Introduction

This analysis seeks to inform the citizens and council of Charleston about the significant impact of forest fires on the city, specifically examining the relationship between smoke from nearby fires and the Air Quality Index (AQI). The motivation behind this study stems from the urgency of addressing a tangible yet often underestimated problem. Forest fires, whether directly or indirectly, pose severe risks to public health and environmental stability. By understanding these repercussions, particularly the strain on healthcare systems and the well-being of Charleston's residents, this analysis contributes to addressing an unresolved research question in environmental health. It is crucial because the harmful effects of poor air quality, exacerbated by forest fires, demand informed policy-making and community preparedness.

Background/Related Work

Research in this area highlights that Charleston has historically experienced significant impacts from forest fires, underscoring its vulnerability to future events. Previous studies have examined both the frequency of forest fires and their devastating effects on South Carolina, where Charleston is located [1][2]. These findings emphasize the critical importance of analyzing the city's susceptibility to forest fire-related consequences.

The primary wildfire data used in this study was sourced from the US Geological Survey's Combined Wildland Fire Polygons Dataset (1800s-Present), available in both ArcGIS and GeoJSON formats. This dataset provides fire polygons, years, and acreage, offering a comprehensive view of wildfire activity across time. However, it lacks specific start and end dates for fires, which could limit the precision of certain analyses. The Air Quality Index (AQI) data was obtained via the EPA Air Quality System (AQS) API. This dataset includes detailed air quality measurements for Charleston, with a specific focus on PM2.5, the primary pollutant associated with wildfire smoke. These datasets were crucial in quantifying the environmental and health impacts of forest fires on Charleston.

A historical review of devastating fires in South Carolina informs the urgency of this analysis. Additionally, an ARIMA model [3] previously used to predict forest fires was adapted for this study. However, due to time constraints, a simplified version of the model was implemented for the project.

In Part 2 of the course project, the focus shifted to healthcare metrics to evaluate the impact of forest fires. Life expectancy and mortality rates were selected as key indicators to demonstrate the healthcare-related repercussions of fire events. Data for this analysis was sourced from the Institute for Health Metrics and Evaluation (IHME), covering the period from 2000 to 2019.

These prior studies, datasets, and models provided a robust foundation for developing the hypotheses and framework for this analysis, reinforcing its relevance to Charleston's residents and policymakers.

Methodology

The analytical methods were carefully chosen to ensure accuracy, relevance, and a focus on human-centered outcomes. For wildfire data, the Reader library was utilized for efficient extraction, and shortest distance calculations were employed to assess proximity to the fire periphery. These methods provided a precise understanding of smoke impact, a crucial element for evaluating how wildfires affect Charleston. Ethical considerations played a key role in this choice, as ensuring data accuracy and transparency was critical to maintaining trust in the findings and avoiding biases that could lead to misinterpretations or misinformed public decisions.

PM2.5 data was selected for air quality analysis due to its well-documented health effects and its primary role in air quality degradation during wildfires. By focusing on this pollutant, the analysis directly addressed human health concerns. To maintain relevance, filters were applied to the dataset, such as limiting the study to wildfire season (May to October) and a 650-mile proximity from Charleston. These filters ensured the study captured data directly impacting the local population while avoiding unnecessary complexity. This approach was ethically grounded in providing actionable insights tailored to Charleston’s residents, without overgeneralizing findings to unrelated contexts or populations.

The smoke estimate calculation utilized a logarithmic scaling formula: fire size in acres / log(1 + fire distance). This method emphasized the significant impacts of nearby fires while appropriately reducing the influence of more distant events. By adopting a realistic scaling approach, the analysis avoided overstating risks and focused on accurately representing threats to air quality, ensuring that the results remained both practical and credible.

The ARIMA model was selected for its robustness in time-series forecasting and its adaptability to datasets with trends and seasonality. ARIMA's ability to handle non-stationary data through differencing made it an ideal choice for predicting the smoke impact over time, particularly for extending the dataset's insights into future years (2025–2050). While a simplified version of the ARIMA model was used due to project constraints, it provided reliable predictions that could guide policy and preparedness efforts. The decision to use ARIMA was also informed by its widespread application in similar studies, ensuring the method was credible and its results comparable to related research. Furthermore, ARIMA's transparency and interpretability allowed findings to be communicated effectively to policymakers and the public, aligning with ethical principles of clarity and accessibility in research.

Finally, healthcare metrics such as life expectancy and mortality rates were analyzed to provide a tangible understanding of the long-term consequences of wildfires on human lives. These metrics were chosen because they are universally recognized indicators of public health and directly reflect quality of life and the effectiveness of healthcare systems. By analyzing trends in life expectancy and mortality, the study uncovered the potential effects of wildfire-induced air quality degradation on overall health, with a particular focus on vulnerable populations, such as children, the elderly, and individuals with preexisting conditions. This human-centered approach ensured that the analysis had real-world relevance, emphasizing its importance for policymakers and the residents of Charleston. The findings aimed to encourage proactive community preparedness, equitable healthcare planning, and interventions designed to mitigate the long-term risks associated with wildfires and air quality degradation.

Findings

Geographical Impact of Forest Fires:

Analysis reveals that a significant number of forest fires have occurred within a 200–300-mile radius of Charleston, as shown in **Figure 1**. This spatial concentration of fires highlights the city's vulnerability to wildfire smoke, reinforcing the importance of addressing its long-term impact on air quality and public health.

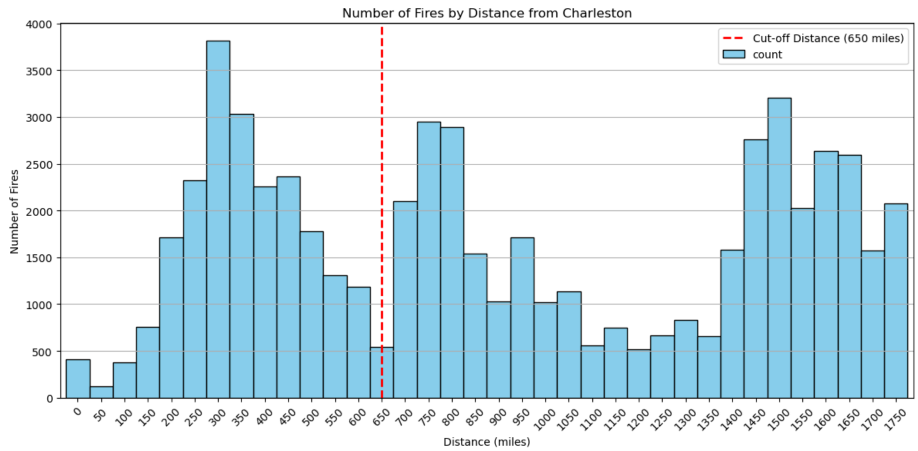

Figure 1

Air Quality and Smoke Estimate Correlation:

A positive correlation (correlation coefficient = 0.35) was observed between the Air Quality Index (AQI) and smoke estimates derived from wildfire data (refer to **Figure 2**). While the correlation is moderate, it indicates that smoke from nearby forest fires has contributed to the deterioration of Charleston's air quality, underscoring the environmental risks posed by such events.

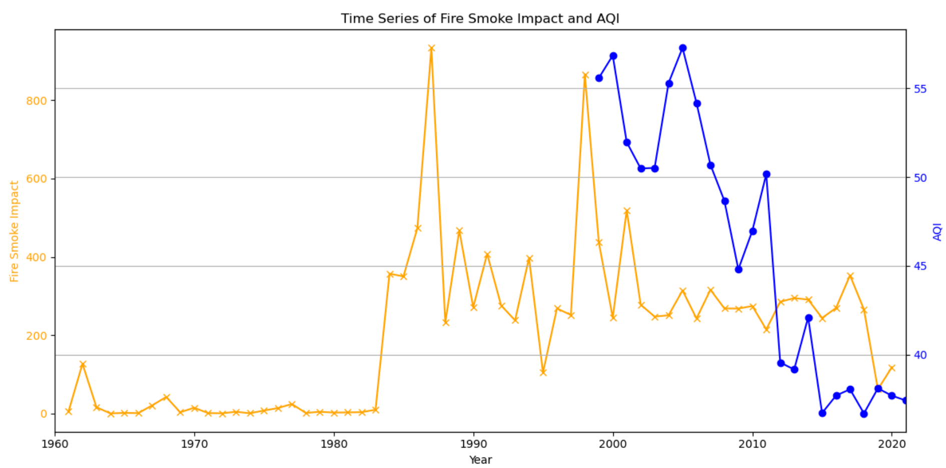

Figure 2

Smoke Estimate Predictions:

Forecasts generated by the ARIMA model project an upward trend in smoke estimates for the next two decades (**Figure 3**). This suggests that Charleston may face an increase in the adverse effects of wildfires, warranting proactive measures to mitigate the potential risks. These findings serve as a warning for citizens and policymakers to prepare for worsening air quality in the coming years.

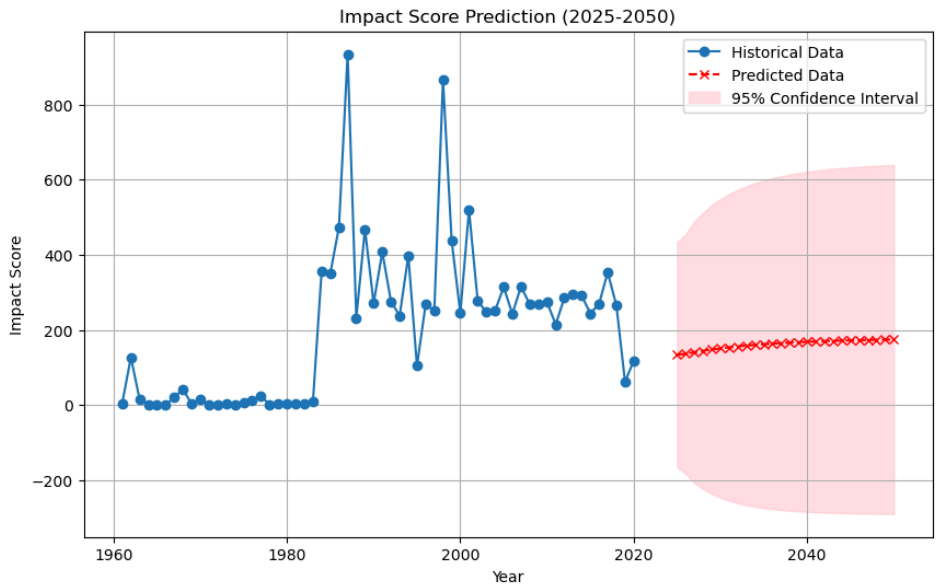

Figure 3

Healthcare Impact:

The analysis of normalized smoke estimates against healthcare metrics revealed significant correlations:

- **Negative correlation with life expectancy**: As smoke estimates increased, life expectancy showed a decline, indicating the detrimental health effects of prolonged exposure to wildfire smoke.
- **Positive correlation with mortality**: An increase in smoke estimates corresponded to a rise in mortality rates (**Figure 4**). This further demonstrates the critical health challenges posed by forest fires, particularly for vulnerable populations.

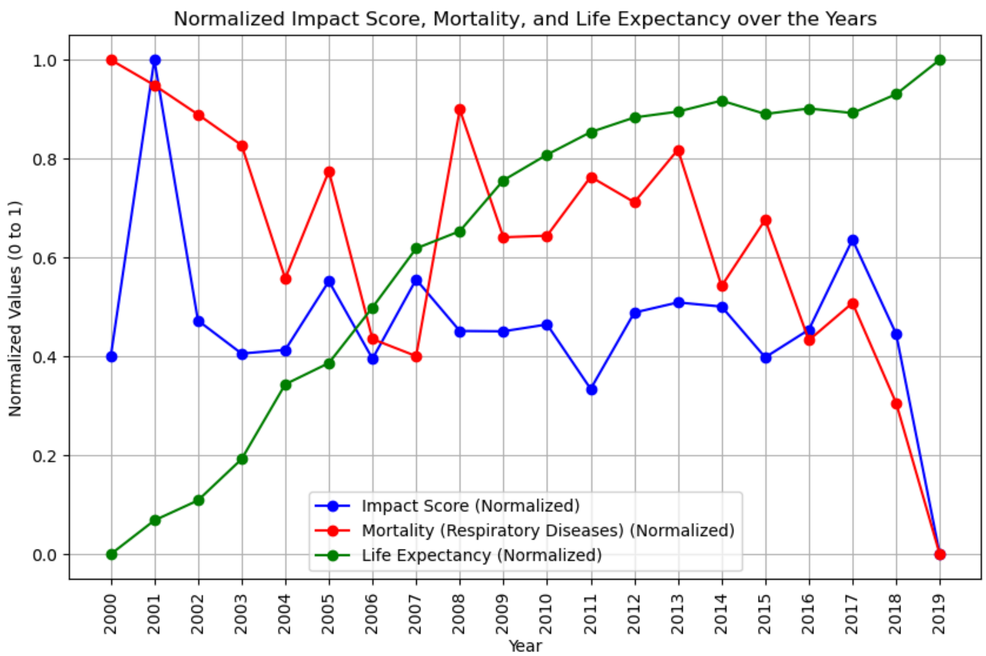

Figure 4

Mortality and Life Expectancy Predictions:

Using the ARIMA model, predictions for future mortality and life expectancy trends were attempted. However, these results were inconclusive due to the simplicity of the model and the presence of confounding factors, such as socioeconomic variables, healthcare access, and other environmental determinants (**Figure 5**). These findings highlight the need for more sophisticated modeling and additional data to fully understand the long-term impacts of forest fires on public health.

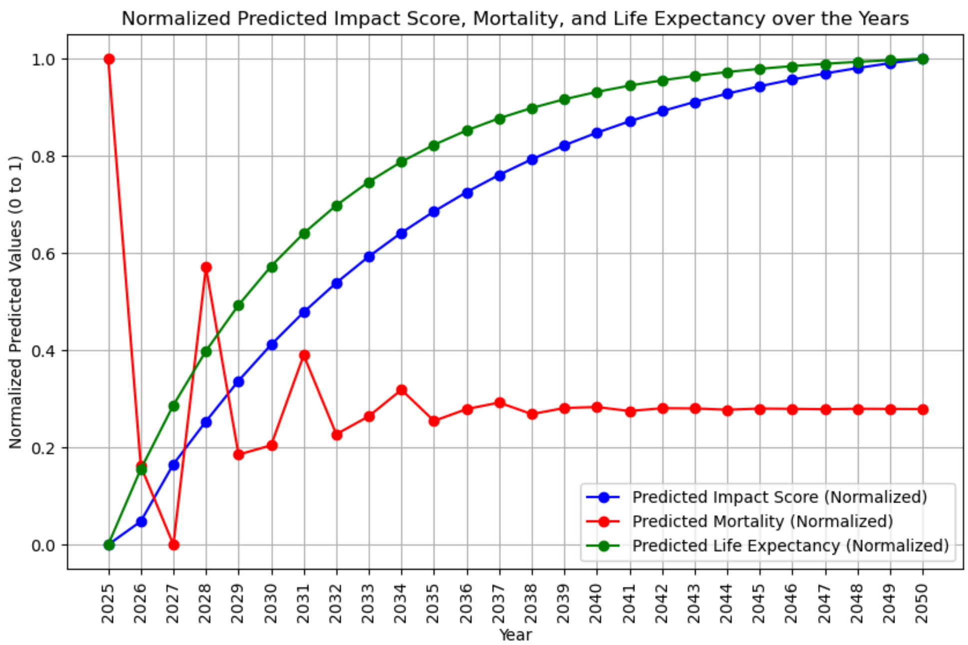

Figure 5

Discussion/Implications

The findings of this project are critical for understanding and addressing Charleston's vulnerability to forest fires and their long-term impacts on air quality and public health. With a clear correlation between wildfire smoke and declining life expectancy, as well as rising mortality rates, the analysis underscores the need for immediate action to protect residents. The forecasted increase in smoke estimates over the next two decades provides a stark warning: without intervention, the adverse effects on public health and quality of life will only worsen.

These findings were informed by human-centered data science principles, ensuring that the project was designed to prioritize the well-being of Charleston residents. Metrics such as life expectancy, mortality, and air quality were deliberately chosen for their direct relevance to human health and their ability to resonate with both policymakers and the public. The decision to focus on these indicators reflects a commitment to addressing tangible, everyday concerns faced by the community. Furthermore, the study employed transparent, ethical methodologies, using publicly available datasets to ensure accessibility and privacy, and communicating results in a way that stakeholders can readily understand and act upon.

To address these findings, the city council should implement stricter air quality monitoring and enforce wildfire-related emergency response protocols. Securing state and federal funding for public health campaigns and resilience initiatives is vital. Additionally, local policymakers must collaborate with experts to craft long-term strategies to mitigate the health and environmental impacts of forest fires.

The city manager and mayor must lead efforts to make Charleston more resilient by prioritizing investments in infrastructure, such as improved air filtration systems in schools, hospitals, and public buildings. Urban greening projects, which reduce urban heat islands and increase environmental resilience, should also be explored. Alongside these initiatives, public education campaigns can empower residents to adopt practices that minimize exposure to wildfire smoke and advocate for stronger local and regional protections.

Residents, meanwhile, can take personal measures to protect themselves and their families, including using air purifiers, staying indoors on high-smoke days, and wearing masks when necessary. Community engagement will also be critical, as widespread participation in preparedness programs can strengthen the city's overall response to wildfire risks.

The timeline for action is short—Charleston has an estimated 2–5 years to implement concrete measures before the projected upward trend in smoke estimates exacerbates existing challenges. This urgency is informed by human-centered design considerations, which emphasize proactive and equitable solutions to minimize harm to the most vulnerable populations, such as children, the elderly, and those with preexisting health conditions.

By integrating human-centered principles throughout the project—from selecting relevant metrics to ensuring ethical data use and clear communication—the study provides actionable insights that prioritize equity, relevance, and the long-term welfare of Charleston's residents. This focus ensures that the findings and recommendations will support decision-making that truly benefits the community and fosters a sustainable, healthier future.

Limitations

Data Coverage and Completeness:

- For AQI estimates, only PM2.5 concentration was considered. While PM2.5 is a primary pollutant associated with wildfire smoke, other particles (e.g., PM10, NOx, and Ozone) were not included, which may have led to an incomplete assessment of air quality degradation.
- Charleston's AQI data was available only from 2000 onward, limiting the analysis to approximately 20 years of data. This restricted timeframe may not fully capture long-term trends or earlier correlations between smoke estimates and air quality.
- Data for life expectancy and mortality was similarly limited, spanning only 2000 to 2019. This constrained dataset might overlook long-term effects or historical variations, potentially impacting the robustness of conclusions.

Data Handling and Assumptions:

- For AQI calculations, a simple average of the available data was used, which does not account for seasonal variations or potential outliers. More sophisticated data processing techniques could improve result accuracy.
- Missing values in some datasets may have been handled with imputation or exclusion, potentially introducing bias into the analysis.

Correlation and Statistical Limitations:

- The analysis relied on Pearson's correlation to evaluate relationships between variables, which assumes linearity. While the observed correlation coefficients provided insights, they do not prove causation or capture potential nonlinear relationships.

ARIMA Model Limitations:

- The ARIMA model used for smoke impact predictions assumes stationarity and linear trends. Although differencing was applied to address stationarity, the model may not fully account for complex, nonlinear trends in wildfire activity or smoke dispersion. Additionally, external factors like changing climate patterns or urban development, which could influence smoke levels, were not included in the model.

Influence of External Factors:

- Socioeconomic conditions, access to healthcare, and demographic variables (e.g., age, race, and income) were not explicitly included in the analysis of mortality and life expectancy. These factors likely contribute significantly to health outcomes and could affect the observed correlations with smoke estimates.

Model Accuracy and Generalization:

- Predicting respiratory mortality and life expectancy using smoke exposure data introduces complexities, as these health outcomes are influenced by a range of confounding variables. Further model tuning, validation, and inclusion of additional factors would be necessary to improve predictive accuracy and generalizability.

Data Accessibility and Licensing:

- Some datasets, particularly those related to local health records or detailed wildfire activity, may have licensing restrictions or gaps in availability. Access to more comprehensive datasets could significantly enhance the depth and reliability of the analysis.

Conclusion

This study sought to address critical questions surrounding the impact of forest fires on Charleston, specifically investigating the relationship between wildfire smoke and air quality, and how this translates into broader health outcomes like life expectancy and mortality. The hypotheses proposed were that wildfire smoke significantly contributes to air quality degradation and that these impacts correlate negatively with life expectancy and positively with mortality rates.

The findings supported these hypotheses to a measurable degree. A moderate positive correlation (0.35) between smoke estimates and the Air Quality Index (AQI) highlighted that wildfire smoke is a meaningful contributor to declining air quality. Smoke estimates were also found to correlate negatively with life expectancy and positively with mortality rates when normalized, reinforcing the health risks posed by prolonged exposure to wildfire-related pollutants. Predictions using an ARIMA model indicated a potential increase in smoke exposure over the next two decades, underscoring the urgency for action. However, limitations in data coverage, statistical methods, and external factors highlight the need for further research to strengthen these conclusions.

This study informs the understanding of human-centered data science by demonstrating how data-driven approaches can be designed to prioritize human well-being and equity. The selection of life expectancy, mortality, and AQI as core metrics ensured the findings directly addressed tangible human impacts. Ethical considerations, such as transparency in methods, reliance on publicly accessible datasets, and clear communication of results, were integral to the study’s approach. Additionally, the analysis emphasized the importance of tailoring insights to inform actionable outcomes for Charleston’s residents, policymakers, and community leaders.

By focusing on the real-world implications of data, this study exemplifies how human-centered data science can guide decision-making and foster sustainable, equitable solutions.

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