels (Fig. 1e). However, remarkably higher aerosol concentrations (represented by red color with index score < 2) were observed in the peak period (average index score 0.5) compared to the onset (average index score –1.181) (Fig. 1f) and slowdown (average index score –0.737) period, 2020 (Fig. 1g) or the corresponding period of 2019 (average index score –0.939 for July 16 – August 15, 2020; average index score –0.955 for August 16–September 15, 2020 and average index score –0.986 for September 16 – October 15, 2020). The central and north regions of California, especially Sacramento, San Francisco and Fresno were among the worst effected cities with substantially higher aerosol concentrations. Overall, the average index values were in negative throughout the study period and reached approximately 0.5 index score during the peak period as observed by the yellow and red color patches (between 0.5 and 2 index score) and reduced drastically in the slowdown phase (Fig. 1h).

Tropospheric CO density was almost similar across all the study period examined in 2019 (Fig. 2a-c), and the average values ranged between 0.025 and 0.027 mol/m2 (Fig. 2d). From July 16 – August 15, 2020, CO concentration were similar (0.026 mol/m2) to the corresponding period in 2019 (Fig. 2e). CO levels increase remarkably during August 16 – September 15, 2020 reaching 0.053 mol/m2 and evident from the yellow or red color patches indicative of higher CO concentration range (Fig. 2f). Similar to AAI, CO concentration reduced during slowdown period (0.035 mol/m2), albeit remain slightly higher than the corresponding period in 2019 (Fig. 2h). This indicates that the environmental effect of wildfires gradually declined by October 2020.

Tropospheric NO2 density remained similar (in the range of 0.0000205 and 0.0000227 mol/m2) across all the study time points in both 2019 and 2020 except August 16 – September 15, 2020 where the pollutant levels spiked to 0.0000253 mol/m2 (Fig. 3a-h). It was interesting to note that NO2 levels were higher in Sacramento and Los Angeles regions as evident from restricted yellow or red color patches both in 2019 and 2020 (Fig. 3e), but the intensity during August 16 – September 15, 2020 were distinctly higher indicating increased concentrations (Fig. 3f). We did not observe any temporal pattern in tropospheric O3 during 2019 and 2020 study periods as seen from the colored graphs (Fig. 4a-c; e-f). The average minimum or maximum values remained in the range of 0.129 and 0.135 (Fig. 4d). Our result suggests that among all the pollutants examined, O3 concentration did not show any significant shift due to wildfires.

Fig. 1. California wildfire impact on tropospheric aerosols index. Maps showing satellite-derived average absorbing aerosol index (AAI) concentrations during (a, and e) 16 July – 15 Aug ust, (b, and f) 16 August – 15 September and, (c, and g) 16 September – 15 October and (d, and h) average values for each time period in 2019 and 2020.
Next, to examine the quantitative impact of wildfires on each pollutant we calculated change in concentration rate. Our analysis reveals that aerosol pollutants (a proxy for PM2.5) showed most remarkable change and corroborate with our previous data (Fig. 5). Compared to 2019, almost 25% and 150% change rate observed respectively for July 16 – August 15, 2020 and August 16 – September 15 in 2020 (Fig. 5). For CO2 and NO2 pollutants, we noted an increment during 16 August – 15 September in 2020 with about 100% and 20%, respectively, (Fig. 5) compared to the corresponding period in 2019.

Wildfires contribute to the increase in aerosol concentrations (Burke et al., 2021). The report of NASA on California wildfire 2020 revealed that the CO concentrations were > 10 times compared to the normal days (Science Daily, 2020). Another study on California wildfire also highlighted that CO concentration highly increased in the initial days of wildfire (Schneising et al., 2020). Sannigrahi et al., (2020) observed that the variations in tropospheric NO2 was nominal compared to aerosol and CO pollutant and interestingly, negative changes were observed in satellite derived O3 pollutants. Our results show a sudden spike in...
tropospheric aerosol index, CO and NO2 that corroborate with the previous findings (Meo et al., 2020, 2021; Preisler et al. 2015).

3.2. Wildfires induced temporal spike in the ground air pollutants

Next, we asked whether wildfires influenced ground pollutant levels during the study period. To this end, five cities viz., Fresno, Los Angeles, Sacramento, San Diego and San Francisco from California that were severely affected by the wildfires were selected to assess the impact of wildfires on the ground pollutant (including PM2.5, CO, NO2 and O3) levels during the same time period (July 16 – October 15) in 2019 and 2020.

Our results show that daily median PM2.5 concentrations were almost similar throughout the period in 2019. PM2.5 levels ranged between 20 and 60 μg/m³ with the highest values observed in Fresno and Los Angeles, while the lowest concentration was noticed for Sacramento and San Francisco stations (Fig. 6a). In 2020, PM2.5 levels were similar in all the stations till the onset period in 2020, thereafter three different spikes (peaks P1, P2 and P3) were observed, which depicts the wildfire-induced pollution (Fig. 6b). P1, P2 and P3 correspond to August 17 – 25, September 10 – 17 and October 1 – 8, 2020, respectively. Fresno and Sacramento had the highest levels of PM2.5 (~200 μg/m²) at P1 (Fig. 6b). After progressive decline, PM2.5 levels increased again after September 10, 2020 (P2) and reached up to 240 μg/m³. This cyclic pattern continues with temporal and gradual reduction and subsequent spike (P3) in PM2.5. This peak was evident in the southern California and at all the investigated stations (Fig. 6b) and corroborated with our satellite generated tropospheric aerosol index map (Fig. 1f).

The CO concentrations (in ppm) and trends in all the stations during the study period of 2019 were similar. CO values ranged within 0.1 to 0.7 ppm and rarely crossed 1.0 ppm, except at Fresno after October 10, 2019 (Fig. 6c). CO levels showed a pattern and trend similar to PM2.5 (Fig. 6b, d). Three different CO spikes overlapped with PM2.5 clearly suggesting contribution of an external event that induced local pollutant levels (Fig. 6d). Sacramento and Fresno stations showed higher CO levels in all three peaks in 2020, whereas, these stations recorded lowest CO (<0.5 ppm) concentrations in 2019 (Fig. 6d) further supporting our hypothesis of wildfire induced pollutant outburst.

In 2019, NO2 levels were recorded at < 10 μg/m³ at all the stations except the Los Angeles, where this pollutant was two-folds higher than other places throughout the study period (Fig. 6e). Intriguingly, unlike other pollutants (PM2.5 and CO), NO2 concentration and temporal pattern did not exhibit any noticeable changes in 2020. Los Angeles ground NO2 levels (~40 μg/m³) were markedly higher compared to other cities; however, some small peaks were noticed for Fresno and San Francisco stations (Fig. 6f). Los Angeles is the largest urban regions of USA where the anthropogenic factors, predominantly fuel burning, and industrial facilities contribute towards NO2 emission (U.S. EPA., 2008; Kerr et al., 2021). Our findings also supported that NO2 levels in Los Angeles were consistently high compared to other places during the study period.

In case of O3, the maximum concentration was recorded at the Fresno station (~30 μg/m³), while other places recorded between 10 and 30 μg/m³, whereas the lowest value was recorded in Los Angeles (Fig. 6g). Sacramento, San Diego and San Francisco stations
showed some minor peaks corresponding to a higher O$_3$ levels (~40 µg/m$^3$) during August 16 – September 15, 2020 (Fig. 6h). We observed cyclic pattern of air pollutant levels after August 15, 2020 at most of the stations since the wildfires started and their containment. Our findings of PM$_{2.5}$ and CO levels and their pattern of daily median indicates that most of the wildfires occurred between August 16 – September 15, 2020 and gradually suppressed at the end of September 2020 (Sannigrahi et al., 2020). Further, we calculated the percentage change in each pollutant in 2020 compared to the corresponding periods in 2019. Our analysis revealed that Sacramento and Fresno showed most remarkable increase ~ 400% and 200%, respectively, in PM$_{2.5}$ during the peak compared to the corresponding time period of 2019 (Fig. 7a). For CO, we noticed marked increase in Fresno (220%), Sacramento (94%) and San Francisco (50%) stations, while Los Angeles and San Diego showed minimal change (Fig. 7b). It is interesting to note that except PM$_{2.5}$ other pollutants exhibit unique pattern and variation during the study period. Similar analysis for NO$_2$ revealed wildfires had relatively less impact on annual changes in this ground pollutant; however, Fresno (50%) and Los Angeles (28%) still showed increase during the peak, while San Diego showed 66% higher NO$_2$ levels during the slowdown period (Fig. 7c). Finally, we analyzed changes in O$_3$ levels but did not observe any significant impact. Only Fresno or Sacramento stations showed approximately 5% increase during the peak period (Fig. 7d). We observed that among all the ground air pollutants, PM$_{2.5}$ was highly induced by the wildfires, followed by CO and O$_3$. Our results corroborate with the findings of Zhou et al., (2021) that showed drastic increase in the PM$_{2.5}$ levels due to wildfire in different counties of California between August 15 – October 5, 2020. Meo et al., (2021) analyzed the changes in air pollutants viz., PM$_{2.5}$, CO, and O$_3$ during California wildfires in 2020 and respectively noticed 220%, 151% and 19% increase lending support to our findings (see Fig. 8).
3.3. COVID-19 cases and mortalities and its association with wildfire-induced air pollutants

Since we noticed marked increase in multiple air pollutants, the impact of adverse air pollution on COVID-19 cases and mortalities was examined. To this end, daily COVID-19 cases and mortality data was procured for Fresno, Los Angeles, Sacramento, San Diego and San Francisco during the study period (July 16 – October 15, 2020) (Fig. 7a-h). A linear trend line was added to highlight the time points with spike in COVID-19 cases and deaths. In general, we noticed increment in both COVID-19 cases and mortalities in all the cities, albeit to a varying extent (Fig. 7a-h). Sacramento and Fresno showed spike in COVID-19 cases that overlaps with the peak period (August 15 – August 30, 2020) and multiple spikes in the infections are evident (Fig. 7c, d). In both of these cities, average daily infections ranged around 300–400, but these numbers increased to 600–650 during the initial days of peak period. However, compared to Fresno, multiple spikes in COVID-19 cases can be noticed suggesting more profound impact of wildfire-induced virus spread. Subtle increments in COVID-19 infections were observed in Los Angeles and San Francisco during July 2020 where wildfires started from mid-June to July (Calfire, 2021). In San Diego multiple small peaks of COVID-19 infections was noticed across the study period.

Assessment of COVID-19 mortality revealed higher rates in all the cities (Fig. 7e-h). Intriguingly, we noticed that COVID-19 mortalities were relatively higher after August 15, 2020 except Los Angeles. In particular, San Diego showed 300% increase in COVID-19 mortalities around September 17–24, 2020 which correlates with active wildfires (September 5–24, 2020). While COVID-19 infections showed more pronounced increase during the onset of wildfires, more consistent increment in COVID-19 mortalities was apparent after the peak period. Previous studies have shown that wildfire-induced pollution levels in ten affected counties in California was attributed to an increase in COVID-19 cases (56.9%) and mortalities (148.2%) (Mee et al., 2021). A study conducted in San Francisco also revealed that wildfire associated pollutants such as PM2.5 and CO had a positive relationship with an increased number of SARS-COV-2 daily cases, cumulative cases and cumulative deaths (Mee et al., 2020). A logical justification is the natural progression of COVID-19, which can take weeks and months; however, severe air pollution can exacerbate the clinical manifestations of disease.

Increased air pollution and its effect on COVID-19 infections is the most heated, debated and deliberated topic among the academicians, researchers, policymakers, stakeholders, etc. Fine particulate matter and other harmful gases are responsible for millions of death annually. Studies have shown that long-term exposure to air pollution leads to higher frequency of respiratory diseases (Brauer, 2010; Guan et al., 2016; Bloemsma et al., 2016; Schiavoni et al., 2017). Higher levels of PM2.5, PM10, NO2, SO2, and O3 show strong association with COVID-19 infection and mortalities (Naqvi et al., 2021(a); Naqvi et al., 2021(b); Wu et al., 2020; Naqvi et al., 2020). In the North America, increased exposure to pollution due to particulate matter was attributed to 17% increase in COVID-19 mortality (Pozzer et al., 2020). In a study by Liang et al. (2020), it was argued that long-term exposure to fine particulate matter pollution, O3, and specifically NO2 is associated with rising rate of deaths due to COVID-19. Li et al., (2020) assessed the relationship between air quality indexes (AQI) and the rate of occurrence of COVID-19 in Wuhan. Of the four major air pollutants (PM2.5, PM10, NO2, and CO) examined, NO2 and PM2.5 levels strongly correlated with the prevalence of COVID-19. Wu et al., (2020) noticed a positive relationship between increased...
COVID-19 mortality and exposure to PM$_{2.5}$ in the United States. In most of the investigated cities, we noticed that the daily COVID-19 cases and deaths overlap with spike in PM$_{2.5}$ and CO levels, as observed by three different peaks during the wildfire period. These findings indicate that COVID-19 cases and mortalities could be directly impacted by wildfires and other natural disasters due to prolonged stay in shelters, often with minimal social distancing to avoid viral spread and demands further investigation.

4. Conclusion

In this study, we examined wildfire-induced short-term changes in the tropospheric and ground air pollutants in five major cities in California, US. Our results show that wildfires contribute to a rapid surge in PM$_{2.5}$ and CO levels during the peak wildfire period (August 16-September 15, 2020). Interestingly, increase in air pollution overlaps with the spike in COVID-19 cases and mortalities in Fresno, Sacramento suggesting that in addition to wildfire generates air pollution, other factors may contribute to the adverse increment in viral spread. Our results highlight the crosstalk between wildfire-induced air pollution, and human health in the wake of a highly transmissible pandemic.

CRediT authorship contribution statement

Hasan Raja Naqvi: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources. Guneet Mutreja: Methodology, Validation, Formal analysis, Resources. Adnan Shakeel: Methodology, Formal analysis, Resources. Karan Singh: Validation, Formal analysis. Kumail Abbas: Formal analysis. Darakhsha Fatma Naqvi: Anis Ahmad Chaudhary: Masood Ahsan Siddiqui: Resources, Writing – review & editing. Alok Sagar Gautam: Validation. Sneha Gautam: Methodology, Validation. Afsar Raza Naqvi: Conceptualization, Investigation, Resources, Writing – original draft.

Fig. 8. Daily COVID-19 cases and mortalities. Bar graphs depicts daily COVID-19 cases from 16 July – 15 October 2020 in (a) Fresno, (b) Los Angeles, (c) Sacramento, (d) San Diego and (e) San Francisco. Similarly, daily COVID-19 deaths are plotted in (f) Fresno, (g) Los Angeles, (h) Sacramento, (i) San Diego and (j) San Francisco during the same time period as referred for cases. Dotted red line indicates the average value and value above this line reflect surge in COVID-19 cases and mortalities. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abatzoglou, J.T., Williams, A.P., 2016. Impact of anthropogenic climate change on wildfire across western US forests. Proc. Natl. Acad. Sci. 113 (42), 1–6. https://doi.org/10.1073/pnas.1607111113.

Adhikari, A., Yin, J., 2020. Short-term effects of ambient ozone, PM2.5, and meteorological factors on COVID-19 confirmed cases and deaths in Queens, New York. Int. J. Environ. Res. Public. Health. 17 (4047). https://doi.org/10.3390/ijerph17114047.

Ambade, B., Sanitar, T.K., Kumar, A., Gautam, A.S., Gautam, S., 2021. COVID-19 lockdowns reduce the Black carbon and polycyclic aromatic hydrocarbons of the Asian atmosphere: source apportionment and health hazard evaluation. Env. Dev. and Sust. 23 (8), 12225–12271. https://doi.org/10.1016/j.envdev.2020.01167-1.

Beltrán, G., Cottenet, J., Mariet, A.S., Georges, M., Piroth, L., Tubert-Bitter, P., Bonnaud, P., Quantin, C., 2021. Chronic respiratory diseases are predictors of severe outcome in COVID-19 hospitalised patients: a nationwide study. Eur. Respir. J. 58, 2004474. https://doi.org/10.1183/13993003.04474-2020.

Blinov-Lewin, D., Hoek, G.E., 2016. Panel studies of air pollution in patients with COPD: systematic review and meta-analysis. Environ. Res. 151, 458–468. https://doi.org/10.1016/j.envres.2016.08.018.

Brauer, M., 2010. How much, how long, what, and where? air pollution exposure assessment for epidemiologic studies of respiratory disease. Proc. Am. Thoracic. Soc. 7, 111–115. https://doi.org/10.1513/ATYS.200908-093RM.

Burke, M., Driscoll, A., Xue, J., Heft-Neal, S., Burney, J., Wara, M., 2021. The changing on the validity and reliability of scales. Edu. Sci.: The. and Prac. 11 (1), 303–309.

Cal Fire, 2020. 2020 incident archive. Retrieved from https://www.fire.ca.gov/.

Brauer, M., 2010. How much, how long, what, and where? air pollution exposure assessment for epidemiologic studies of respiratory disease. Proc. Am. Thoracic. Soc. 7, 111–115. https://doi.org/10.1513/ATYS.200908-093RM.

Chelami, A., Gautam, S., 2021. Lockdown during COVID-19 pandemic: A case study from Indian cities showing insignificant effects on persistent property of urban air quality. Geosci. Front. 101284. https://doi.org/10.1016/j.gsf.2021.101284.

Cheng, F.J., Lee, K.H., Lee, C.W., Hsu, P.C., 2019. Association between particulate matter air pollution and hospital emergency room visits for pneumonia with septicaemia: a retrospective analysis. Aerosol. Air. Qual. Res. 15, 345–354. https://doi.org/10.4209/aqar.2018.08.0285.

Cokluk, O., Kayri, M., 2011. The effects of methods of imputation for missing values on the validity and reliability of scales. Edu. Sci.: The. and Prac. 1 (1), 303–309.

Cole, M.A., Ozgen, C., Strobl, E., 2020. Air Pollution Exposure and COVID-19. DISCUSSION PAPER SERIESIZA DP No. 13367. IZA – Institute of Labor Economics. 76, 581-610. https://ftp.itpza.de/papers/13367.pdf.

Copat, C., Cristaldi, A., Fiore, M., Grassi, A., Zucchiello, P., Signorelli, S.S., Conti, G.D., Ferrante, M., 2020. The role of air pollution (PM and NO2) in COVID-19 spread and lethality: a systematic review. Environ. Res. 191, https://doi.org/10.1016/j.envres.2020.110129.

COVID-19 Tracker-John Hopkins. 2020, https://www.graeminstar.com/g-coronas-v-covid-19-live-cases-tracker-john-hopkins/ (Cited date July 05, 2021).

Davis, R., Yang, Z., Yost, A., Belongie, C., Cohen, W., 2017. The normal fire environment—Modeling environmental suitability for large forest wildfires using past, present, and future climate normals. Forest Eco. Mang 390, 173–186. https://doi.org/10.1016/j.foreco.2017.01.027.

Deryugina, T., Heutel, G., Miller, N.H., Molitor, D., Reif, R., 2019. The mortality and lethality: a systematic review. Environ. Res. Epidemiol. 31 (1), 1–20. https://doi.org/10.1038/s41370-2020-00267-4.

Deryugina, T., Heutel, G., Miller, N.H., Molitor, D., Reif, R., 2019. The mortality and lethality: a systematic review. Environ. Res. Epidemiol. 31 (1), 1–20. https://doi.org/10.1038/s41370-2020-00267-4.

Deryugina, T., Heutel, G., Miller, N.H., Molitor, D., Reif, R., 2019. The mortality and lethality: a systematic review. Environ. Res. Epidemiol. 31 (1), 1–20. https://doi.org/10.1038/s41370-2020-00267-4.

Deryugina, T., Heutel, G., Miller, N.H., Molitor, D., Reif, R., 2019. The mortality and lethality: a systematic review. Environ. Res. Epidemiol. 31 (1), 1–20. https://doi.org/10.1038/s41370-2020-00267-4.

Deryugina, T., Heutel, G., Miller, N.H., Molitor, D., Reif, R., 2019. The mortality and lethality: a systematic review. Environ. Res. Epidemiol. 31 (1), 1–20. https://doi.org/10.1038/s41370-2020-00267-4.

Deryugina, T., Heutel, G., Miller, N.H., Molitor, D., Reif, R., 2019. The mortality and lethality: a systematic review. Environ. Res. Epidemiol. 31 (1), 1–20. https://doi.org/10.1038/s41370-2020-00267-4.

Deryugina, T., Heutel, G., Miller, N.H., Molitor, D., Reif, R., 2019. The mortality and lethality: a systematic review. Environ. Res. Epidemiol. 31 (1), 1–20. https://doi.org/10.1038/s41370-2020-00267-4.

Deryugina, T., Heutel, G., Miller, N.H., Molitor, D., Reif, R., 2019. The mortality and lethality: a systematic review. Environ. Res. Epidemiol. 31 (1), 1–20. https://doi.org/10.1038/s41370-2020-00267-4.
Santín, C., Doerr, S.H., 2016. Fire effects on soils: the human dimension. Phil. Trans. R. Soc. B 371 (1696), 20150171.

Schiavoni, G., D’Amato, G., Afferni, C., 2017. The dangerous liaison between pollens and pollution in respiratory allergy. Ann. Allergy Asthma. Immunol. 118 (3), 269–275. https://doi.org/10.1016/j.anai.2016.12.019.

Schneising, O., Buchwitz, M., Reuter, M., Boeversmann, H., Burrows, J.P., 2020. Severe Californian wildfires in November 2018 observed from space: the carbon monoxide perspective. Atmos. Chem. Phys. 20, 3317–3332. https://doi.org/10.5194/acp-20-3317-2020.

Science Daily., 2020. NASA/Jet Propulsion Laboratory. “NASA monitors carbon monoxide from California wildfires”. 14 September 2020.

Sun, Y.K., Sung, H.J., 2020. Particulate-Matter Related Respiratory Diseases. Tuberc. Respir. Dis. (Seoul) 83 (2), 116–121.

Tomshin, O., Solovyev, V., 2021. Spatio-temporal patterns of wildfires in Siberia during 2001–2020. Geoc. Int. doi: 10.1080/10106049.2021.1973581.

Travaglio, M., Yu, Y., Popovic, R., Selley, L., Leal, N.S., Martins, L.M., 2021. Links between air pollution and COVID-19 in England. Environ. Pollut. 268, (Pt A). https://doi.org/10.1016/j.envpol.2020.115859. 115859.

U.S. EPA. Risk and Exposure Assessment to Support the Review of the NO2 Primary National Ambient Air Quality Standard. EPA-452/R-08-008a, November 2008. Available at: http://www.epa.gov/ttn/naaqs/standards/nox/data/20081121_NO2_REA_final.pdf.

USGS: https://lpdaac.usgs.gov/products/mcd19a2v006/.

Veerkind, J.P., Aben, I., McMullan, K., Förster, H., de Vries, J., Otter, G., Claas, J., Eskes, H.J., de Haan, J.F., Kleipool, Q., van Weele, M., Hasekamp, O., Hoogeveen, R., Landgraf, J., Snel, R., Tol, P., Ingmann, P., Voors, R., Kruizinga, B., Vink, R., Visser, H., Levelt, P.F., 2012. TROPOMI on the ESA Sentinel-5 Precursor: a GMES mission for global observations of the atmospheric composition for climate, air quality and ozone layer applications. R. Sens. Env. 120, 70–83.

Villeneuve, P.J., Goldberg, M.S., 2020. Methodological considerations for epidemiological studies of air pollution and the SARS and COVID-19 coronavirus outbreaks. Environ Health. Perspect. 128 (9), 95001. https://doi.org/10.1289/EHP7411.

Westerling, A.L., 2016. Increasing western US forest wildfire activity: sensitivity to changes in the timing of spring. Philos. Trans. R. Soc. Lond. B Biol. Sci. 371 (1896), 20150178. https://doi.org/10.1098/rstb.2015.0178.

Wonjun, J.S., Park, Y.R., Kim, H.R., Hwan-Cheol, K., Choi, C.M., 2017. Prolonged effect of air pollution on pneumonia: a nationwide cohort study. Eur. Resp. J. 50. https://doi.org/10.1183/13930033.congress-2017.OA467.

Worldometer., 2020. https://www.worldometers.info/demographics/demographics-of-africa/ (Cited date July 05, 2021).

Wu, X., Nethary, R.C., Sabath, M.B., Braun, D., Dominici, F., 2020. Air pollution and COVID-19 mortality in the United States: strengths and limitations of an ecological regression analysis. Sci. Adv. 6(45):eabd4049. https://doi.org/10.1126/sciadv.abd4049.

Zanobetti, A., Woodhead, M., 2010. Air pollution and pneumonia the “Old Man” has a new “Friend”. Am. J. Respir. Crit. Care Med. 181 (1), 5–6.

Zhou, X., Josey, K., Kamareddine, L., Caine, M.C., Liu, T., Mickley, L.J., Cooper, M., Dominici, F., 2021. Excess of COVID-19 cases and deaths due to fine particulate matter exposure during the 2020 wildfires in the United States. Sci. Adv. 7 (33). https://doi.org/10.1126/sciadv.aba7889.