Wildland Fire Smoke Impact Respiratory Illnesses in West Valley City, UT

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1. Introduction

Air pollution is a pervasive and escalating global challenge that significantly impacts human health, ecosystems, and economies. The World Health Organization (WHO) estimates that air pollution contributes to over 6.7 million premature deaths annually, with respiratory diseases being one of the primary health outcomes (2024). Despite substantial research linking air quality to adverse health effects, identifying and quantifying the specific environmental factors contributing to various respiratory illnesses remain critical for targeted policymaking and intervention strategies.

West Valley City, Utah, exemplifies an urban area where environmental and public health concerns intersect. West Valley City's official government website reported that it is the second-largest city in the state, with a population exceeding 145,000. The city faces challenges typical of rapidly growing urban centers, including exposure to pollutants from industrial activity, vehicle emissions, and wildfire smoke. Its diverse population and history of progress make it an ideal setting for examining the health implications of air pollution, particularly as the city continues to prioritize economic development and community well-being.

This analysis explores the relationship between key air pollutants and respiratory health outcomes, focusing on four major conditions: lower respiratory infections, otitis media, respiratory infections tuberculosis, and upper respiratory infections. By identifying significant predictors of these illnesses, this study seeks to address unresolved questions about the magnitude and direction of these relationships and provide actionable insights for public health and environmental policy.

The findings hold particular relevance for communities like West Valley City, where data-driven policies can mitigate the health burden of pollution, inform healthcare resource allocation, and guide sustainable urban development. By integrating environmental and health data, this study aims to empower policymakers to improve the quality of life while fostering resilience against the challenges posed by environmental and climate changes.

2. Background

The ClimateCheck report has shown that West Valley City is expected to experience a significant increase in extreme heat days due to climate change. Around 1990, the city averaged 7 days per year with temperatures exceeding 96.9°F. By 2050, this number is projected to rise to an average of 41 days annually, contributing to the intensification of heat waves. This heat rise is closely linked to broader climate change trends. Additionally, the city faces a heightened fire risk, particularly on dangerous fire weather days, which is also projected to escalate through 2050. West Valley City has 97 census tracts, and over a quarter of the buildings in 56 of these tracts have significant fire risk. In 46 tracts, more than half the buildings are at significant fire risk. This increase in fire risk is primarily attributed to hotter and drier conditions resulting from climate change. ClimateCheck's fire risk ratings, based on weather projections and U.S. Forest Service fire behavior models, reflect this growing threat. While these risks are considerable, there are opportunities for mitigation through actions by individuals, communities, and government entities.

According to the Wildland Firefighter's Association (2023), wildfire smoke can travel vast distances, often carried by prevailing winds across hundreds or even thousands of miles. This can affect air quality in areas far from the fire's origin. Fine particulate matter in the smoke can remain in the atmosphere for days or even weeks, depending on weather conditions, wind patterns, and the intensity of the fire. In West Valley City, the impact of wildfire smoke can be substantial, even from fires located far outside the immediate vicinity. This presents a significant challenge for assessing air quality, as the smoke can persist long after the fires themselves have been extinguished, potentially exacerbating respiratory health issues for residents.

The increasing intensity of heatwaves and fire risk in West Valley City, coupled with the far-reaching and lingering impacts of wildfire smoke, highlights the importance of understanding how wildfires influence air quality over time. The challenges in predicting smoke concentrations due to the unpredictable nature of wildfires, combined with the need for continuous monitoring, underscores the complexity of accurately assessing air quality and its long-term health implications. In light of these factors, my research will address two primary questions:

1. How do wildland fires impact air pollution levels over time?
2. Which air pollutants consistently contribute to deaths caused by respiratory illnesses?

Predicting smoke concentrations during a wildfire is challenging due to the complex interplay of various factors, including wind, weather, terrain, and fire intensity. According to the U.S. Environmental Protection Agency (EPA), wildfires are inherently unpredictable, with wind having complex effects on smoke dispersal—sometimes clearing it, but other times intensifying the fire or pushing the smoke further. The intensity of the fire can propel smoke into the atmosphere, where it remains until it cools and spreads, and terrain features like mountains and valleys influence how smoke moves. Given the lack of direct access to detailed smoke concentration data, I will develop a formulation using the wildland fire dataset from the USGS to estimate smoke concentrations and their impact on West Valley City. This formulation will consider the areas burned and fire locations, and I will test the estimates by comparing them with Air Quality Index (AQI) data from the Air Quality System (AQS) API. By setting an appropriate threshold to filter out distant fires and accounting for the cumulative effects of smoke over time, I aim to improve the accuracy of smoke predictions for the region.

Given the far-reaching impact of wildfire smoke, for my analysis, I will establish an appropriate threshold to filter out fires that are too distant to significantly affect West Valley City's air quality. This threshold will allow the model to focus on fires within a relevant range, ensuring more accurate predictions of smoke exposure. Additionally, because smoke can accumulate over time, I will incorporate a formulation that accounts for the cumulative effect of smoke emissions from year to year. This approach will capture the lingering nature of smoke and help predict its long-term impact on air quality and public health, providing a more accurate and comprehensive analysis of wildfire smoke exposure in the region.

3. Methodology

3.1. Estimating Smoke Impact from Wildland Fires on Air Pollution

Based on findings from the literature that wildfire smoke can travel thousands of miles, I investigated the spatial distribution of wildfires around West Valley City over the past 60 years. I plotted the distances of wildfires from the city to identify a natural cutoff point where the density of fires sharply declined. This threshold was then used to define a maximum radius, within which only the fires were included in the smoke analysis. This approach allowed me to focus on the most impactful fires while ensuring the methodology was grounded in empirical observations and aligned with the geographic patterns of wildfire occurrence.

To estimate wildland fire smoke emissions, I calculated the smoke for each fire by dividing the burned acres by the distance to population centers, as proximity significantly influences smoke concentration levels. To account for annual variations, I computed cumulative smoke estimates by summing all smoke for each year and introducing a 20% carryover from the previous year. This carryover reflects my understanding that while most smoke dissipates over time, a portion lingers and continues to impact air quality. The 20% factor was chosen as a conservative estimate to model worst-case scenarios for lingering smoke.

$$\text{Smoke}_{\text{fire}} = \frac{\text{Burned Acres}}{\text{Distance}}$$

$$\text{Cumulative Smoke}_t = \sum_{i=1}^{N_t} \text{Smoke}_{\text{fire},i} + 0.2 \cdot \text{Cumulative Smoke}_{t-1}$$

Given that wildfire smoke tends to accumulate over time and affect air quality in subsequent years, I selected linear regression as the primary model to predict smoke emissions over multiple years. Linear regression is well-suited to modeling trends in time-series data where the relationship between variables can be approximated as linear. This model will help assess how smoke from wildfires accumulates annually, using previous years' data to forecast future levels of smoke emissions.

The effectiveness of the linear regression model will be assessed using the R^2 value, with a threshold of 0.5 indicating that the model adequately captures the relationship between wildfire activity and smoke emissions. If the R^2 exceeds 0.5, the model will be deemed sufficient. If the model does not meet this threshold, I will consider more complex models like Vector AutoRegression (VAR) or Long Short-Term Memory (LSTM) Networks. However, the goal is to use the simplest model that provides an adequate explanation of the data, so I will stop refining the model once an R^2 greater than 0.5 is achieved, or if linear regression fails to meet this benchmark, I will move to a more complex model and select the one with the highest accuracy.

Finally, I will use the chosen model to forecast smoke levels from 2025 to 2050. This forecast will help provide insight into the long-term impacts of wildfire smoke on air quality, informing strategies for mitigation and public health management.

To validate the smoke estimates and examine the impact of wildland fires on air pollution, I compared the predicted smoke levels to historical Air Quality Index (AQI) data from the US EPA. This comparison was essential for understanding the relationship between wildland fire smoke and air quality. By grounding the analysis in observed AQI data, this methodology ensured the reliability of the estimates while providing critical insights into the extent and patterns of air pollution caused by wildland fires. This approach also emphasizes transparency and adaptability, enabling ongoing model refinement and further exploration of air quality dynamics.

3.2. Identifying Contributing Factors to Respiratory Illnesses

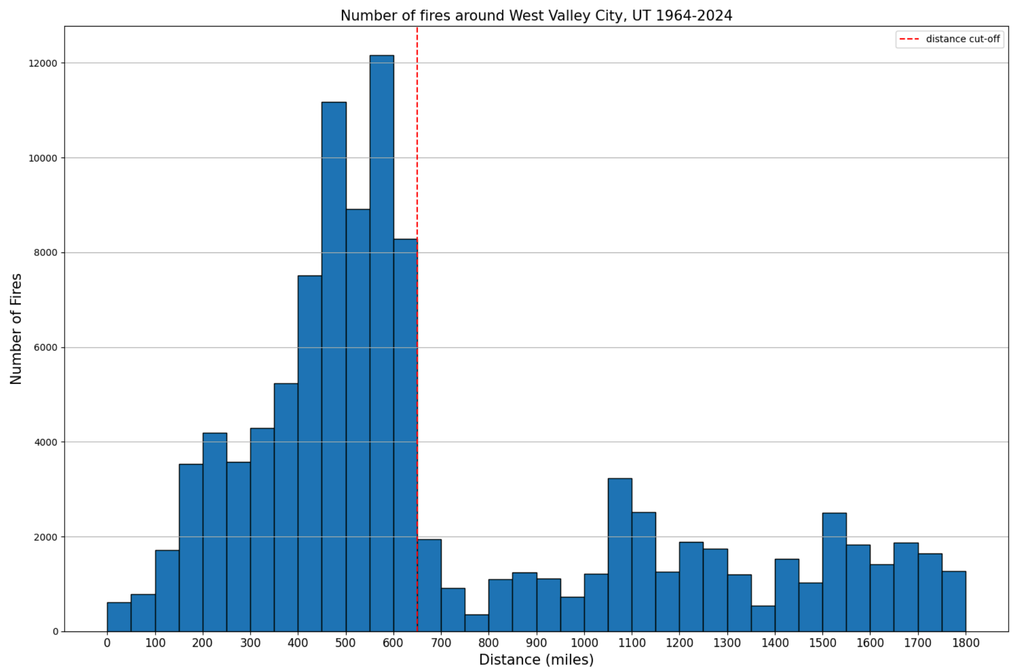
To understand how air pollution impacts respiratory health, I used multivariate Linear Regression to analyze the relationship between air pollutants and mortality rates for four respiratory conditions: lower respiratory infections, otitis media, respiratory infections and tuberculosis, and upper respiratory infections. The predictors used in the analysis include cumulative smoke, acres burnt, distance to pollution sources, ozone, air pollutants - carbon monoxide, nitrogen dioxide (NO_2), sulfur dioxide - and particulate predictors, including acceptable PM2.5 AQI & Speciation Mass, PM10 Total 0-10um STP, and PM2.5 - Local Conditions. This approach allowed me to identify the most significant contributors to each illness and quantify their effects. By including multiple predictors simultaneously, I minimized the risk of confounding variables influencing the results, ensuring a robust and comprehensive analysis.

3.3. Ethical and Human-Centered Considerations

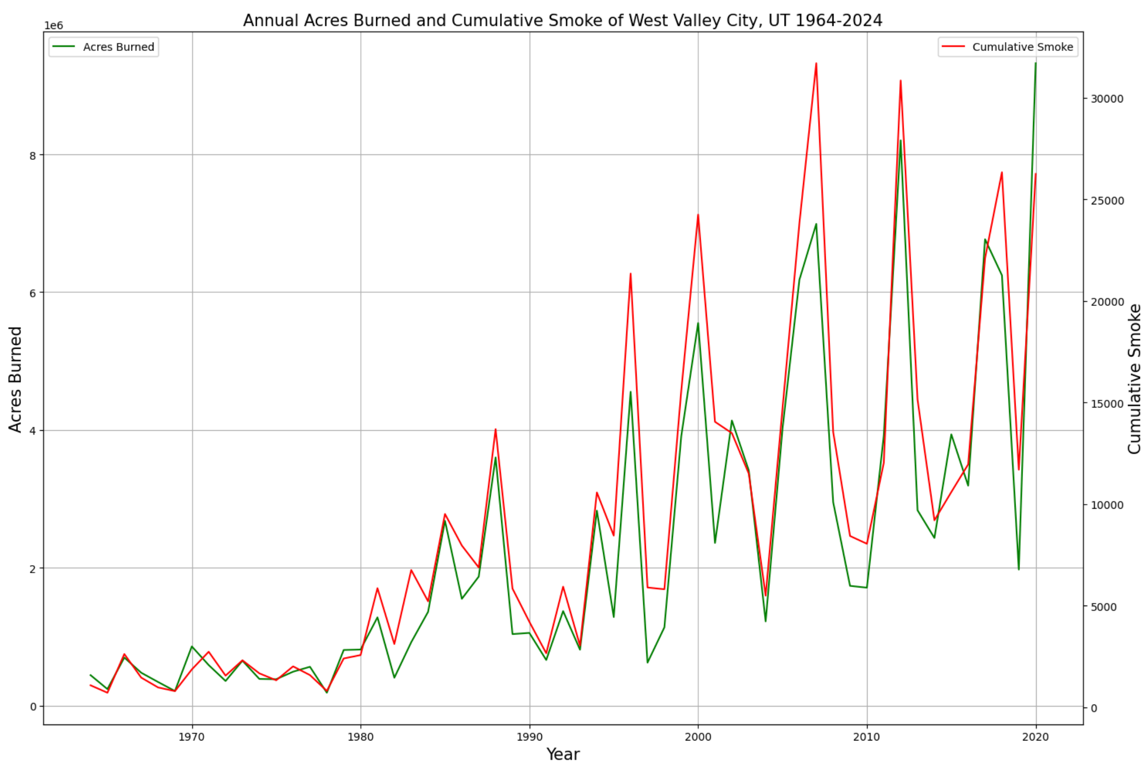
Ethical and human-centered considerations informed every step of my methodology. The 20% carryover factor in smoke estimates was a deliberate, conservative choice, prioritizing public health by accounting for lingering pollutants. Transparency was maintained by validating smoke estimates against AQI data, fostering trust in the results. In examining respiratory health, I ensured inclusivity by considering diverse pollutants and their compounded effects on vulnerable populations. My commitment to reducing health disparities and providing actionable insights guided every decision in this study, emphasizing beneficence, equity, and accountability.

Findings

The analysis revealed that wildfire smoke impacting West Valley City predominantly originated from fires within a radius of 650 miles. The spatial distribution plot demonstrated a steep decline in fire density beyond this distance, confirming the selected threshold as a logical boundary for the study. Within this radius, 71982 fires were recorded over the past 60 years, contributing significantly to the city's smoke exposure. This finding aligns with literature emphasizing the long-range transport of wildfire smoke but highlights that fires closer to population centers remain the most impactful on air quality and public health. By focusing on this defined area, the study ensured a targeted and data-driven approach to understanding the between wildfire events and air pollution in West Valley City.

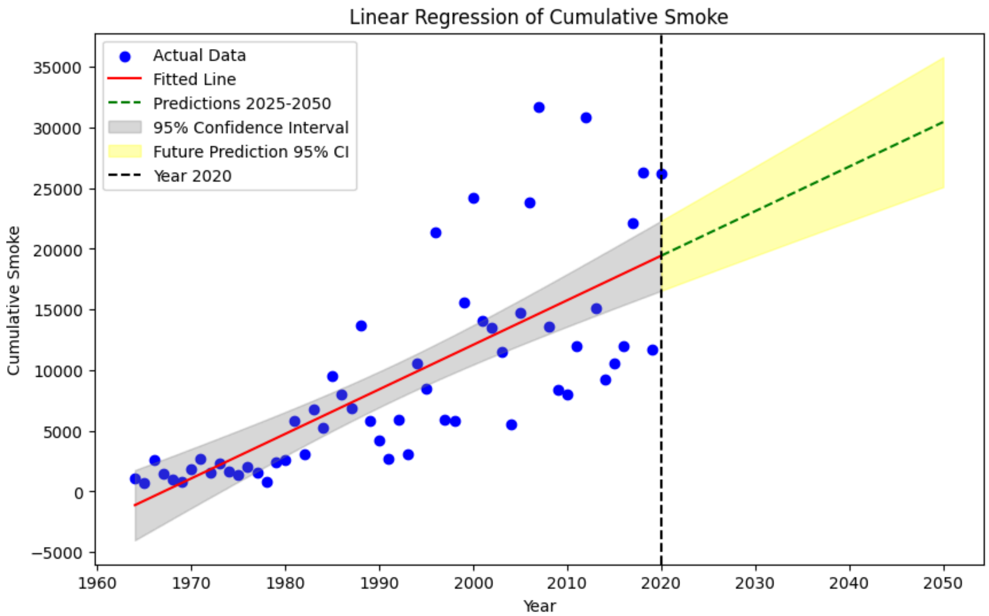


Using the formulation for smoke estimates based on distance, acres burned, and year, the graph below shows the annual cumulative smoke emissions and acres burned for the past 60 years. After each decade, there is a noticeable rapid increase in smoke emissions, similar to the corresponding rise in acres burned. This trend underscores the growing impact of wildfire activity on air quality over time.



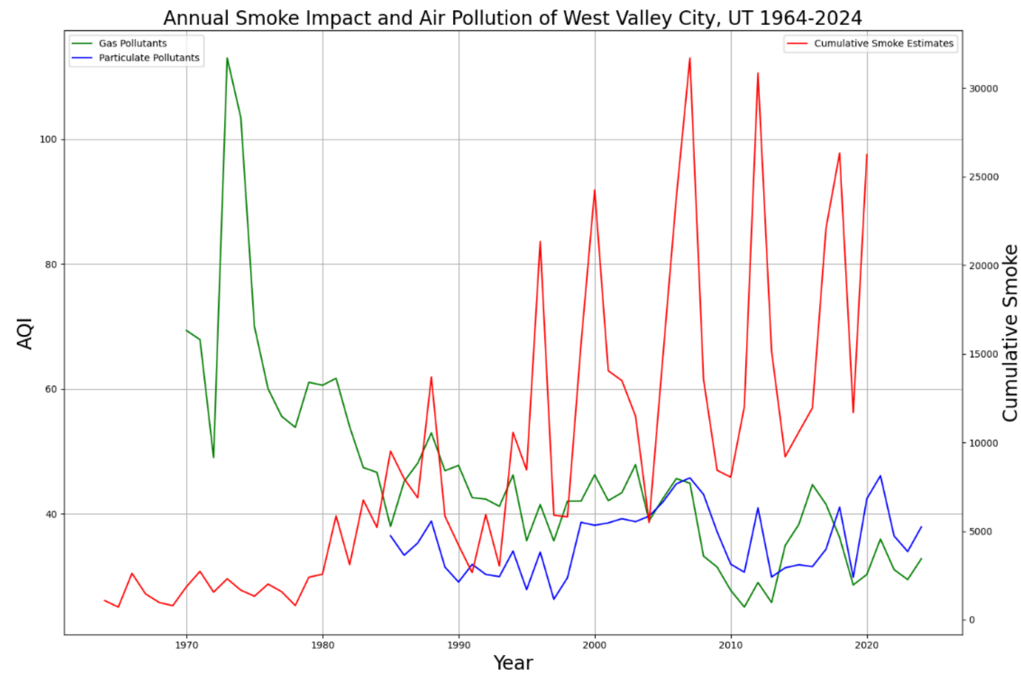
After applying the linear regression model to the annual smoke emission data, I obtained an R^2 value of 0.555, which exceeds the 0.5 threshold, indicating that the model adequately captures the relationship between wildfire activity and smoke emissions. Given this result, I chose to proceed with linear regression as the most suitable model for this analysis.

Additionally, I produced a forecast of smoke levels from 2025 to 2050 using this model. The forecast shows a clear projection of smoke levels, highlighting the anticipated long-term impact of wildfire emissions on air quality.



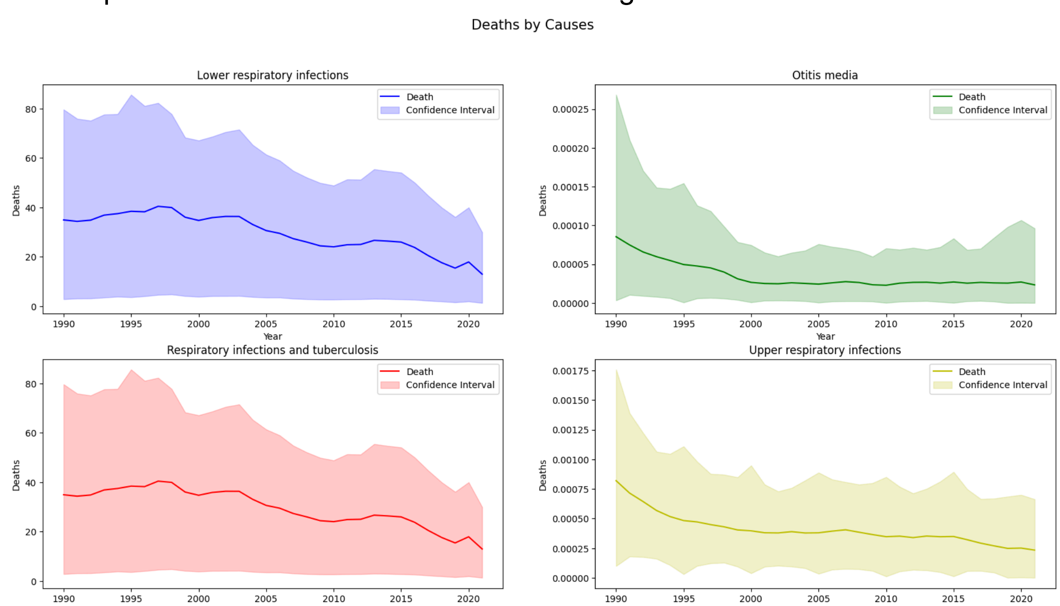
Considering that time alone can explain 55.5% of the variability in smoke emissions, future research could explore incorporating additional features, such as fire intensity, wind patterns, or geographical variations, to refine the model and improve the understanding of smoke dynamics. This would help increase the accuracy of predictions and provide a more comprehensive analysis of how wildfire activity influences air quality over time.

I then validate the smoke estimates and examine the impact of wildland fires on air pollution with a plot of the annual smoke impact alongside the averaged gas and particulate pollutant levels. The plot revealed an interesting trend: while smoke emissions have been increasing over time, gas and particulate pollutants have not followed the same pattern of consistent growth. One theory I have is that the natural surroundings of West Valley City, which are encircled by vast natural areas, may contribute to the mitigation of smoke in the air, potentially buffering the city from the full impact of wildfire smoke.



Still, I continue to investigate which specific indicators—among gas, particulate pollutants, and smoke levels—contribute most significantly to the number of deaths from respiratory illnesses in the area. To explore this, I will focus on identifying the pollutants that have the strongest correlation with mortality rates related to respiratory conditions.

First, examining the number of deaths from respiratory illnesses over the years reveals a clear declining trend. This reduction prompts an exploration of the predictors contributing to this positive development. Let's delve into the factors driving this trend.



I constructed models using multivariate linear regression to explore the relationship between air quality and environmental predictors and the prevalence of various respiratory illnesses. The predictors used in the analysis include cumulative smoke, acres burnt, distance to pollution sources, ozone, air pollutants - carbon monoxide, nitrogen dioxide (NO2), sulfur dioxide - and particulate predictors, including acceptable PM2.5 AQI & Speciation Mass, PM10 Total 0-10um STP, and PM2.5 - Local Conditions. The respiratory conditions examined are lower respiratory infections, otitis media, respiratory infections tuberculosis, and upper respiratory infections. The findings shed light on the contribution of these predictors to each condition, highlighting the complex dynamics of environmental factors and respiratory health. The table below presents the significant predictors and their coefficients for each respiratory condition model.

Predictor	Lower Respiratory Infections	Otitis Media	Respiratory Infections and Tuberculosis	Upper Respiratory Infections
Cumulative Smoke	-0.000261	3.52E-10	-0.000261	8.12E-10
Carbon Monoxide	1.712507	8.45E-07	1.712521	1.34E-05
Nitrogen Dioxide (NO2)	0.124396	-3.55E-07	0.124393	-2.45E-06
Sulfur Dioxide	-0.124819	4.62E-07	-0.124813	5.66E-06
PM10 Total 0-10um STP	-0.334183		-0.334187	-3.76E-06
Ozone		-2.28E-07		-1.17E-07
PM2.5 - Local Conditions		-4.00E-07		-6.32E-07

The findings reveal that Carbon Monoxide is a consistent positive predictor across models for four respiratory illnesses, indicating its strong association with increased risk across conditions. Interestingly, PM10, PM2.5, and Ozone consistently exhibit negative relationships with respiratory illnesses where they are significant, suggesting potential protective effects or correlations with factors mitigating illness risk. In contrast, Sulfur Dioxide, Nitrogen Dioxide, and Cumulative Smoke display mixed effects pointing to the possibility of complex interactions between these predictors. All models demonstrate predictive power R^2 larger than 0.9, indicating strong explanatory performance across diseases. This highlights the need for further research into how varying smoke concentrations and environmental interactions contribute to respiratory health outcomes and a deeper exploration of the mechanisms behind these mixed effects.

Discussion

Our findings have important implications for public health, urban planning, and environmental policy in West Valley City. The observed decline in respiratory-related deaths is an encouraging trend that suggests improvements in air quality, healthcare access, or public awareness. However, it also raises critical questions about how these gains can be sustained or enhanced in the face of increasing wildfire activity and smoke emissions. While the reduction in respiratory illnesses is promising, it is essential to understand the underlying factors driving this positive trend and ensure that conditions are maintained to preserve public health.

The study provides valuable insights into the local and regional factors that influence wildfire smoke and its complex relationship with air pollutants and respiratory health. The steep decline in fire density beyond a 650-mile radius highlights a clear geographic boundary that can help target wildfire management efforts more effectively. Furthermore, the relationship between pollutants and health outcomes is complex, underscoring the need for tailored interventions that address specific environmental and health dynamics. This is especially important as projections show increasing smoke emissions in the future, which could potentially reverse the positive trends without timely action.

For the city council and policymakers, it is crucial to prioritize strategies aimed at preventing wildfires within the 650-mile radius, as these fires significantly contribute to the city's smoke exposure. Additionally, investing in more advanced air quality monitoring systems will help track pollutants more accurately and allow for a better understanding of their health impacts. Community health programs should also focus on vulnerable populations, particularly in mitigating exposure to Carbon Monoxide, which consistently correlates with increased respiratory illness. Fire monitoring efforts should be intensified, especially during high heat and drought months, to better estimate and respond to smoke impacts.

For residents of West Valley City, it is important to stay informed about air quality conditions and participate in local wildfire prevention efforts, such as fire-safe landscaping and vegetation management. During times of poor air quality, residents should consider using air purifiers and limiting outdoor activities to reduce exposure to harmful pollutants.

To refine smoke impact estimations, closer monitoring of wildfire events is needed, particularly during periods of high heat and drought. More granular, monthly data will provide a better understanding of the dynamics of smoke emissions and their effects on air quality. By incorporating these data into existing models, the city can enhance its ability to forecast smoke impacts and implement more effective interventions to protect public health.

Limitations

This study faced several limitations that may have influenced the results of the findings. Firstly, the absence of monthly data on wildfire occurrences is a significant limitation. Wildfires can vary in intensity and duration, and their impact on air quality can fluctuate on a monthly basis, especially during fire seasons. The lack of this granular data makes it challenging to track the precise timing and intensity of air pollution following fire events, which could affect the accuracy of smoke emission forecasts and the understanding of their health impacts. Additionally, there is a lack of detailed data about the fires themselves, such as their duration, the specific weather conditions, and fire intensity. These factors can significantly influence the amount of smoke produced and its dispersal into the atmosphere, which were not accounted for in this study.

Another limitation pertains to the health data used in the analysis. The health data was sourced at the state level, not specific to West Valley City or the county, which means the health estimates may not accurately reflect the situation within the city itself. Respiratory health outcomes in the city could differ from state-level averages, and the absence of localized health data introduces uncertainty in the analysis of the relationship between air pollution and respiratory illnesses.

Lastly, while the linear regression model used in this study provides useful insights, it relies on certain assumptions, such as linear relationships between variables and normally distributed errors. If these assumptions do not hold for the data, the results could be biased or less reliable. Future studies could benefit from exploring more complex modeling techniques that account for potential non-linear relationships and other underlying factors.

Despite these limitations, the study provides a solid foundation for understanding the relationship between wildfires, air pollution, and respiratory health in West Valley City. Addressing these limitations in future research would help to refine the model and improve the accuracy of smoke impact estimations.

Conclusion

The primary research question of this study was to understand the impact of wildfire smoke on air quality and respiratory health in West Valley City, specifically how the number of wildfires, acres burned, and smoke emissions relate to air pollution levels and respiratory illness rates. The hypothesis was that an increase in wildfire activity and smoke emissions would correlate with worsening air quality and higher rates of respiratory illnesses.

The findings of this study indicate that wildfire smoke in West Valley City is predominantly driven by fires within a 650-mile radius, with a significant increase in both the number of fires and acres burned over the past 60 years. This trend is mirrored by rising smoke emissions, suggesting a close link between wildfire intensity and air pollution. The linear regression model, while revealing a moderate relationship between wildfire activity and smoke emissions, highlights the need for further refinement of the model by incorporating more detailed data on fire intensity, weather conditions, and monthly variations in fire occurrences. Additionally, the study explored the declining trend in respiratory illness deaths, suggesting that certain environmental factors may be contributing to this positive development, though more research is needed to identify the specific causes.

This study demonstrates the relevance of human-centered data science in addressing public health issues. By focusing on the intersection of environmental data (wildfires and air pollution) with health outcomes, the study underscores the importance of understanding the human implications of environmental phenomena. Through data-driven approaches, we can identify patterns, make informed decisions, and guide future research that takes into account the lived experiences of people impacted by these environmental hazards. Ultimately, the findings of this study provide valuable insights for city managers, policymakers, and residents, informing decisions that can mitigate the negative effects of wildfire smoke on both air quality and public health.

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Data Sources

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2. IHME Data Sources
3. USGS Dataset