Increase in Pediatric Respiratory Visits Associated with Santa Ana Wind-driven Wildfire Smoke and $PM_{2.5}$ levels in San Diego County

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SL, MN, AG, TB designed the study, analyzed the data, and wrote the manuscript

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Abstract

Rationale: There is significant evidence of increased healthcare utilization from cardiopulmonary causes in adults from exposure to wildfire smoke, but evidence in pediatric age groups is limited.

Objectives: To quantify and examine the healthcare utilization effects of the December 2017 Lilac Fire in San Diego County among pediatric patients at the Rady Children's Hospital (RCH) Emergency Department (ED) and Urgent Care (UC) clinics.

Methods: Utilizing data from 2011–2017, including data on daily particulate matter less than 2.5 micrometers ($PM_{2.5}$) in an inverse-distance interpolation model and RCH electronic medical records, we retrospectively analyzed pediatric respiratory visits at the RCH ED and UC clinics during the Santa Ana Wind (SAW)-driven Lilac Fire from December 7–16, 2017. An interrupted time series (ITS) study design was applied as our primary analysis to compare the observed pediatric respiratory visits from December 7–16, 2017, to what would have occurred in a counterfactual situation, namely, if the Lilac Fire had not occurred. A complementary descriptive spatial analysis was also employed to evaluate the geographic distribution of respiratory visits in relationship to satellite imaging of the Lilac Fire and the associated wind pattern.

Results: The Lilac Fire was associated with 16.0 (95% CI: 11.2, 20.9) excess respiratory visits per day at the RCH ED across all pediatric age groups. Children aged 0-5 years had the highest absolute excess respiratory visits per day with 7.3 (95% CI: 3.0, 11.7) while those aged 6-12 years had the highest relative increase in visits, with 3.4 (95% CI: 2.3, 4.6). RCH UC clinics had similar results.

The top 5 ZIP codes in San Diego County with the highest standard deviations of age-adjusted respiratory visits were all located generally downwind of the fire perimeter, as expected for the SAW pattern.

Conclusions: We have demonstrated an increase in pediatric respiratory visits during the SAW-driven Lilac Fire in San Diego County in a patterned geographic distribution that is attributable to an increase in $PM_{2.5}$ exposure. Younger children were particularly affected. Climate change is expected to result in more frequent and extensive wildfires in the region and will require greater preparedness and adaptation efforts to protect vulnerable populations such as young children.

Clinical Trial Registration

This study was not a clinical trial

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Introduction

There is mounting evidence that demonstrates increased healthcare utilization, both emergency department (ED) visits and hospitalizations, from cardiopulmonary causes during wildfire outbreaks due to smoke exposure (1-6). Specifically, wildfire smoke contains fine particulate matter 2.5 micrometers or less in diameter ($PM_{2.5}$) that can affect communities located miles from the wildfire (7). $PM_{2.5}$ from wildfires can deposit in the respiratory tract and affect vulnerable populations, such as those with asthma (8, 9). Acute inhalation of $PM_{2.5}$ can affect lung immune responses, lead to increased lung infections in children and result in increased pediatric healthcare utilization (10). Several reviews have been conducted to summarize the epidemiological evidence of the health impacts associated with wildfires (11-13), linking smoke exposure to respiratory morbidity and all-cause premature mortality. However, such evidence among pediatric populations is more limited (3, 14-16).

From December 7-16, 2017, a modest-sized wildfire, the Lilac Fire, burned 4,100 acres and caused nine million dollars in damage in San Diego County (17). The Lilac Fire and similar past wildfire occurrences in San Diego County were sparked by human-caused ignitions (18) and were primed by prolonged antecedent dryness resulting in flammable vegetation coinciding with Santa Ana winds (SAWs). SAWs are a regional phenomenon of dry and gusty winds that blow from the northeast towards the southwest, fanning backcountry wildfires, carrying embers and transporting smoke across long distances (19). The Lilac Fire ignited during the same SAW event as the Thomas Fire, which burned for over a month in Ventura and Santa Barbara Counties to temporarily become (at 282,000 acres) the largest wildfire in California's recorded history; this fire was later surpassed by the Ranch Fire of the Mendocino Fire Complex in Northern California the following summer. A recent study considered health utilization in the Medi-Cal population in San Diego County after the catastrophic 2007 wildfires that burned 248,000 acres (14). This cluster of wildfire events, the largest of which, the Witch Fire, alone burned 198,000 acres, was much larger than the 2017 Lilac Fire, but occurred prior to electronic medical record (EMR) implementation at Rady Children's Hospital (RCH).

As the only free-standing children's hospital in San Diego County, RCH provides medical care for 91% of San Diego County's hospitalized children and has urgent care (UC) facilities in its network throughout the county (20). In 2017, there were 154,983 emergency department and urgent care visits in the RCH network (21). Over half of the hospital's patients do not have private health insurance, and most patients are insured by Medi-Cal, California's Medicaid program. The hospital implemented the EPIC EMR in 2011, enabling retrospective analysis of all ED and UC respiratory visits between January 2011 and December 2017.

The primary aim of this study was to quantify the healthcare utilization effects of the Lilac wildfire in December 2017 among pediatric patients under 19 years old presenting to the ED and urgent care clinics. Utilizing RCH's EPIC EMR and $PM_{2.5}$ data from the US Environmental Protection Agency from 2011–2017, we used an interrupted time series approach in which we compared the observed pediatric respiratory visits to what would have occurred in a counterfactual situation, namely, if the Lilac Fire event had not occurred. We also conducted a complementary descriptive spatial analysis to demonstrate geographic patterns of healthcare utilization.

Methods

Health Data

All RCH ED and UC visits from 2011 to 2017 were collected through EPIC EMR. The specific data fields analyzed included date of visit, date of birth, ZIP code of residence, insurance type, language, and respiratory/non-respiratory visit. Respiratory visits were defined by the following specific data field chief complaints: difficulty breathing, respiratory distress, wheezing, asthma, or cough. The chief complaint is a single specific data field captured at triage/intake and updated throughout the encounter to indicate the intent of the visit in the EMR. Utilizing the visit's chief complaint captured a greater number of visits with an indication of a respiratory condition compared to utilizing ICD-9/ICD-10 diagnostic codes.

Data Analysis

We used an interrupted time series (ITS) study design to quantify the excess respiratory ED and UC visits during the Lilac Fire. The ITS approach consists of three stages: 1) first, model daily respiratory visits for the study period (excluding the Lilac Fire days); 2) assess the accuracy of the predictive model by comparing it to the observed values; and 3) conduct a model to infer the difference (change in slope) between the predicted and observed daily visits during the Lilac Fire event. The ITS was designed to capitalize on a natural experiment, such as a wildfire event, to evaluate specific health effects by understanding and modeling pre-event trends (26-28). Understanding pre-event trends creates a model of the counterfactual (29-31) scenario that would have happened in the absence of the event of interest (i.e., the Lilac Fire). Pre-event trends include seasonal and long-term trends in the outcome of interest. We modeled these time trends and fitted a model that best predicts variations in the outcome of interest (before the event of interest) and compared, during the Lilac Fire, the modeled estimates to what was actually observed. We then quantified the excess respiratory visits attributable to the Lilac Fire. We first conducted the analysis on all pediatric respiratory UC and ED visits and then conducted an analysis for specific age groups (0–5, 6–12, and 13–19 years of age).

We assumed that without the event of interest, the pre-event trend would continue unchanged into the post-intervention period and that there would be no external events that occurred exactly at the same time of the Lilac Fire. We also confirmed that no other fire event occurred during this same week (December 7–16) in previous years (2011–2016). In addition, as a "falsification test", we applied the same approach to the same days but in the previous year, December 7–16, 2016, as a control period. Our hypothesis was that there was no change in the pediatric visits in this December 7–16, 2016, period using a similar ITS approach.

The unit of analysis was the number of respiratory visits per day to Rady's ED or UC Clinics per ZIP code. We used Poisson regression to model the time trends in respiratory visits (Stage 1 of the ITS analysis). Sensitivity analysis was conducted with a negative binomial regression to ensure there was no over-dispersion, but no differences were observed. We used years (2011–2017), month of the year (1–12), weeks of the year (1–52) and days of the week (1–7) as our independent variables. We used natural cubic splines (32) with different knots to obtain the best fit of respiratory visits per day.

The number of spline knots and degrees of freedom to control for seasonal and longtime patterns were decided based on the Akaike information criterion (AIC) (33). To ensure that no autocorrelation remained in the residuals, we visually inspected the partial autocorrelation plots and used the white noise statistical test. The final model has been selected based on the lowest AIC and visual inspection of predicted and observed values in the time series preceding the Lilac fire period. This final model included four knots for years and month of the year, six knots for weeks of the year and a dummy variable for weekend days vs. weekdays (stage 2 of the ITS analysis). We finally quantified the number of daily respiratory visits (and 95% CI) attributable to the Lilac Fire event by quantifying the difference between the predicted and observed daily visits during this period (stage 3 of the ITS analysis).

We conducted a similar analysis to quantify the average daily increase in $PM_{2.5}$ levels during the Lilac Fire event across San Diego County. Specifically, we conducted the same 3 ITS stages and included the same independent variables: years (2011–2017), month of the year (1–12), weeks of the year (1–52) and days of the week (1–7). The final model for $PM_{2.5}$ also included four knots for years and month of the year, 4 knots for weeks of the year and a dummy variable for weekend days vs. weekdays (stage 2 of the ITS analysis).We finally quantified the excess $PM_{2.5}$ that would not have been observed in the absence of the Lilac Fire (stage 3 of the ITS analysis). We also conducted a “falsification test” considering December 7–16, in previous years (2013-2016) separately for each year.

We gathered population data from the United States Decennial Census 2010 to calculate the age-adjusted visit rate by ZIP code. This data was utilized for spatial analysis. To provide further visual context of the effects of the Lilac Fire, we used ArcGIS Pro 2.2.4 (Redlands, CA) to geocode (map) the primary home ZIP code, reported at the time of the visit, for any patient under the age of 19 years presenting with a respiratory complaint to the RCH ED or any RCH UC location from December 7–16, 2017. In this planned analysis, we then compared the locations of the ZIP codes with the highest standard deviations in age-adjusted respiratory visits in relation to the Lilac Fire boundaries to assess proximity. Thus, the analysis is based on the standard deviation of ZIP code daily age-adjusted respiratory visits. We chose the standard deviation method of data classification as it best demonstrated the spread of the number of visits across this specific geography for the given study time. Data visualization of age-adjusted respiratory visit rates (change in standard deviation) allows depiction of the fire exposure impact on the surrounding population. This analysis is descriptive and serves to support the primary data analysis.

Spatial and Environmental Data

Satellite images before and during the Lilac Fire were obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) Rapid Response System https://lance.modaps.eosdis.nasa.gov/cgi-bin/imagery/gallery.cgi at MODIS' maximum spatial resolution of 250 meters. The fire perimeter for the Lilac Fire was obtained from the Fire and Resource Assessment Program (FRAP; http://frap.fire.ca.gov/) of the California Department of Forestry and Fire Protection. Santa Ana wind patterns were modeled by Guzman-Morales *et al.* (22) utilizing National Centers for Environmental Predictions-National Center for Atmospheric Research (NCEP-NCAR) wind data with a spatial resolution of 2.5×2.5 degrees. The resulting downscaled winds were resolved on a 10×10 km grid (22).

The daily concentrations of $PM_{2.5}$ (measured in μg/m^3) were obtained from 24-hour daily sampling from the US Environmental Protection Agency (US EPA). Daily means were calculated and reported by the US EPA Air Quality System (AQS) for San Diego County from 2011–2017. Measured concentrations of $PM_{2.5}$ from ten fixed-site monitoring stations were used to interpolate values across San Diego (Figure E1). We used an inverse-distance interpolation model to analyze measurements from stations within 12 miles of each population-weighted ZIP code centroid in San Diego County, which were then averaged and assigned to specific ZIP codes (23-25). The measured concentrations of $PM_{2.5}$ were weighted by the squared inverse distance to each point of interest, which gave greater importance to values reported by stations closer to the point of interest than stations farther away. The estimated values of $PM_{2.5}$ at each centroid were then assigned to each ZIP code for daily ZIP code-specific concentrations of $PM_{2.5}$ (Table E1).

Results

The patient characteristics of 154,983 visits to Rady Children's Hospital ED and UC clinics in 2017 are outlined in Table 1. The mean patient age was 6.1 years old. The majority of patients (69%) had Medi-Cal insurance while 25% had private insurance. English was the primary language spoken in the home, followed by Spanish. The median respiratory visit rate per 10,000 children per ZIP code for all children under 19 years of age, presenting to an UC or Rady Main ED from December 7 to 16, 2017 was 10.5 with a standard deviation of 50.2 visits. The highest rate of age-adjusted respiratory visits was 297 per 10,000 children for our study population. During the Lilac Fire, the mean average daily number of respiratory visits was 75.1 (SD: 18.6) compared to 55 (SD 6.1) the week before the fire. This data is summarized in Table 2. Healthcare utilization trends from 2011–2017 are demonstrated in Figure E2. Visits increased over the 7-year time period with seasonal peaks in visits during the winter and troughs in the summer.

As shown in Figure 1, we observed that conditions at the start of the Lilac Fire on December 7th were exceptionally dangerous due to a combination of drought, dead and highly combustible vegetation, and the Santa Ana wind conditions (regional maximum velocity of 35 mph). More than 77,000 people were affected, and more than 1,300 evacuees were reported (17). A total of 4,100 acres burned, of which 75% was contained by December 10th, when residents were allowed to return to their homes.

All 181 ZIP codes specific to San Diego County were included in our analysis. In Figure 2, we observed that the top 5 ZIP codes with the highest standard deviations in age-adjusted respiratory visits were generally downwind of the fire, and 3 of the 5 ZIP codes were located within a 10-mile radius of the fire perimeter. The locations of the RCH ED and UC facilities are indicated as well.

In Table 3, the estimates from the ITS models of excess daily ED and UC respiratory visits during the Lilac Fire event are presented (stage 3). For the entire pediatric population (aged 0–19 years), we found that the Lilac Fire was responsible for 16.03 (95% CI: 11.2, 20.9) daily respiratory ED visits. We found an impact of the Lilac Fire on each subgroup with varying impact. The age group 6-12 experienced the greatest change in number of visits associated with the wildfire and thus were the most impacted group with 3.4 additional daily excess respiratory ED visits (95% CI: 2.3, 4.6). Younger children aged 0-5 had the highest absolute daily excess ED visits with 7.3 (95% CI 3.0, 11.7). Conversely, no increases in respiratory visits were detected during the “falsification test” period (the same period in 2016 when no wildfire occurred). Similar null findings of increased utilization were seen in UC visits and when using other “falsification test” years (2013 to 2015).

When assessing the specific change in $PM_{2.5}$ due to the Lilac event using the ITS model, we found an average daily increase of 5.6 μg/m^3 (95% CI: 3.9, 7.4) across all ZIP codes in San Diego that were attributable to smoke from the Lilac Fire. Conversely, no increase in $PM_{2.5}$ was detected during the “falsification test” period in previous years (when no wildfire occurred) with an estimate of 0.2 μg/m^3 (95% CI: −0.8, 1.2) for the same period in 2016.

Discussion

In this study, we evaluated the impact of the SAW-driven Lilac Fire on respiratory visits to the RCH ED and UC clinics and found an increase in pediatric healthcare utilization in a patterned geographic distribution. This increase in utilization was seen across all age groups in both the ED and UC clinics but was most notable in younger children with those age 0-5 having the highest absolute excess visits and those age 6-12 having the largest increase in excess visits. Although children have been identified as a specific vulnerable group in studies examining ambient particulate matter (PM) exposure (34), there are few studies that have demonstrated increased vulnerability in children during wildfires (14, 35, 36). Jacobson *et al.* (35) showed that wildfire smoke exposure led to declines in lung function among non-asthmatic children. Another study found increased short-acting beta agonist (SABA) medication use in obese children with asthma after the 2003 and 2007 fires in San Diego (15). In contrast to our analysis, these studies were conducted with a smaller and more select sample size (between 234 and 3,965 children) and did not allow for the quantification of impact due to smoke from wildfire events on broader pediatric respiratory conditions at the population level.

Hutchinson *et al.* (14) recently evaluated the health effects of the San Diego 2007 wildfires. These researchers considered a different wildfire event and demonstrated that younger children are disproportionately affected, which is consistent with our findings. Specifically, these researchers found a 70% increase in ER presentations for respiratory diagnoses in children aged 0–4 years and a 243% increase in asthma diagnoses for very young children (age 0–1 years) compared to a control period. A disproportionate increase in respiratory symptoms in children is a consistent finding in the literature and may relate to children's smaller airways and higher ventilation rate compared to adults (36). $PM_{2.5}$ can penetrate deeply into the lung where it can induce lung injury, potentially through oxidative stress (37). In one study, the deposition rate of aerosolized 2 μm particles normalized to the lung surface area was

35% greater in children compared to adults (38). Understanding these impacts on vulnerable pediatric populations is crucial for developing adaptive strategies, such as early warning systems and community coordination with schools and healthcare facilities (39-41).

By utilizing descriptive spatial analysis, we were able to demonstrate a novel finding of increased healthcare utilization downwind of the Lilac wildfire perimeter, which may inform responses to future wildfires in the region. Delayed winter precipitation and warming prior to the Lilac Fire and other recent wildfires in the region suggest we may be seeing a new trend of prolonged fire seasons (42). Climate change is reducing the frequency of precipitation, particularly in the fall and spring (43, 44), while simultaneously increasing the intensity of precipitation extremes, particularly in mid-winter (45, 46). Less frequent but more intense precipitation periods increase the volatility in Southern California's precipitation regime with increased risk of flood and drought (44-47). The very wet winter of 2017 followed five years of exceptional drought and spurred vegetation growth. A dry fall and early winter primed the vegetation to be abundant, dry, and flammable in December of 2017, enabling the human-ignited Lilac Fire to burn during the peak of the SAW season. SAWs blowing from the northeast accelerate down the lee slopes of the coastal mountains towards more densely populated coastal communities (19). These same winds that fan wildfires also transport the smoke to the coastal zone. This directionality helps explain the increased healthcare utilization of children living downwind of the Lilac Fire perimeter. Given California's changing precipitation regime (44), we expect to see a prolonged wildfire season with more wildfires occurring later in the year (42). The most recent projections of the Santa

Ana winds in a changing climate (22), together with projected precipitation and temperature changes, suggest a gradual migration of Southern California's wildfire season from October towards December as this century progresses (47).

Creating early warning systems that forecast smoke exposure during wildfires can help improve public health responses. A wildfire smoke forecasting system was developed in British Colombia by estimating the association between exposure measures (daily $PM_{2.5}$ smoke plume tracings) and health indicators (daily asthma medication dispensations and asthma-related physician visits) in local geographic health areas. The researchers found a 30 $\mu g/m^3$ increase in $PM_{2.5}$ was associated with an 8% increase in salbutamol dispensations and a 5% increase in asthma-related physician visits (40, 41). The authors concluded that these forecasts were predictive of respiratory health indicators and could be useful for public health protection. Additionally, regional coordination between CalFire and forecast meteorologists at the National Weather Service in San Diego, with consideration of wind direction, may be helpful for future fire events to identify downwind geographic areas that are at high risk of wildfire smoke exposure.

The San Diego Association of Governments (SANDAG) estimates that the population of San Diego County will increase by 1 million people by the year 2030 (48). These warning systems may become increasingly important as the growing population expands the urban-wildland boundary (49). As climate change increases the risk of wildfires and the population in the wildland-urban interface encroaches further into the wildfire-prone hilly backcountry, providing more opportunity for human-caused ignitions, the effects on local and downwind human populations will increase. Efforts to develop the wildfire-prone backcountry in San Diego County are being contested primarily due to wildfire-related concerns (50). Our results can further inform such deliberations and their developmental policy implications.

We believe there are many strengths to this study that make our findings compelling. Focusing on specific pediatric age groups allowed us to identify quantifiable increases in respiratory visits in each of these groups using ITS modeling. Furthermore, we evaluated all pediatric respiratory visits as opposed to specific respiratory conditions, as the latter may lead to an underestimation of the healthcare utilization effects of wildfires. Lastly, we were able to visually demonstrate a patterned geographic distribution of pediatric healthcare utilization driven by the regional phenomenon of SAWs that has not previously been demonstrated in the literature.

However, our study is not without limitations. One potential limitation is that we only evaluated one wildfire episode. While larger-scale fires in San Diego County—particularly in 2003 and 2007—have occurred, these fires took place prior to the implementation of the current EMR system. Other studies have also chosen to focus on one wildfire event (19, 35) and by choosing the Lilac Fire in December of 2017, we limited potential confounders, such as increased temperature (and heat waves), usually associated with early and late season SAWs. We did not specifically evaluate weather-related confounders, including temperature and humidity, during the study period, but we presume these would have a small effect on our results in the ITS model. Additionally, we detected a small increase in one estimate of the ITS model when focusing on the control year 2016 (emergency department visits by the 0–5 years age group), which would imply that the attributable burden we found (7.3; 95% CI: 3.0, 11.7) may be slightly overestimated. Finally, by examining all respiratory causes, there could have been an increased signal given an anomalously active viral respiratory season in 2017 compared to prior years. However, we would not expect to see the patterned geographic distribution of increased healthcare utilization downwind of the Fire perimeter if it were due to increased viral load alone.

Conclusion

We have demonstrated an increase in pediatric ED and UC respiratory visits associated with increased $PM_{2.5}$ during the December 2017 Santa Ana wind-driven Lilac Fire in San Diego County. The largest impact was quantified in the age 6-12 age group. We also visually demonstrated that this impact occurred generally downwind of the fire perimeter. As the population increases and pushes the boundaries of the wildland-urban interface, ignition sources will increase, and a growing population will be exposed to smoke blown towards the densely populated coast. Future wildfires will increasingly affect a larger susceptible pediatric population and will require greater preparedness and evidence-based mitigation efforts.

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Legends for Figures

Figure 1. Satellite Imaging of San Diego County during the Lilac Fire

(A) Image of the San Diego County region from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on board the Terra satellite during the morning overpass on December 7th at 18:15 UTC (11:15 am in local time). (B) Image of the same region by MODIS (Aqua satellite) on the same day at 21:30 UTC (2:30 pm). At the time, the Lilac Fire (area shown in red) had been burning for a few hours, and the plume of smoke is visible and moving southwest towards the coast. There is cloud-cover noted in the southwest corner of the image. Daily, statistically downscaled SAW wind vectors (black arrows; Guzman-Morales and Gershunov, 2019) for December 7th are shown. The size of the arrows represents the magnitude of the wind velocity, with a regional maximum of 35 mph and a value of 18 mph nearby the fire perimeter.

Figure 2. Age-Adjusted Respiratory Visits during the Lilac Fire, 2017

Change in standard deviation age-adjusted respiratory visits per primary home ZIP code at Rady Children's Hospital Emergency Department and Urgent Care Clinics from December 7th-16, 2017. Lilac Fire boundary and Rady Children's Hospital Emergency Department and Urgent Care Clinics locations. Notated. ArcGIS Pro 2.2.4

Table 1.
Characteristics of Patients Visiting Rady Children's Hospital Emergency Department and Urgent Care Clinics in 2017

Age: Mean age; (SD) Standard Deviation; Age Category, Primary Insurance, Respiratory Visit Type, Primary Language: Absolute; (%) Percentage

Table 2: Daily age-adjusted rate of respiratory visits per ZIP code to Rady emergency

department or urgent care clinics,2017 (SD) Standard Deviation; Range: Daily Respiratory Visits during designated time period

Table 3: Impacts of the Lilac Fire on Rady Children's Hospital Emergency Department and Urgent Care Respiratory Visits in San Diego, 2017

* Results from stage 3 of the ITS models. The excess daily visits represent the difference between the observed number of visits versus the model predicted number of visits for that time period

Rady Children's Hospital Emergency Department and Urgent Care Clinics Respiratory Visits by age group with mean visits (observed values 2011-2017), excess daily visits during the Lilac Fire and excess daily visits during the control period. Mean Respiratory Visit: Mean average; (SD) Standard Deviation, Excess Daily Respiratory Visits during Lilac Fire and control period: Mean average; (95% CI) 95% confidence interval

Table E1: Descriptive Statistics for Daily $PM_{2.5}$ (μg/m^3)

Modeled using an inverse-distance interpolation model and measurements from Agency Air Quality System (AQS) monitoring stations for San Diego, 2011–2017 Daily $PM_{2.5}$ (Particulate Matter equal to or less than 2.5 microns (μg/m^3))

Figure E1 Air Quality System (AQS) $PM_{2.5}$ Monitoring Stations in San Diego County

Locations of Environmental Protection Agency Air Quality Monitoring System (AQS) Monitoring Stations in San Diego County (n=10)

Figure E2 Rady Children's Hospital Emergency Department and Urgent Care Clinics Visits

Daily Rady Children's Hospital Emergency Department and Urgent Care Clinics visits (red) and respiratory visits (blue) in 2017 (top) and 2011–2017(bottom). Control period and Lilac Fire demarcated with solid vertical lines. Seasonal and long-term trends are well captured.

Tables

Table 1:

Characteristics of Patients Visiting Rady Children's Hospital Emergency Department and Urgent Care Clinics in 2017

	Emergency Department (n = 97345)	Urgent Care (n = 57638)	Overall (n = 154983)
Mean Age (SD)	6.3 (5.8)	5.8 (4.9)	6.1 (5.5)
Age Category*			
0-5 Years	57021 (58.6%)	35462 (61.5%)	92483 (59.7%)
6-12 Years	22985 (23.6%)	14879 (25.8%)	37864 (24.4%)
13-19 Years	17336 (17.8%)	7297 (12.7%)	24633 (15.9%)
Primary Financial Class			
Unspecified Hospital Account	6 (0.0%)	0 (0.0%)	6 (0.0%)
Private	26036 (26.7%)	12150 (21.1%)	38186 (24.6%)
Medi-Cal	63364 (65.1%)	42753 (74.2%)	106117 (68.5%)
Medicare	75 (0.1%)	4 (0.0%)	79 (0.1%)
Other	3 (0.0%)	0 (0.0%)	3 (0.0%)
Out of State Medicaid	381 (0.4%)	147 (0.3%)	528 (0.3%)
Self-pay	2782 (2.9%)	1294 (2.2%)	4076 (2.6%)
Military	4688 (4.8%)	1290 (2.2%)	5978 (3.9%)
Worker's Comp	10 (0.0%)	0 (0.0%)	10 (0.0%)
Respiratory Visit?			

No	79377 (81.5%)	45519 (79.0%)	124896 (80.6%)
Yes	17968 (18.5%)	12119 (21.0%)	30087 (19.4%)
Primary Language (Simplified)			
English	77317 (79.4%)	42402 (73.6%)	119719 (77.2%)
Spanish	16669 (17.1%)	13378 (23.2%)	30047 (19.4%)
Other	3359 (3.5%)	1858 (3.2%)	5217 (3.4%)

Patient Characteristics of Rady Children's Hospital Emergency Department and Urgent Care Clinics. Age: Mean age; (SD) Standard Deviation; Age Category, Primary Insurance, Respiratory Visit Type, Primary Language: Absolute; (%) Percentage

Table 2: Daily age-adjusted rate of respiratory visits per 10,000 children per ZIP code to Rady emergency department or urgent care clinics,2017

Time frames(SD and Range)	
Lilac Fire Median	10.5 (SD 50.2) Range:40-111
Week before Lilac Fire Mean	55 (SD: 6.1) Range: 47- 61
Lilac Fire Mean	75.1 (SD: 18.6) Range: 40-111

(SD) Standard Deviation; Range: Daily Respiratory Visits during designated time period

Table 3: Impacts of the Lilac fire on Rady children's daily hospital emergency department and urgent care respiratory visits in San Diego, 2017

Emergency Department Visits	Mean visits (SD) (2011-2017)	Excess daily visits during the Lilac Fire (95% CI)* 12/7/2017 - 12/16/2017	Excess daily visits during the control period (95% CI)* 12/7/2016 - 12/16/2016
All	44.2 (20.7)	16.0 (11.2, 20.9)	3.1 (-1.8, 8.0)
0-5 Years	32.4 (16.6)	7.3 (3.0, 11.7)	5.0(1.0, 8.9)
6-12 Years	4.8 (3.3)	3.4 (2.3, 4.6)	-1.4 (-2.6, -0.3)
13-19 Years	3.2 (2.3)	2.0 (1.0, 3.0)	0.1 (-0.7, 0.9)
Urgent Care Visits			
All	30.5 (17.7)	16.6 (11.6, 21.6)	-2.4 (-6.6, 1.7)
0-5 Years	22.5 (13.2)	7.7 (4.1, 11.3)	0.00 (-3.1, 3.2)
6-12 Years	5.2 (4.0)	3.6 (2.3, 4.9)	-1.1(-2.3, 0.1)
13-19 Years	2.8 (2.5)	3.3 (2.3, 4.2)	- 1.2 (-2.0, 0.5)

* Results from stage 3 of the ITS models. The excess daily visits represent the difference between the observed number of visits versus the model predicted number of visits for that time period

Rady Children's Hospital Emergency Department and Urgent Care Clinics Respiratory Visits by age group with mean visits (observed values 2011-2017), excess daily visits during the Lilac Fire and excess daily visits during the control period. Mean Respiratory Visit: Mean average; (SD) Standard Deviation, Excess Daily Respiratory Visits during Lilac Fire and control period: Mean average; (95% CI) 95% confidence interval

Figures

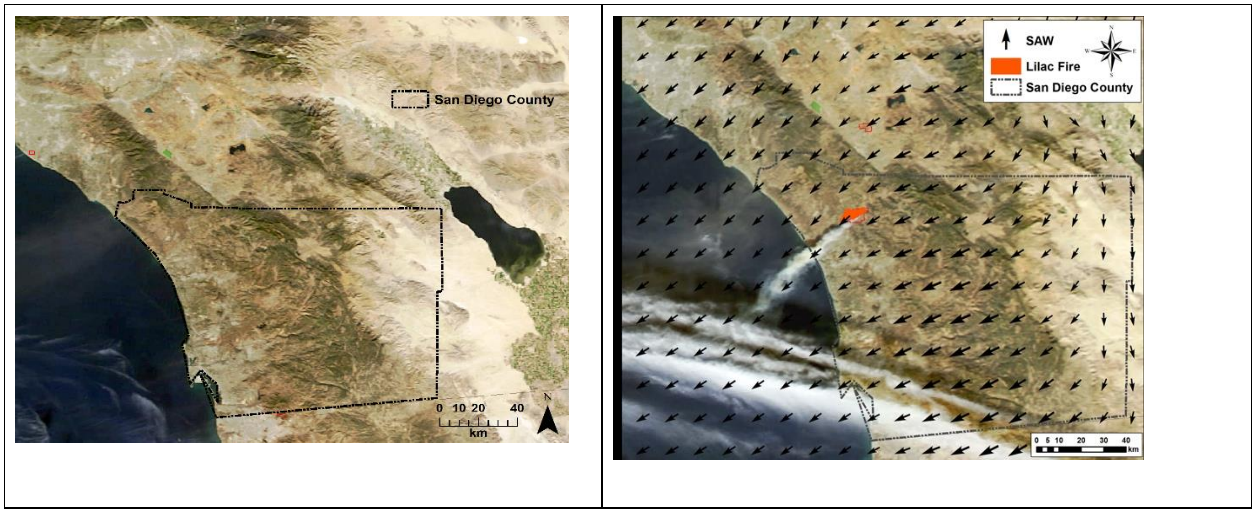

Figure 1

(a) Image of the San Diego County region from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on board the Terra satellite during the morning overpass on December 7th at 18:15 UTC (11:15 am in local time). (b) Image of the same region by MODIS (Aqua satellite) on the same day at 21:30 UTC (2:30 pm). At the time, the Lilac Fire (area shown in red) had been burning for a few hours, and the plume of smoke is visible and moving southwest towards the coast. There is cloud-cover noted in the southwest corner of the image. Daily, statistically downscaled SAW wind vectors (black arrows; Guzman-Morales and Gershunov, 2019) for December 7th are shown. The size of the arrows represents the magnitude of the wind velocity, with a regional maximum of 35 mph and a value of 18 mph nearby the fire perimeter.

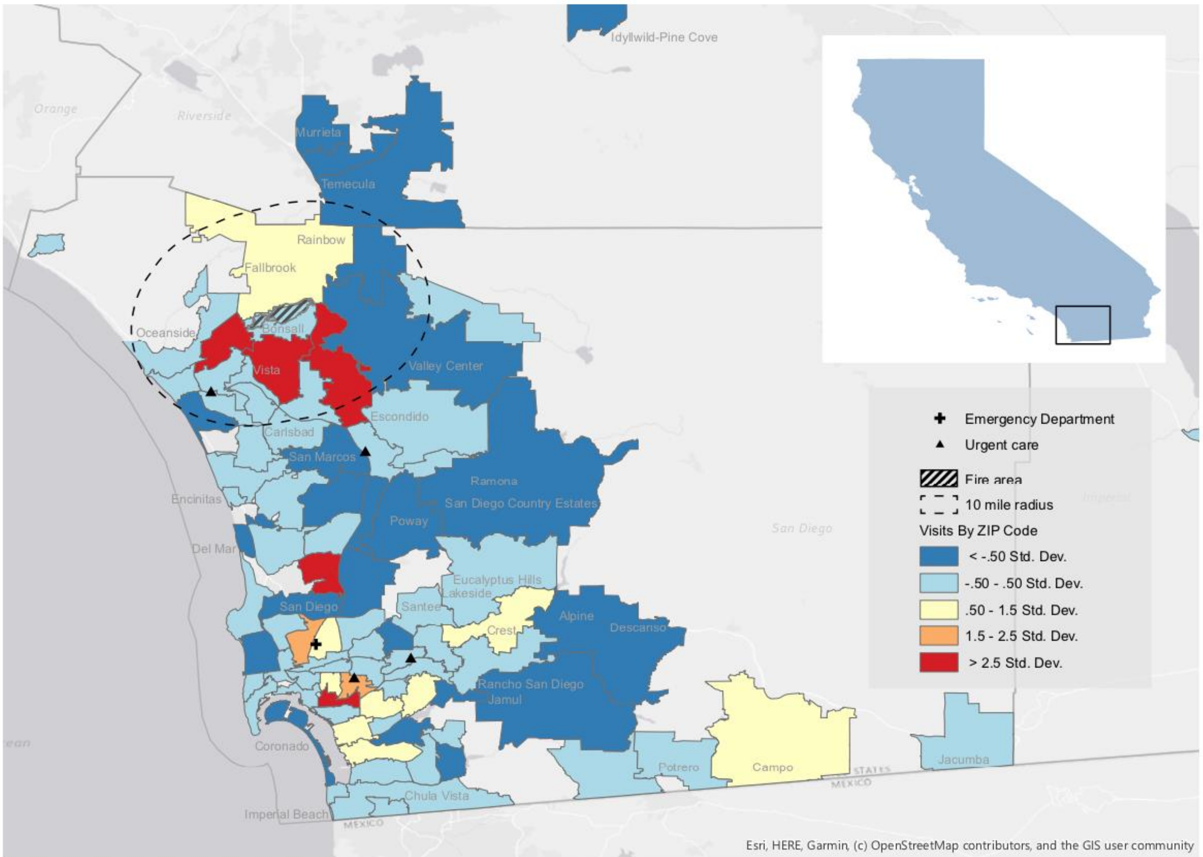

Figure 2. This map illustrates the impact of the Lilac Fire on age-adjusted daily respiratory visits (change in standard deviation) by ZIP code from December 7 to 16, 2017. (based on ZIP code daily age-adjusted respiratory visits standard deviations) Within the 10 mile radius of the Lilac Fire, there are three ZIP codes with visit rates greater than 2.5 standard deviations of the mean.

Online Supplements

Table E1: Descriptive statistics for daily $PM_{2.5}$ (μg/m³)

	Minimum	**Maximum**	**Median**	**Mean**	**Standard Deviation**
Modeled Daily $PM_{2.5}$ values*	3.3	41.6	9.4	10.0	4.0

* Modeled using an inverse-distance interpolation model and measurements from Agency Air Quality System (AQS) monitoring stations for San Diego, 2011-2017

Daily $PM_{2.5}$ (Particulate matter equal to or less than 2.5 microns (μg/m³))

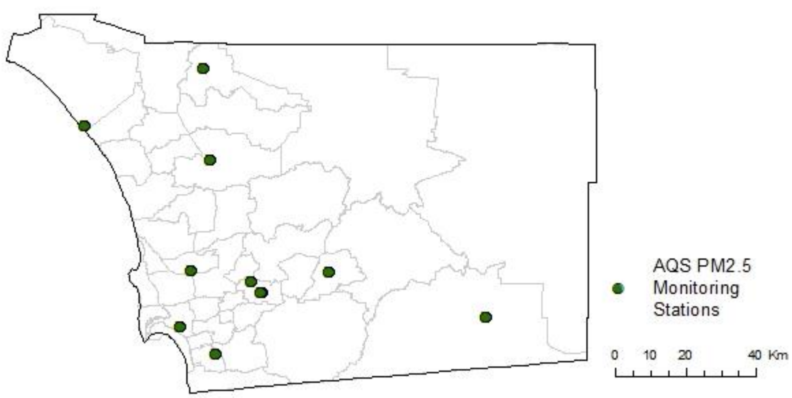

Figure E1. Air Quality System (AQS) $PM_{2.5}$ Monitoring Stations in San Diego County Locations of Environmental Protection Agency Air Quality Monitoring System (AQS) Monitoring Stations in San Diego County (n=10)

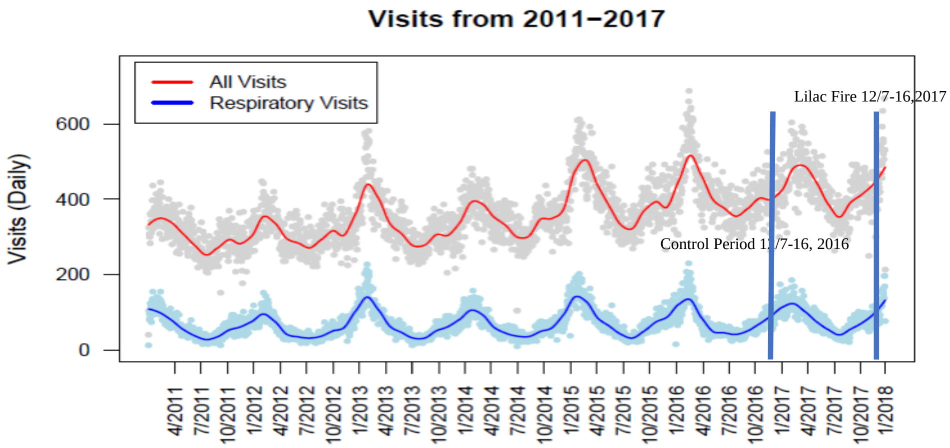

Figure E2. Rady Children's Hospital Emergency Department and Urgent Care Clinics Visits

Daily Rady Children's Hospital Emergency Department and Urgent Care Clinics visits (red) and respiratory visits (blue) from 2011–2017(bottom). Control period and Lilac Fire demarcated with solid vertical lines. Red and blue lines represent the daily average of observed values for the whole time series for all visits and respiratory visits respectively.