CENTER FOR ADVANCING INTERDISCIPLINARY RESEARCH ON THE ENVIRONMENT



AIRE

RESEARCH & REFLECTIONS

Prescribed Burns, Hospitalizations, and Pollutants

ISSUE 1
2024

ADVANCING INTERDISCIPLINARY RESEARCH ON THE ENVIRONMENT

Oregon TECH





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Lee Mitchell, Ph.D.

Background

The EPA and US Forest Service executed a pilot project during spring 2024 in Deschutes County, Oregon, to explore the potential to increase the acreage of prescribed burns during a year. For more information on the program, see:

https://www.fs.usda.gov/detailfull/r6/fire-aviation/?cid=FSEPRD1170659

Deschutes County, Oregon, Prescribed Burning Pilot Study Research Projects (On-Going)

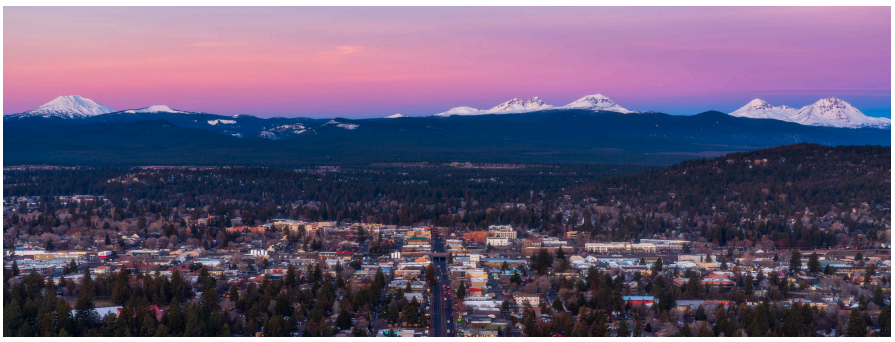
A group of researchers was convened to explore impacts from this prescribed burn pilot project on the community. Of the potential projects discussed, community members involved in the project were most interested in understanding the knowledge of and sentiment toward prescribed fire practices among Deschutes County residents, and the impact of smoke pollution on indoor air quality.

Survey Project
The aim of the survey is to understand the Deschutes County public's:

- Perception of a specific prescribed fire event
- Knowledge and sentiment regarding prescribed fire
- Awareness of a communication strategy regarding prescribed fire
- Protective behaviors adopted to mitigate health risks

The survey project is being completed under a joint effort between staff at Deschutes Collaborative Forest Project, Oregon Institute of Technology AIRE Center, and the US Forest Service.

A random sample of N=4, 250 households were sent letters and one reminder (if necessary) inviting them to complete the survey. Data collection is occurring during June 2024.



Simultaneously with the initial survey, a separate instance of the survey was distributed through local community volunteer groups and public service channels under a non-probability, convenience sampling approach. Data collection is occurring during May and June 2024.

Outdoor air quality measures across Deschutes County will be obtained from public outdoor PurpleAir measurements and local regulatory monitors. This data will be used to compare perceptions of smoke impacts to actual PM2.5 concentrations.

Traffic, bicycle, and pedestrian counts will be obtained through the Oregon Department of Transportation. This data will be used to compare survey responses on behavioral adaptations to smoke pollution to measured behavior data.

Analyses will be performed separately for the random sample and the convenience sample; results between sampling strategies will be compared. The analyses will:

- Describe average perception of smoke exposure during prescribed fire season
- Compare perceived air quality impacts to actual air pollution concentrations
- Describe average public support of and knowledge about prescribed burning using survey questions
- Describe average preferred information channels
- Measure changes in behavior during smoke events
- Compare actual rates of behavior change to rates of adopted behaviors as stated in the survey

Analysis results are expected to be distributed during fall 2024.

Indoor Air Quality Project

The aim of the indoor air quality project is to quantify how indoor air quality compares to outdoor air quality during times with no smoke impact, prescribed burn smoke impacts, and wildfire smoke impacts around Bend, Oregon.



Figure 1: Westward view from Pilot Butte toward downtown Bend and the Cascade Range, September 2022. Permissions Deschutes County.

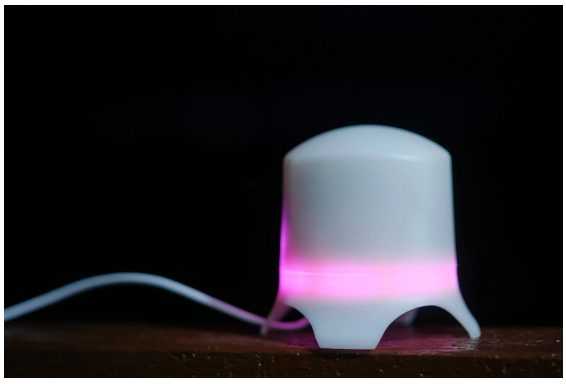


Figure 2: Purple Air Monitors Used to Measure Indoor Air Quality

The indoor air quality project is being completed as a joint effort between staff at Deschutes Collaborative Forest Project, Deschutes County Public Health, Oregon Institute of Technology AIRE Center, the US Forest Service, and the Environmental Protection Agency.

The indoor air quality project study area includes a 10-mile radius around Bend, Oregon. A total of N=78 PurpleAir monitors were distributed across the study area. PM2.5 concentrations are being collected every minute during fire season 2024, from May 1st through September 30th. Participants completed a survey describing home characteristics that could impact the indoor air quality.

Outdoor air quality across the study area will be modeled as a grid across the study based on all public outdoor PurpleAir measurements and local regulatory monitors. The EPA correction factor will be applied to all indoor and outdoor measurements.

Analyses will include:

- Spatial autocorrelation (Global Moran's I) to identify clusters of low and high indoor and outdoor air quality concentrations
- Statistical correlation coefficients between indoor and outdoor air quality concentrations for each condition (clear, prescribed burn, wildfire)
- Regression to explore the impact of potential explanatory variables from the participant questionnaire, including room type, type of housing, age of housing, primary construction material, type and age of heating/cooling systems, presence of wood-burning fireplace or stove, presence of smoking/smudging/incense/candles, pets, window count, nearby pollution activities, and smoke mitigation actions taken

Acknowledgments:

This project is made possible through a collaborative partnership between Deschutes County residents, the Deschutes Collaborative Forest Project, Deschutes County Public Health, the Environmental Protection Agency, the U.S. Forest Service, and the Oregon Institute of Technology AIRE Center. A special appreciation is given to the residents who conducted the indoor air quality monitoring.

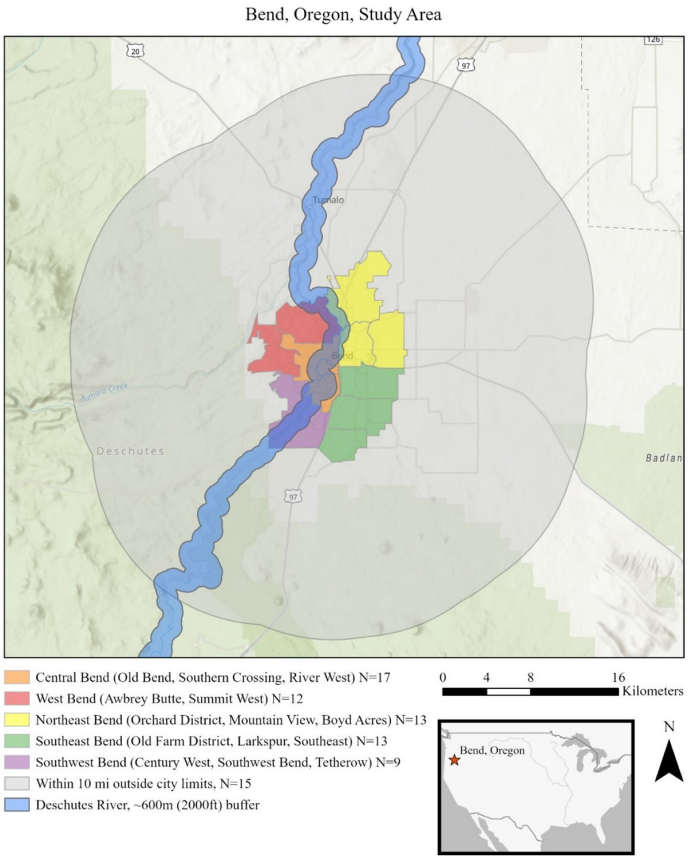


Figure 1: Bend, Oregon, indoor air quality project study area showing the 16 km project buffer, the 600 km buffer along the Deschutes River, and neighborhood group boundaries with the N number of participants in the legend.



Lee Mitchell, Ph.D.

Kyle Chapman, Ph.D.

Background

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https://www.fs.usda.gov/detailfull/r6/fire-aviation/?cid=FSEPRD1170659

Case-Crossover Analysis of Smoke Impacts on Respiratory and Cardiovascular Health in Southwestern Oregon

Summary
The aim of this study was to quantify the respiratory and cardiovascular health outcomes associated with wildfire smoke pollution in southwestern Oregon. Every 10 µ/m3 increase in PM2.5 is associated with a 1.6% increase in same day hospital or emergency room admission rates for respiratory conditions (OR=1.0157; 95% CI: 1.0024 – 1.0287) and no significant increase in admission rates for cardiovascular conditions. A 10 µ/m3 increase in PM2.5 lasting fifteen days is associated with a 6.5% increase in hospital or emergency room admission rates for respiratory conditions (OR=1.0645; 95% CI: 1.0400 – 1.0894) and a 4.9% increase in hospital or emergency room admission rates for cardiovascular conditions (OR=1.0493; 95% CI: 1.0265 – 1.0723). As the duration of poor air quality increases, the risk of negative respiratory and cardiovascular health outcomes increases.

Study area
The study area includes Josephine, Jackson, and Klamath Counties in southwestern Oregon.

Study time
The study encompasses the years 2016 through 2022.



Figure 1: Smoke rises over the Miles Fire, part of the South Umpqua Complex in southern Oregon. Courtesy Linda Kessler.

Health data
Patient diagnoses and home coordinates at a 4-km resolution were obtained from four of the five hospitals in the study area, including Sky Lakes Medical Center, Ashland Community Hospital, Rogue Regional Medical Center, and Three Rivers Medical Center. Patient records with a primary discharge diagnosis within the I00-I99 and J00-J99 ICD-10 codes within the study timeframe were retained for a total N=24,421 with a home location within the study area.

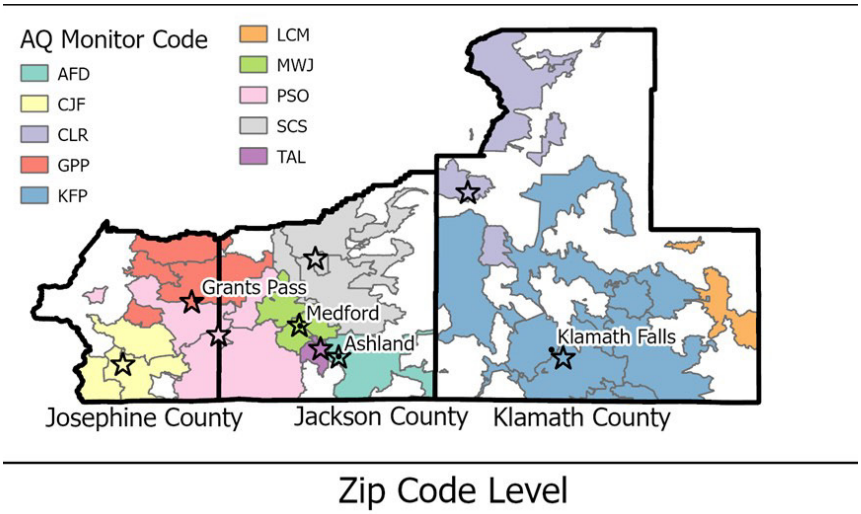


Figure 1. Map of the Study Area: air quality monitors are marked by a star.

Exposure data
Daily mean PM2.5 concentrations were derived from 4-km resolution airshed scaling factors applied to values measured from the monitor associated with the airshed. Cumulative lag values for 3-, 5-, 7-, 9-, 11-, 13- and 15-day exposures were calculated as the average concentration of the lag period from the date backward in time. As shown in Figure 1, particularly through the Klamath Falls Peterson Elementary (KFP) and Shady Cove School (SCS) monitors, the upper range of the lagged values begins to even out after about two weeks.

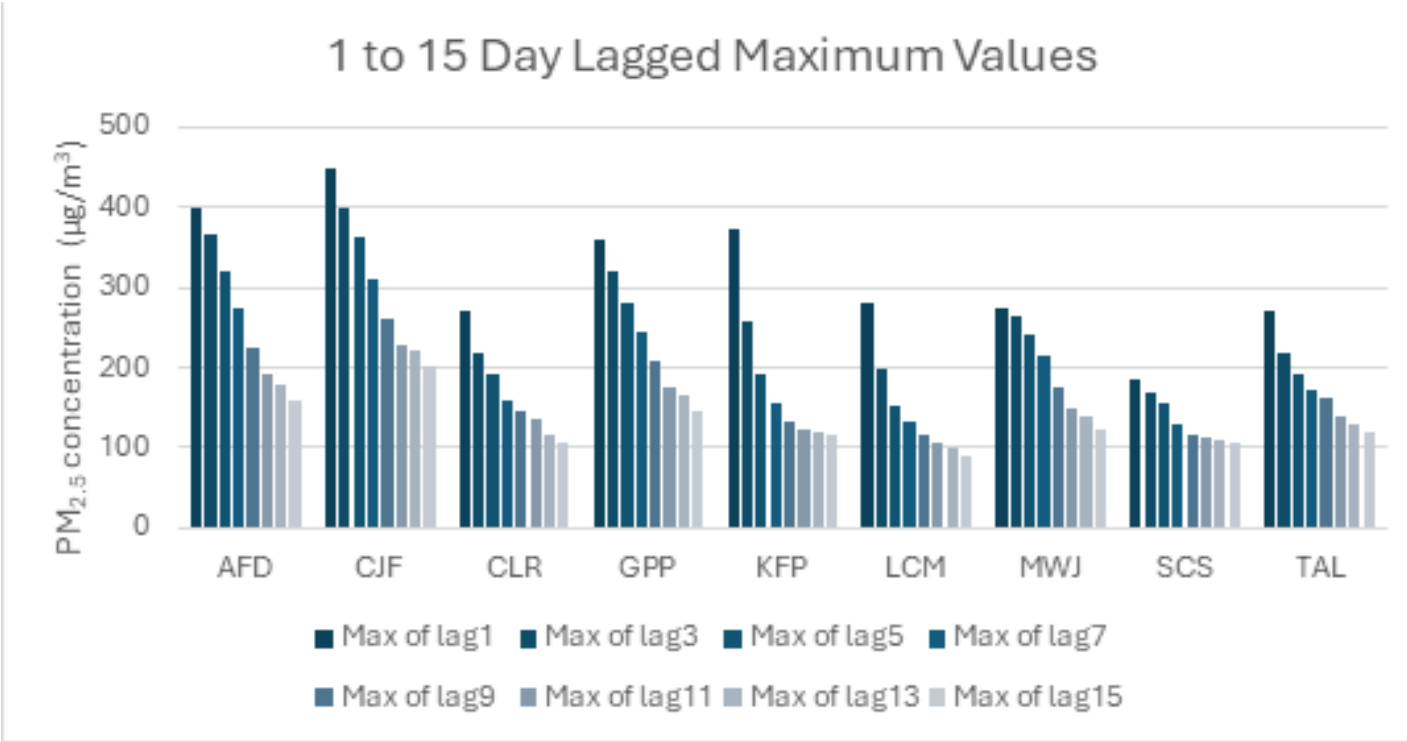


Figure 2: Maximum PM2.5 concentration values for cumulative lags from 1 to 15 days for each monitor in the study area.

Methods
The study adopted a case-crossover approach using conditional Poisson regression for analysis of time stratified patient counts while controlling for mean temperature. The time strata, in day of week – month – year format, helped control for intra-annual variation such as wintertime cold and flu season. The analysis was implemented using the R gnm library function: gnm(formula = PatientCount ~ PM25 + MeanTemperature, eliminate = factor (TimeStrata), family = poisson(), data = DataTable).

Findings
Results are presented for all patients admitted to the hospital or emergency room during the study time frame, N=24,421; respiratory patients with a J00-J99 ICD-10 primary diagnosis code, N=12,782; and cardiovascular patients with a I00-I99 ICD-10 primary diagnosis code, N=11,639. Figure 2 shows a 10 µ/m3 increase in PM2.5 is associated with a 1.1% increase in all patient admissions (OR=1.0108; 95% CI: 1.0018 – 1.0197); a 1.6% increase in same-day admission rates for respiratory conditions (OR=1.0157; 95% CI: 1.0024 – 1.0287); and an insignificant impact on cardiovascular admissions as the 95% confidence interval encompasses the value of 1.00 (OR=1.0066; 95% CI: 0.9942 – 1.0187).

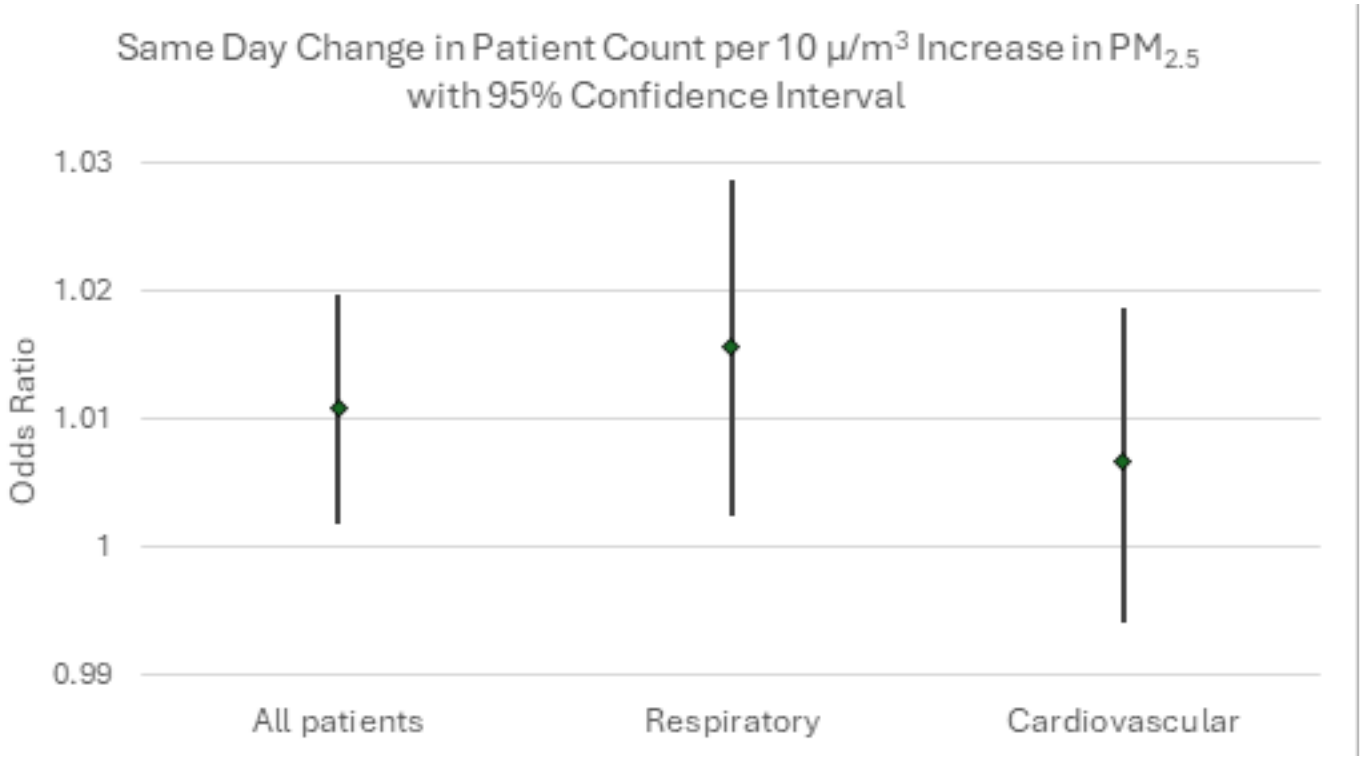


Figure 3: Odds ratio with 95% confidence intervals for the same day increase in patient counts related to the increase in PM2.5 concentrations.

All Patients
The cumulative lag values were calculated for odd numbers of days from 1 through 15 to extend to an average of just over two weeks. A lag of 0 indicates same day admissions. As shown in Figure 3, the increase in all patients counts almost dropped out of significance with a 1-day lag (OR=1.0098; 95% CI: 1.0001 – 1.0193). Then the odds ratio increases each lag period to an expected 5.6% increase in admissions with a 10 µ/m3 increase the average PM2.5 across a 15-day lag (OR=1.0563; 95% CI: 1.0396 – 1.0732).

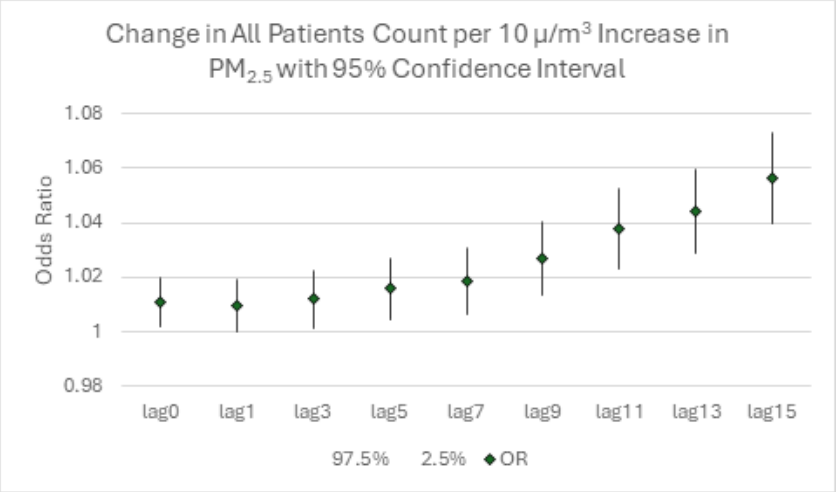


Figure 4: Odds ratio with 95% confidence intervals for the increase in all patient counts related to the increase in the cumulative lagged average, from lag=0 to lag=15, of PM2.5 concentrations.

Respiratory Patients
The odds ratios for the lagged averages associated with respiratory patient admissions are shown in Figure 4. While there is a significant increase in same day respiratory patients associated with a 10 µ/m3 increase the average PM2.5 as discussed earlier, the increase is insignificant for a cumulative lagged average of both 1 day (OR=1.0125; 95% CI: 0.9982 – 1.0264) and 3 days (OR=1.0125; 95% CI: 1.000 – 1.0302). The increase in respiratory patients is significant again with a 5-day lag (OR=1.0197; 95% CI: 1.0033 – 1.0358); and increases each lag period to an expected 6.4% increase in respiratory admissions for the 15-day lag period (OR=1.0645; 95% CI: 1.0400 – 1.0894).

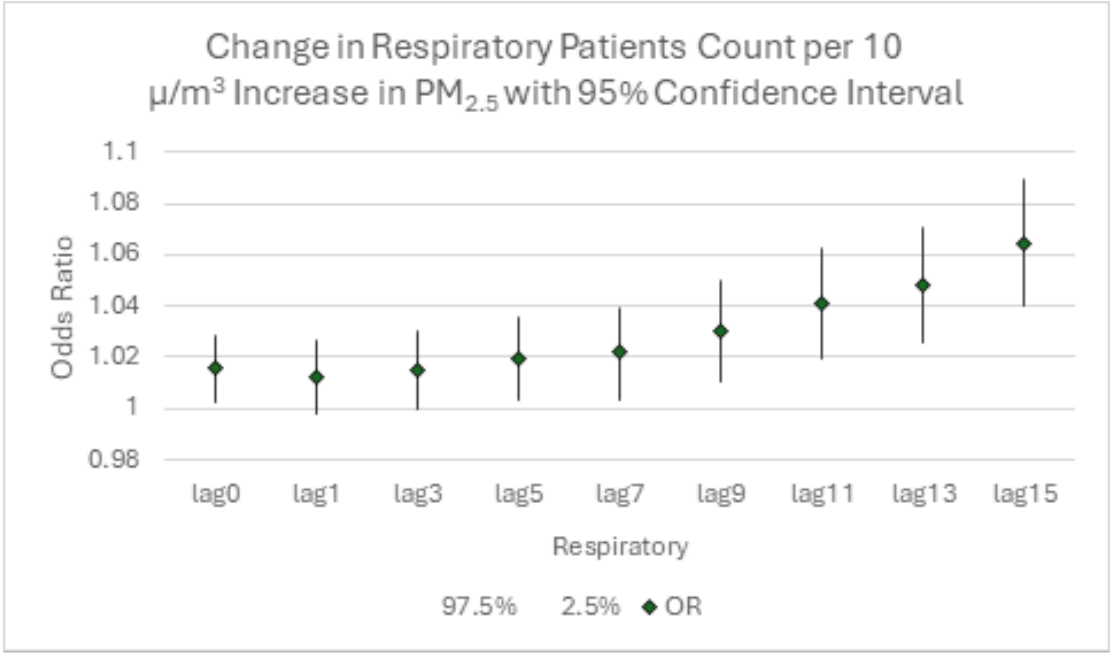


Figure 4: Odds ratio with 95% confidence intervals for the increase in respiratory patient counts related to the increase in the cumulative lagged average, from lag=0 to lag=15, of PM2.5 concentrations.

Cardiovascular Patients
The odds ratios for the lagged averages associated with cardiovascular patient admissions are shown in Figure 5. Expected cardiovascular patient counts increase but remain insignificant through a 7-day lag period. The odds ratio becomes significant with a 10 μ/m3 increase the average PM2.5 across a 9-day lag period with an expected 2.4% increase in cardiovascular patients (OR=1.0239; 95% CI: 1.0054 – 1.0422); and continues to increase through a 15-day lag period with an expected 4.9% increase in admissions with a (OR=1.0493; 95% CI: 1.0265 – 1.0723).

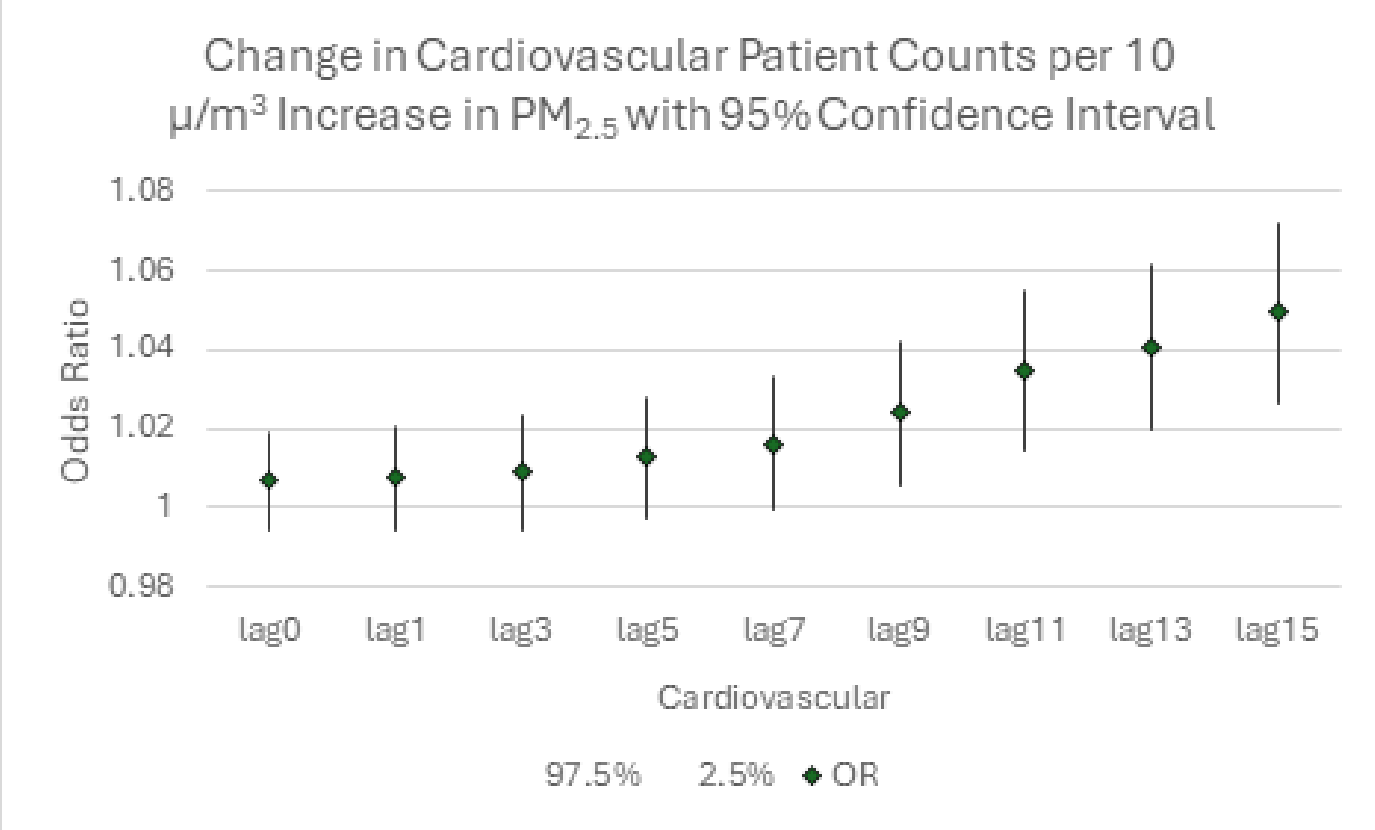


Figure 5: Odds ratio with 95% confidence intervals for the increase in cardiovascular patient counts related to the increase in the cumulative lagged average, from lag=0 to lag=15, of PM2.5 concentrations.

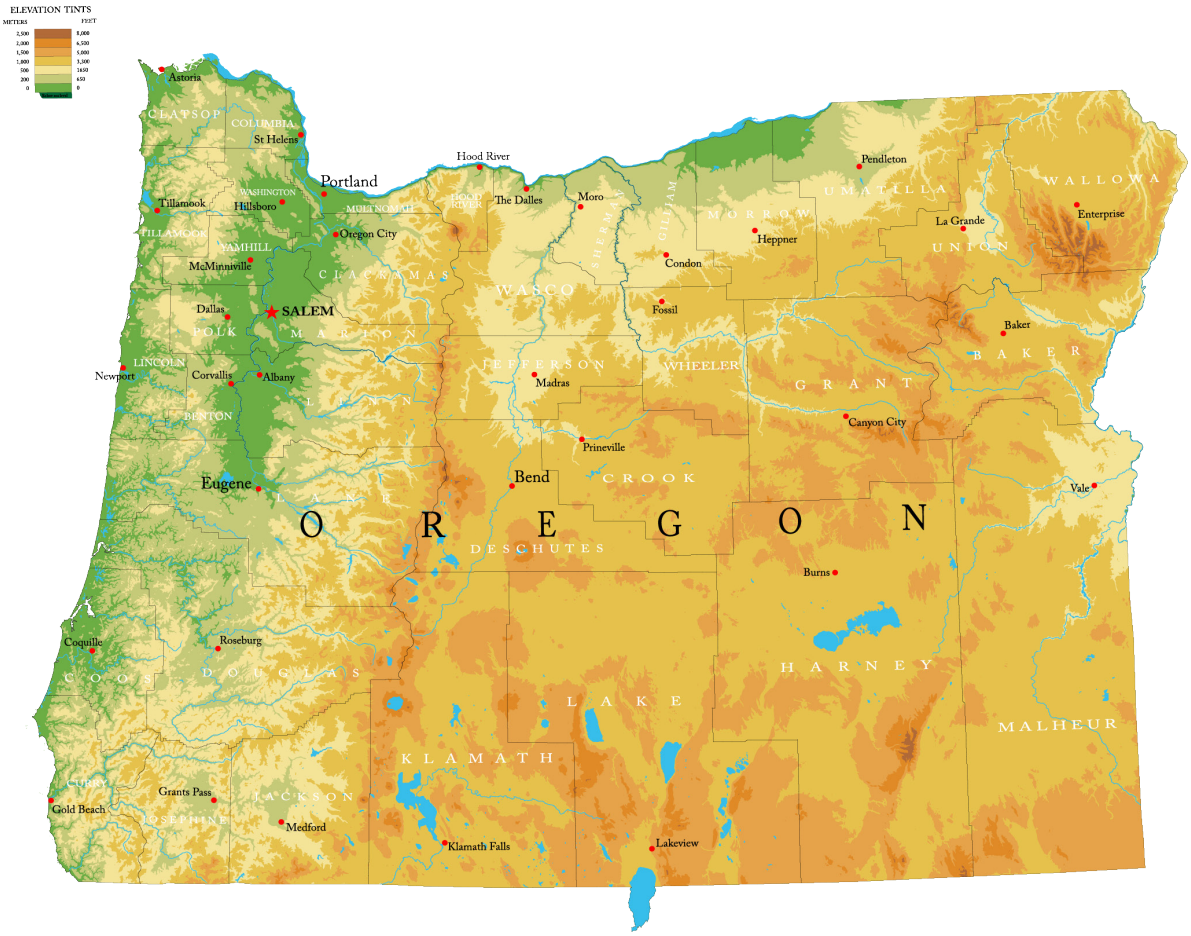
Conclusions
Poor air quality for a day is associated with an expected increase in respiratory patients. When poor air quality lasts over a week, there is an increase in the expected number of both respiratory and cardiovascular patients. These findings suggest that the cardiovascular health impacts of wildfire smoke may be more evident with prolonged exposure rather than acute exposure, highlighting the importance of considering exposure duration in health impact assessments. Overall, this analysis has important implications for a range of policy and processes at community and state levels. Findings from this study can be used by area hospitals and health systems to inform staffing and resource allocation during smoke events.

Identifying Health Care Access Gaps in Areas of Oregon at High Risk of Respiratory Hospitalization

Lee Mitchell, Ph.D.

Summary
Wildfire smoke causes respiratory health concerns and is a growing threat in Oregon. This paper outlines a process for estimating respiratory hospitalization risk from wildfires and identifies concentrations of smoke-sensitive groups far from a hospital.

Environmental factors that were statistically significant predictors of hospitalization risk were identified using a subset of the state for training. These significant environmental factors were used along with wildfire and pollution concentrations were used to predict respiratory hospitalizations from wildfire smoke. A weighted overlay of these factors formed a statewide risk layer. The driving distance to the nearest hospital was calculated for each Census block across the state. A hot spot analysis was applied to identify clusters of smoke sensitive groups as determined through Census demographics.



Data

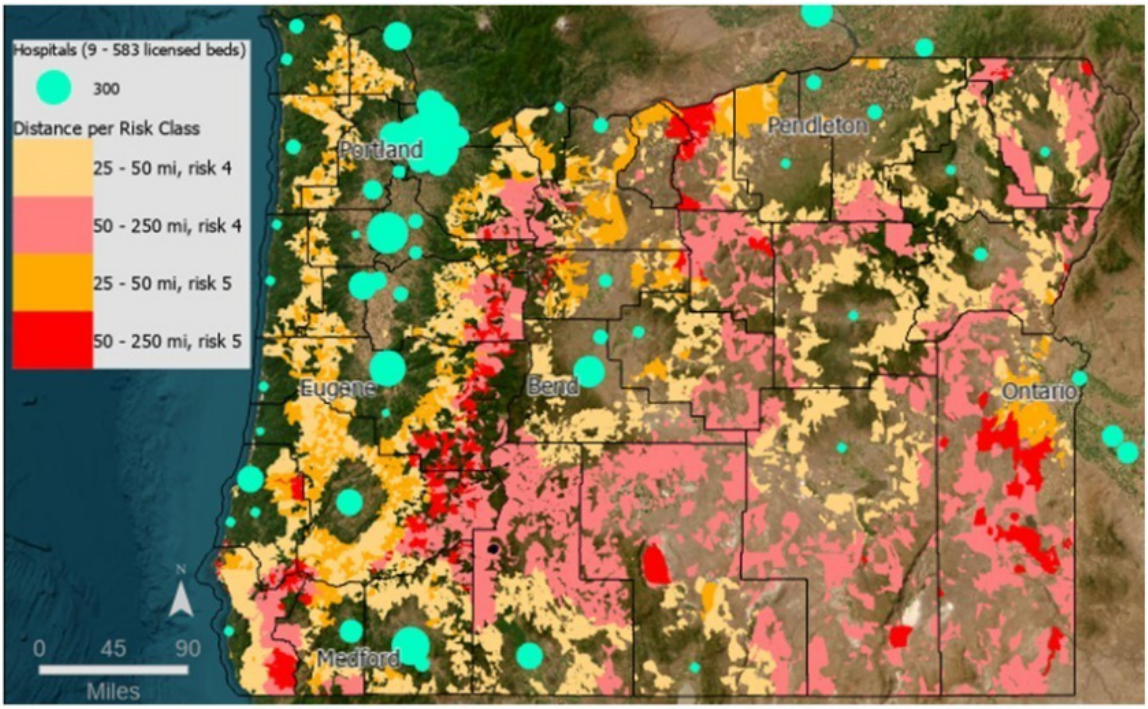
Hospital Variables
- Hospital Admissions
  - Respiratory conditions from 2016-2019 for two counties in southern Oregon
  - Hospital locations: 25 mile proximity

Demographic Variables
- Age: under 18 and over 65
- Households with 1+ persons with a disability
- Households below poverty level
- Hispanic population
- Occupation: Farm/Fish/Forestry & Construction/Extraction

Fire and Pollution Variables
- PM2.5 concentrations: daily average, cumulative
- Fire location: zip acreage burned, distance to fire

Environmental Variables
- Elevation, 10m: min, mean, max elevation; elevation range
- Weather, 4km: mean and maximum temperature, dew point, relative humidity
- Vegetation, 250m: average and majority NDVI (Normalized Difference Vegetation Index) and LAI (Leaf Area Index).

Highest Populated Risk Areas over 25 miles from a Hospital



Methods

Model variables were selected based on strength of relationship between potential variables and respiratory patients. Then random trees regression was performed with all candidate variables and generalized linear regression was used to determine best fit.

Weighted overlay was created using weights derived from the strength of the correlation between the variables and health outcome:

- Distance to fire: 3%
- Daily average PM2.5: 18%
- Mean elevation: 23%
- Mean NDVI: 23%
- Mean temperature: 33%

Lastly, proximity analysis was used to identify areas further than 25 driving miles from a hospital and people in these high-risk areas:

- Populated areas
- Clusters of sensitive populations

Results

The significant environmental factors included: daily average PM2.5, distance to fire, mean elevation, mean temperature, and average NDVI.

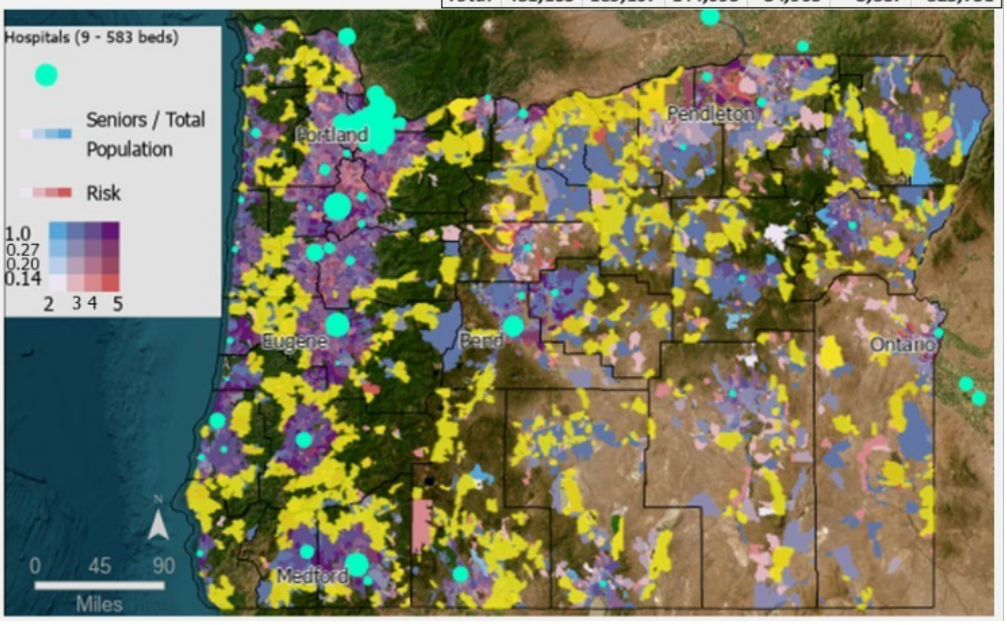
The following maps show the Census block level populations in areas at high risk from respiratory hospitalization from wildfires, shown as risk categories 4 and 5 in the maps, further than 25 miles, approximately 40km, from a hospital. The hospitals are symbolized based on bed capacity, so larger symbols indicate larger hospitals.

Bivariate analyses show areas with a high risk of respiratory hospitalizations and a high proportion of people in a smoke sensitive group. The high-risk areas that are highlighted yellow are over 25 miles from a hospital.

Results, Senior Population

Count of Seniors (65+)

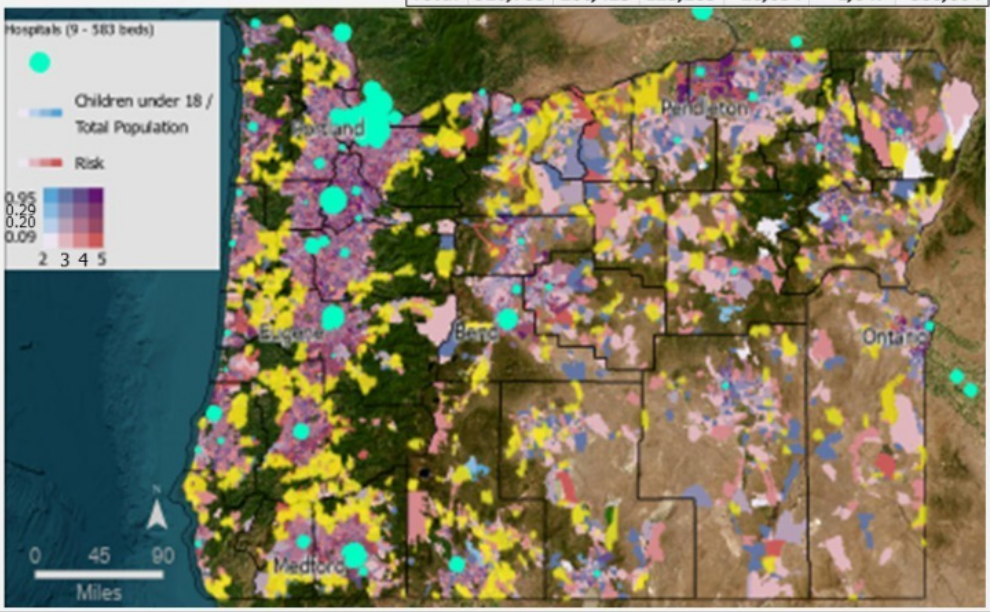
Risk Category	Drive Distance to Hospital: 5 mi	10 mi	25 mi	50 mi	250 mi	*Total*
2	0	0	56	61	31	***148***
3	10,220	14,384	20,382	8,189	1,798	***54,983***
4	381,857	155,302	105,955	22,600	1,770	***667,502***
5	59,078	19,421	18,302	4,058	238	***101,098***
Total	***451,155***	***189,107***	***144,695***	***34,908***	***3,837***	***823,731***



Results, Children

Count of Children (0 - 18 years)

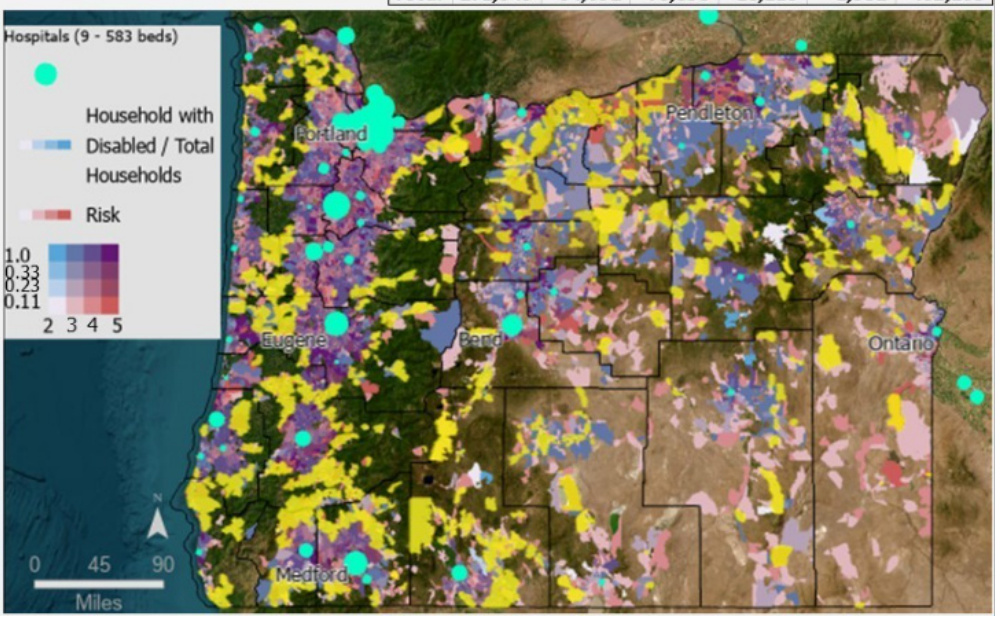
Risk Category	Drive Distance to Hospital: 5 mi	10 mi	25 mi	50 mi	250 mi	Total
2	0	0	33	57	13	***103***
3	7,844	11,158	13,673	4,672	1,009	***38,357***
4	449,409	168,605	94,425	13,000	893	***726,340***
5	63,530	20,660	15,157	2,325	132	***101,804***
Total	***520,783***	***200,423***	***123,288***	***20,054***	***2,047***	***866,604***



Results, Persons with Disability

Count of Households with 1+ Disabled Persons

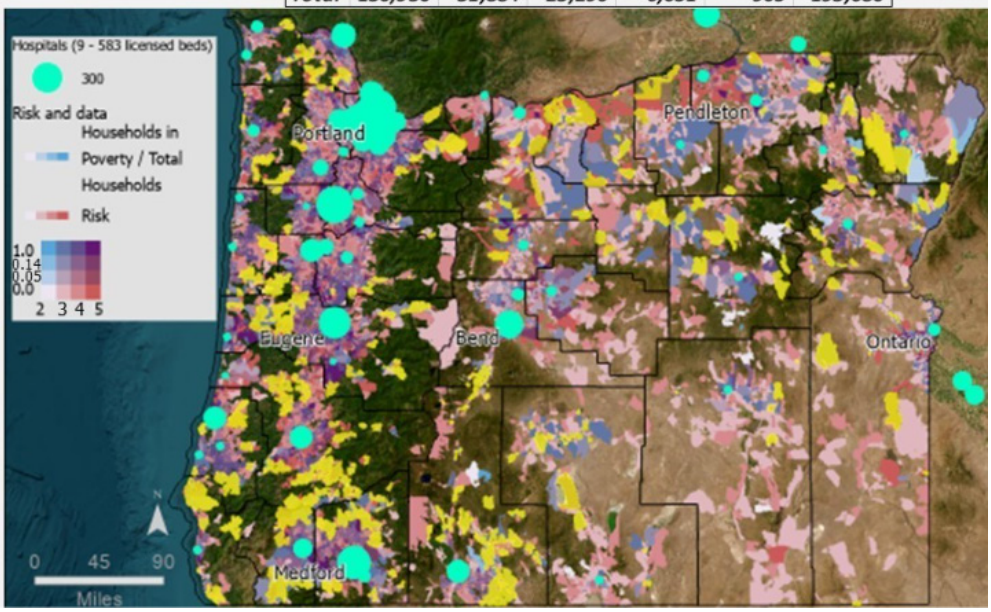
Risk Category	Drive Distance to Hospital: 5 mi	10 mi	25 mi	50 mi	250 mi	Total
2	0	0	11	33	11	***55***
3	5,576	6,865	9,747	4,155	943	***27,294***
4	223,462	78,282	56,685	11,773	925	***371,135***
5	42,511	9,544	9,452	2,158	103	***63,769***
Total	***271,549***	***94,691***	***75,895***	***18,119***	***1,982***	***462,253***



Results, Low Income

Count of Households under Poverty Level

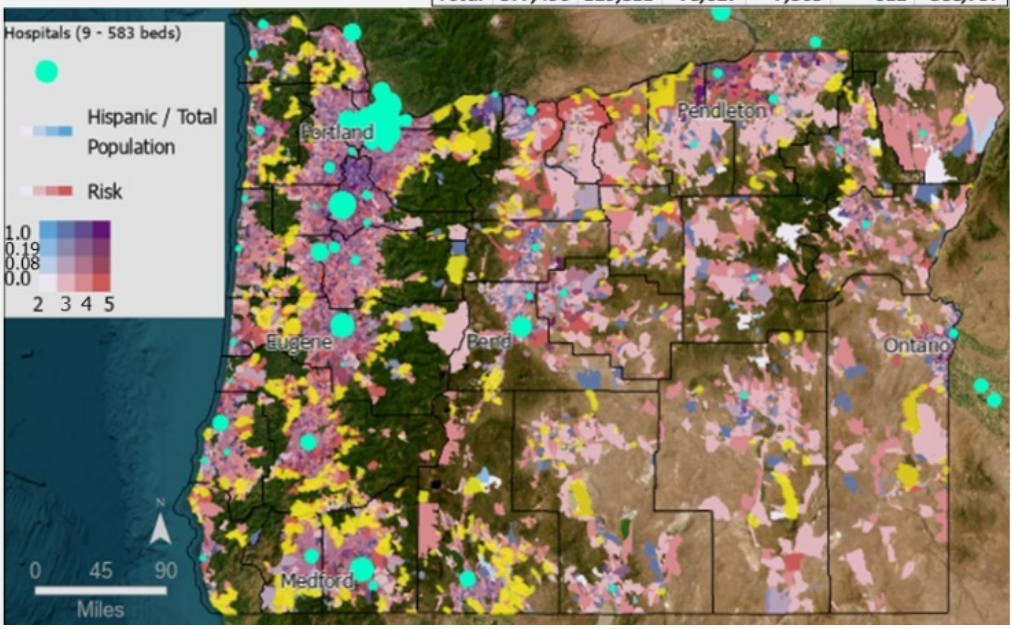
Risk Category	Drive Distance to Hospital: 5 mi	10 mi	25 mi	50 mi	250 mi	Total
2	0	0	13	7	6	***26***
3	2,385	2,367	2,697	1,453	438	***9,347***
4	104,485	26,555	17,690	4,457	424	***153,618***
5	24,060	2,962	2,896	734	37	***30,689***
Total	***130,930***	***31,884***	***23,296***	***6,651***	***905***	***193,680***



Results, Hispanic Persons

Count of Hispanic Persons

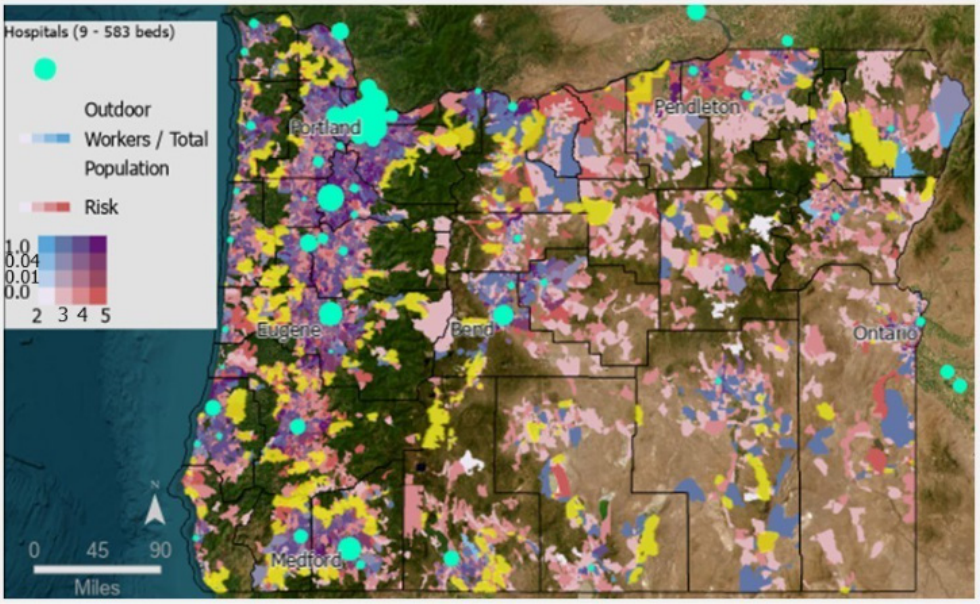
Risk Category	Drive Distance to Hospital: 5 mi	10 mi	25 mi	50 mi	250 mi	Total
2	0	0	4	16	2	***22***
3	3,800	5,170	4,512	1,463	259	***15,204***
4	309,309	109,248	59,421	5,071	283	***483,335***
5	64,387	15,093	9,690	958	68	***90,196***
Total	***377,496***	***129,511***	***73,627***	***7,508***	***612***	***588,757***



Results, Outdoor Workers

Count of Outdoor Workers

Risk Category	Drive Distance to Hospital: 5 mi	10 mi	25 mi	50 mi	250 mi	*Total*
2	0	0	8	3	4	***15***
3	1,244	1,842	3,209	1,076	171	***7,543***
4	56,115	20,575	17,758	2,443	155	***97,048***
5	10,284	3,699	3,428	517	28	***17,956***
Total	***67,643***	***26,116***	***24,403***	***4,039***	***358***	***122,562***



PM2.5 Pollution Trends in Klamath Falls, Oregon, from 1999 through 2023

Lee Mitchell, Ph.D.

PM2.5 Pollution in Klamath Falls

The Klamath Falls area has been designated nonattainment for PM2.5 pollution since the year 2009. This means the area does not meet the federal health-based Clean Air Act standard for fine particulate matter (PM2.5) air pollution.

Wood stove emissions contribute to poor air quality, particularly during the winter. In an effort to improve air quality, officials have implemented programs aimed at reducing emissions from wood stoves (US EPA, 2017).

However, wildfires and PM2.5 pollution from wildfire smoke have been a growing problem across the western US in recent decades (O'Dell et al., 2019). Prior to 2010, PM2.5 concentrations were on a downward trend, but the increase in wildfire emissions has reversed this trend in Western states. Despite large inter-annual variations, PM2.5 emissions and associated health risks have been on the rise (Wei et al., 2023).

This data brief explores PM2.5 pollution trends in Klamath Falls, Oregon, over the past 24 years.







PM2.5 Trends in Klamath Falls

We conducted an analysis of daily average PM2.5 concentrations spanning from 1999 to 2023, sourced from the air quality monitor stationed at the Peterson Elementary School in Klamath Falls. We downloaded the data through the Oregon Department of Environmental Quality (DEQ) Station Report tool at https://aqi.oregon.gov/, then generated weekly and yearly averages for insight into the area's air quality trends. Missing data were calculated as the average of the data from surrounding dates.

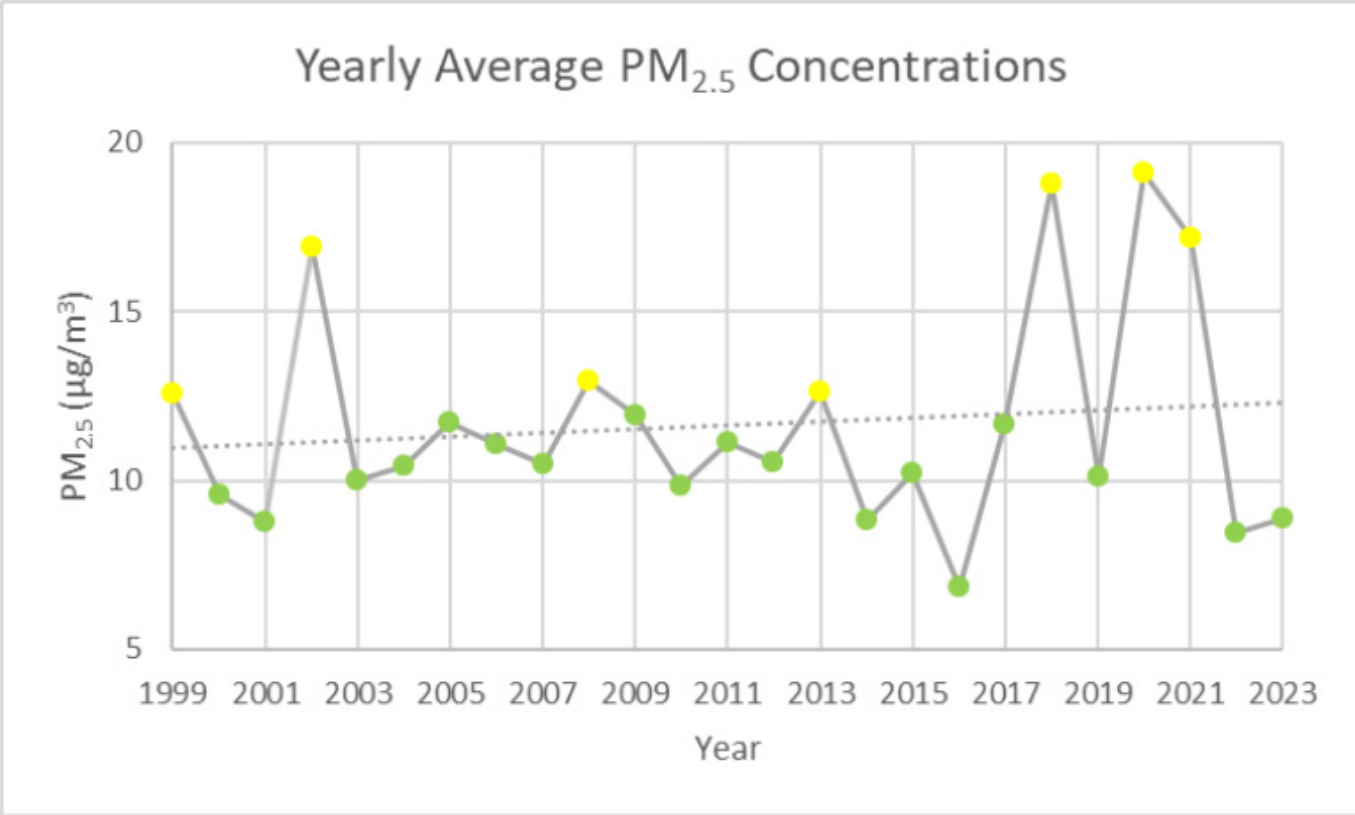


Figure 1: Yearly average PM-2.5 concentrations in Klamath Falls, Oregon.

Results

The findings, shown in Figure 1, illustrate the yearly average PM2.5 concentrations in Klamath Falls from 1999 to 2023. The green points represent years where the daily average fell within the PM2.5 AQI category labeled "good," denoting average levels 12.0 µg/m3 or lower. The yellow points represent years the daily average was in the PM2.5 AQI category "moderate," with average levels ranging from 12.1 to 35.4 µg/m3. The year 2016 had the lowest average concentration, while years 2017 and 2018 had the highest average concentrations.

Further analysis of the plotted data reveals a discernible trend characterized by an upward trajectory over the years, as indicated by the dotted line on Figure 1. This trend underscores the persistence of increasing PM2.5 concentrations in Klamath Falls over the timeframe, highlighting the importance of continued vigilance and the need for proactive measures to address air quality concerns and safeguard public health and environmental well-being in the region.

Air Quality over the Year and Years

Figure 2 explores the cumulative concentrations of PM2.5 from 1999 through 2022. The most recent data are shown in a lighter color. The cumulative values of these recent years tend to be lower than earlier years through June. An increase in impacts from summer fire seasons in more recent years are seen through the steep increases in those lighter colored lines during July through September.

Likewise, it appears that in more recent years, cumulative air quality is lower until a wildfire occurs. This means that Klamath Falls may be improving its winter time air pollution by reducing woodburning emissions, but experiencing overall worse air quality over the year.

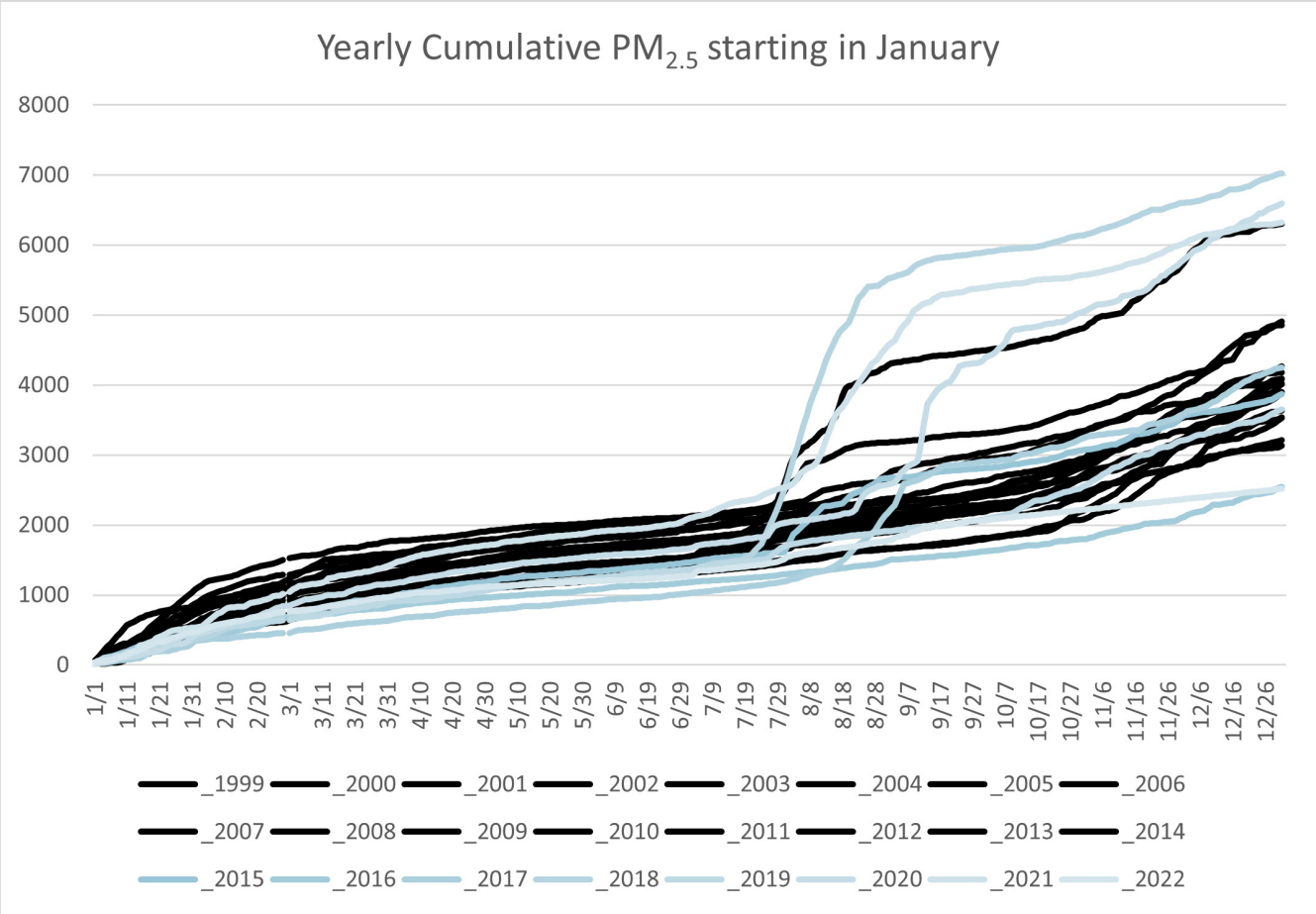


Figure 2. Yearly Cumulative PM2.5 starting in January, 1999-2022.

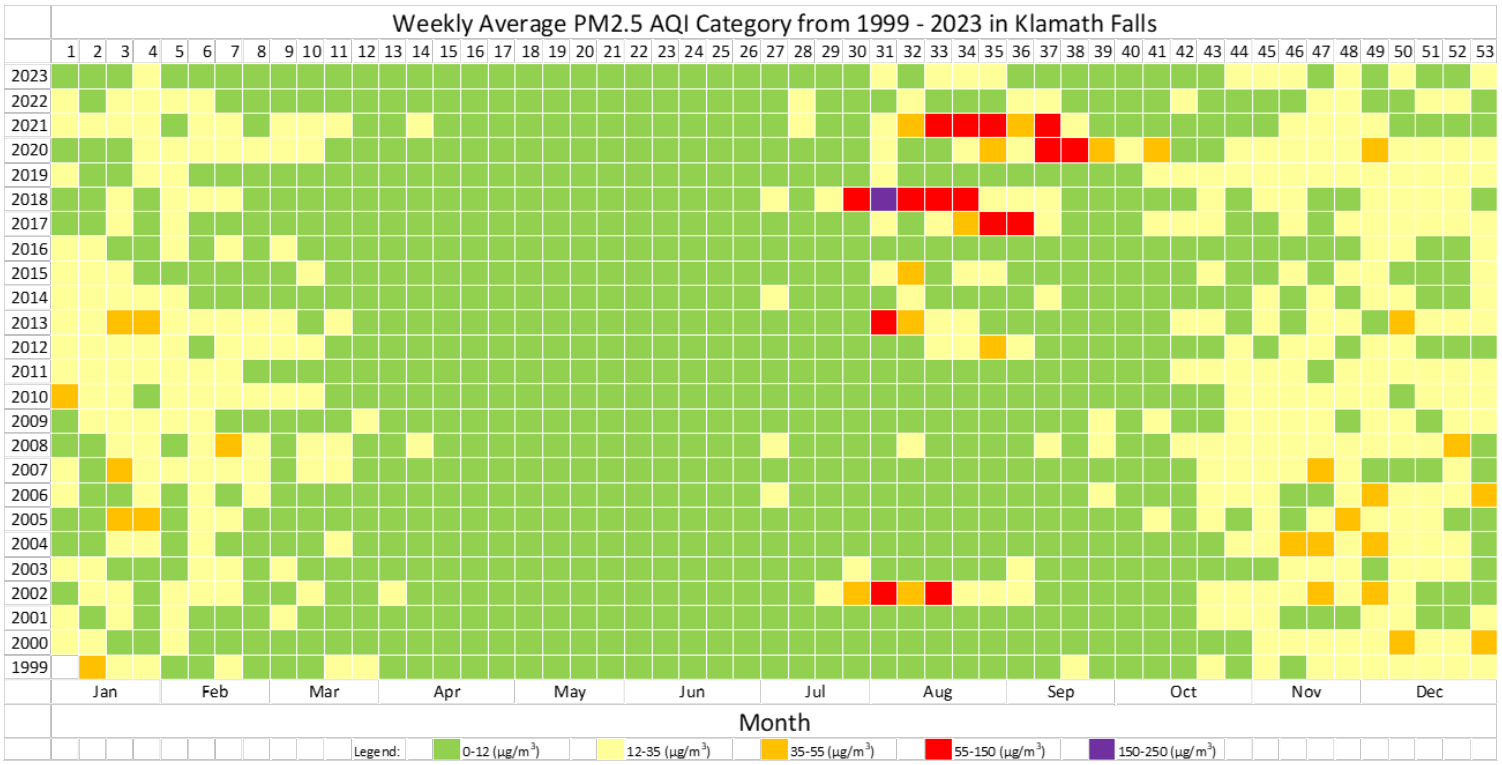


Figure 3. Weekly Average PM2.5 Presented in AQI colors: Klamath Falls, 1999-2023.

Figure 3 provides a detailed examination of weekly average PM2.5 concentrations, offering insights into seasonal variations and trends. The color-coded representation in the chart aligns with the EPA PM AQI categories, delineating levels of air quality including "good," "moderate," "unhealthy for sensitive groups," "unhealthy," and "very unhealthy."

Notable patterns emerge from this view of the data. Specifically, the chart reveals a discernible trend of fewer orange or "unhealthy for sensitive groups" weekly averages during the winter months over the past decade. Conversely, there has been a noticeable increase in red days, signifying "unhealthy" air quality, during the summer season over the past decade.

Significance

This observed shift in air quality patterns in Klamath Falls shows an improvement in wintertime pollution, likely attributable to efforts aimed at reducing emissions from wood stoves. However, despite these advancements, the overall progress in enhancing wintertime air quality appears to be overshadowed by the escalating impact of summer wildfire emissions.

Indeed, the data underscores the challenge posed by the increasing prevalence and severity of wildfires, which have become a significant contributor to PM2.5 pollution during the summer season. While strides have been made in addressing localized sources of pollution, the burgeoning influence of wildfires necessitates a comprehensive and multifaceted approach to air quality management in Klamath Falls. Efforts to mitigate the impacts of wildfire emissions, alongside continued focus on reducing local sources of pollution, are imperative to ensuring sustained progress in safeguarding the health and well-being of the community.

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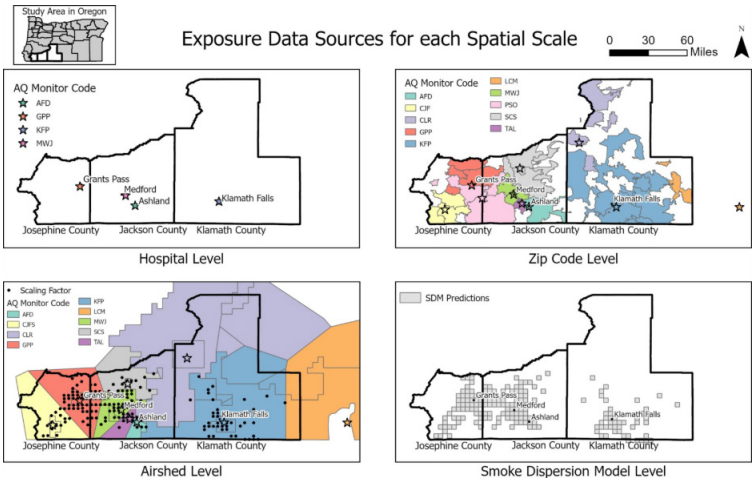
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Source: Unknown. Smoke in the Klamath Basin

Comparative Analysis of PM2.5 Data Choices for Studying Health Effects of Wildfire Smoke in Southwestern Oregon



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Summary

This analysis aims to uncover the most appropriate outdoor PM2.5 exposure data to use in southwestern Oregon to provide accurate estimates of health impacts. The study compares results from analyses using exposure data at different levels of detail: treatment hospitals, zip codes, airsheds, and smoke dispersion models. Statistical comparisons encompass descriptive statistics, mean differences, correlations, and regression parameters, to illuminate the impact of data choices on the health-smoke exposure relationship. The airshed level data outperforms the other datasets in almost all statistical tests.

Study area
Josephine, Jackson, and Klamath Counties

Study time
2018-2022 fire seasons (June-September) to target health impacts from wildfire smoke

Health data
Patient records were obtained from 4 of the 5 hospitals in the tri-county area. Patient home locations were rounded to the nearest 0.05 decimal degree coordinate for a spatial resolution of ~5km. Patient counts were summarized based on the spatial scale of each exposure level for analysis. The analysis included counts of patients per day with respiratory conditions, including ICD-10 codes J00-J99, R05, R06, R09, diagnosed in the ER or admitted to a hospital.

Exposure data
Daily mean PM2.5 concentrations were estimated at different spatial scales and for different pollution concentration estimation methods.

Hospital level
Monitors nearest each hospital were used to generate the exposure estimate for every patient in that hospital.

Zip code level
Monitors nearest each zip code were used to generate the exposure estimate for everyone within that zip code.

Airshed scaling factors from DEQ
Scaling factors were applied to measurements from the monitor associated with each airshed to generate exposure estimates across the study area.

Smoke dispersion models (SDM) from the USFS AirFire team
Daily BlueSky runs provided forecasted daily exposure values across the study area.

Results

Previous research indicates that wildfire smoke has a small but significant impact on respiratory health outcomes. We expect to identify this relationship through descriptive statistics applied to each level of exposure data.

Table 1 shows the range of spatial scales across the levels of exposure data under review, from approximately 55 km^2 when the exposure data is summarized at the level of the hospitals, to 4 km^2 when summarized for each airshed scaling factor and for the SDM gridded outputs. Summarizing the data at different spatial scales generates a different total number of records for the analysis. For example, counts of patients summarized at the four hospitals on each day of the study timeframe, 122 days each of the 5 years, generates a total N = (122 * 5 *4) = 2,440.

Table 1: Dataset size and spatial scale of each level of exposure data

	Hospital	Zip Code	Airshed	SDM
N	2,440	25,620	107,360	107,970
Scale	~ 55km	~ 19km	4km	4km

Table 2 shows differences in summary statistics from each of the data scale levels under review. Summarizing the patient counts at each exposure scale impacts basic summary statistics; for example, the average patient count ranges from 0.02 to 0.99. The airshed and SDM data have the lowest variance.

Table 2: Summary statistics for patient counts and PM2.5 concentrations at each data level.

		Hospital	Zip Code	Airshed	SDM
PM2.5 Concentration	min	0.2	0.2	0.0	0.0
	median	5.5	5.2	3.8	0.3
	mean	18.3	17.5	12.7	23.5
	max	457.6	457.6	498.3	54858.4
	variance	1358.4	1200.1	725.6	86090.6
Patient Count	min	0	0	0	0
	median	1	0	0	0
	mean	.99	.09	.02	.02
	max	7	5	4	4
	variance	1.30	.12	.03	.03

Figures 1 and 2 show the spatial distribution of exposure estimates and patient counts, respectively, across the data scale levels under review. Notably, the hospital level data shows lowest exposure concentrations in the west and increasing eastward, while the pattern for patient counts is the opposite, with lower patient concentrations on the eastern side than on the western side. Visual comparisons between exposure and patient concentrations for the other spatial scales show mixed results.

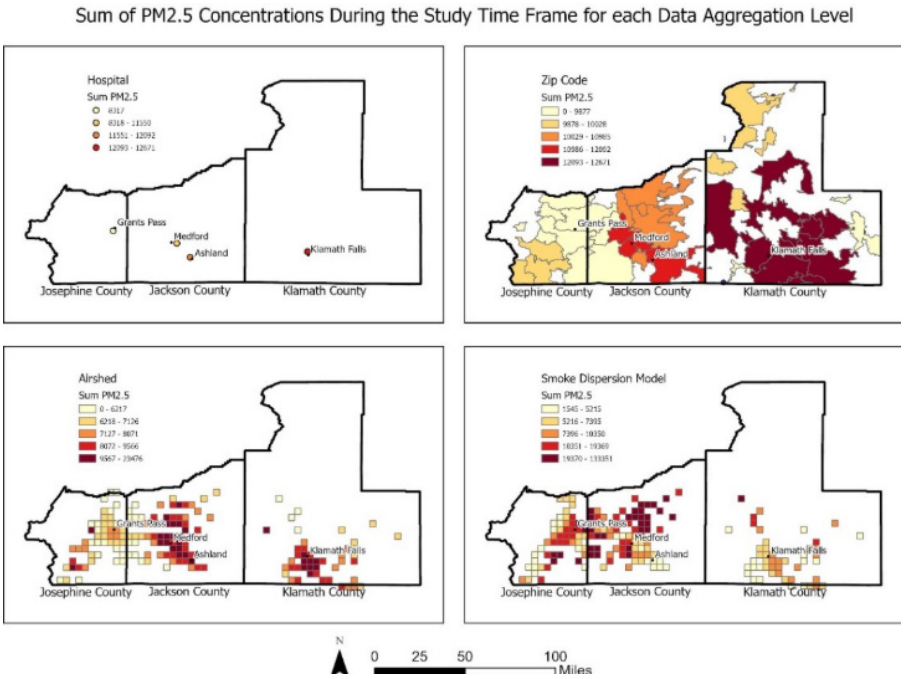


Figure 1: The total sum of PM2.5 concentrations during fire seasons from 2018 – 2022 for each of the four data aggregation levels, displayed by quantile.

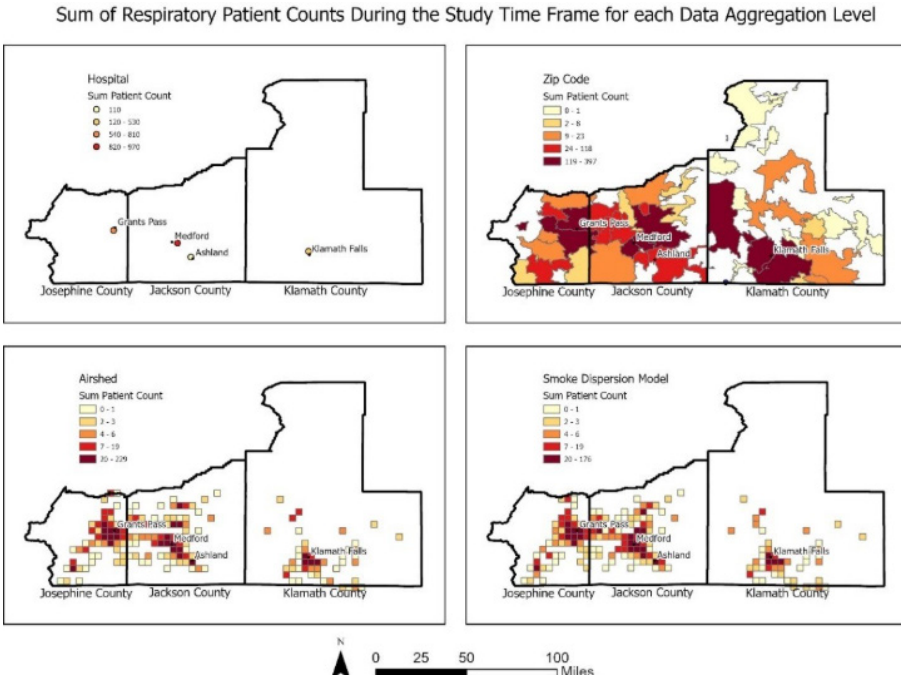


Figure 2: The sum of patient counts during fire seasons from 2018 – 2022 for each of the four data aggregation levels, displayed by quantile.

Comparison of means

Based on ANOVA, means for patient counts are significantly different between the spatial levels. Based on a Tukey's test, means for PM2.5 concentrations are significantly different between zip code, airshed, and dispersion model levels, but are not significantly different between the hospital level and the other levels. This difference in means between aggregation levels is a common characteristic of the Modifiable Areal Unit Problem (MAUP) which influences the outcome of statistical tests and so impacts results. This highlights the need to use caution when choosing between datasets representing exposure estimates

Correlation

The correlation between patient counts and PM2.5 exposure was calculated for each exposure data level. The confidence interval for the correlation coefficient, shown in Figure 3, encompasses 0 for most data levels so there is not a significant correlation. The exception is the airshed data level which has a small but significant positive correlation between these variables. This is the expected relationship between smoke exposure and respiratory hospitalizations.

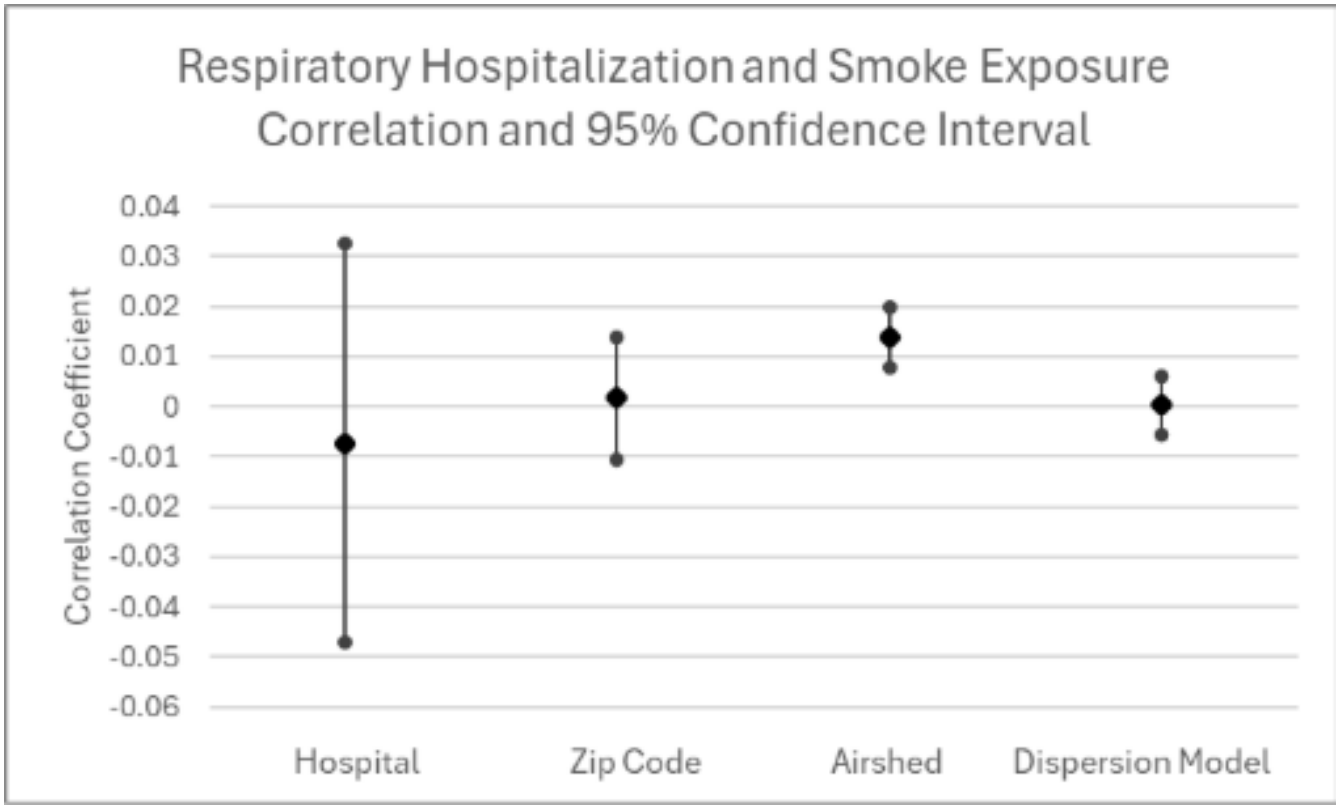


Figure 3: Correlation and 95% confidence intervals between respiratory hospitalizations and smoke exposure for each of the four different exposure spatial scales under review.

Spatial Autocorrelation

Global Moran's I was calculated for patient counts and PM2.5 exposure for each of the data levels under review. All results indicated a less than 1% likelihood that the clustered pattern was a result of random chance, so all the data levels are spatially autocorrelated. This can violate assumptions of independence of residuals and impact results from statistical tests.

Regressions

A linear regression of PM2.5 exposure on patient counts was conducted for each spatial level. PM2.5 was insignificant in explaining variations in patient counts for all levels except the airsheds. For the airshed linear regression, the overall regression was statistically significant ($R2 = 0.0002$, $p<0.0001$); PM2.5 significantly predicted patient counts ($\beta=0.0001$, $p<0.0001$).

A Poisson regression was conducted for each spatial level to accommodate the nature of count data. A chi-square goodness-of-fit test shows the Poisson distribution does not fit the hospital data ($p<0.05$), but does fit the zip code, airshed, and SDM data levels ($p=1.0$). As with the linear regression, the PM2.5 variable was significant only for the airshed data level ($\beta=0.0029$, $p<0.0001$).

The ArcGIS Exploratory Regression tool was used to explore the relationship between patient counts and level of PM2.5 exposure data. PM2.5 was a significant predictor only for the airshed level data ($p<0.01$).

ArcGIS Bivariate Relationship tool was run to explore the relationship between patient counts and level of PM2.5 exposure data. None of the four data levels generated any significant results.

The ArcGIS Forest-based Classification and Regression tool was used to explore the relationship between patient counts and level of PM2.5 exposure data. This tool provides the opportunity to consider counts as categorical variables rather than numeric and to compensate for sparse categories. The airshed level data had the highest overall accuracy, 25.7%, based on a confusion matrix of the classification performance. Overall accuracy for the SDM level data was 11.8%, for the zip code level data was 10.6%, and for the hospital level data was 8.9%.

Time and technical skills

Each PM2.5 exposure data level requires different preprocessing steps and software to generate the final analysis files. The hospital level data is the fastest to process and has the most general software requirements. The data can be downloaded and processed into the final form within a few days using spreadsheet software. The zip code level data requires spreadsheet or database software as well as spatial analysis software to identify the air quality monitor closest to each zip code; the data can be downloaded and processed into the final form within one week. The airshed level data requires spreadsheet or database software as well as spatial analysis software to identify the scaling factor closest to the patient's home location; the data can be in final form for analysis within a week. The smoke dispersion model level data requires spreadsheet or database software as well as spatial analysis and modeling software; the data requires a few weeks to be processed into the final analysis format.

Results summary

Table 3 summarizes the results. Green shading indicates particularly favorable outcomes while red indicates unfavorable outcomes. The airshed data had the most favorable descriptive results.

Table 3: Summary of results with green indicating Notably favorable results and red indicating notably unfavorable results.

Test	Hospital	Zip Code	Airshed	SDM
Map patterns	Backward	Not similar	Similar	Most Similar
Correlation	-0.0073	0.0017	0.0139	0.0002
Linear regression	R^2=5.3e-05; model p=0.7198	R^2=2.9e-06; Model p=0.7849	R^2=0.0002; Model p=5.3-e06	R^2=5.3e-08; Model p=0.9397
Poisson regression	Coefficient p=0.680	Coefficient p=0.755	Coefficient p=0.1.3e-06	Coefficient p=0.936
Negative bi-nomial regression	Coefficient p=0.724	Coefficient p=0.791	Coefficient p=7.2e-06	Coefficient p=0.937
Zero-inflation regression	Logit and count coefficient p>0.1	Logit and count coefficient p>0.1	P=0,0833; count coefficient p>0.1	count coefficient p<0.0001
ArcGIS Exploratory Regression	coefficient p>0.05	coefficient p>0.05	coefficient p<0.05	coefficient p>0.05
ArcGIS Forest-based classification	8.90%	10.60%	25.70%	11.80%
Processing Time	Few days	A week	A week	Few weeks
Software requirements	Spreadsheet	Spreadsheet/database, geospatial analysis	Spreadsheet/database, geospatial analysis	Spreadsheet/database, geospatial analysis, modeling

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Work featured in this issue was funded, in part, by the following organizations:

- Health Resources and Services Administration
- Environmental Protection Agency
- Oregon Department of Environmental Quality
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