Study on the Impact of wildfire smoke on Public Health

Grand Island - Hall County - Nebraska

Author: Sayani Boral, University of Washington

I. INTRODUCTION

In this report, we will be studying the impact of wildfire smoke on the respiratory health of the population residing in Grand Island in Hall County, Nebraska. According to this NCBI article[2], wildfires elevate the risk of smoke exposure for a significant portion of the US population. However, certain groups, particularly outdoor workers, firefighters and socially disadvantaged communities with limited adaptive capacity, face a disproportionately higher risk of exposure. The health impacts associated with exposure to wildfire smoke are highlighted, affecting both children and adults. These impacts include the exacerbation of pre-existing respiratory conditions such as asthma and chronic obstructive pulmonary disease (COPD), adverse effects on birth outcomes, and an increased incidence of cardiovascular and respiratory diseases. We want to focus on studying the correlation between these key metrics: AQI, Smoke impact Estimate, ER visits, Hospitalization and mortality attributed to COPD and Asthma. We want to also understand if a certain population demographic like ethnicity or gender is more vulnerable or not.

II. MOTIVATION

So why is this study on the impact of wildfire smoke on public health relevant and why should our city council members of Grand Island care about it. In the latest County Health Rankings[4] published for **2023**, Hall County, Nebraska, where Grand Island is located, ranked as the 59th county out of 79 counties in Nebraska. This ranking is based on 2 measures: Health Outcomes and Health Factors, for both of which the county has below average ranking. The city council will be motivated to improve these rankings for the benefit of the public health and society.

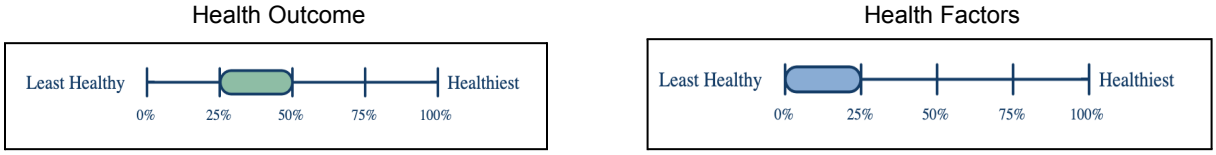


Fig 1: Health Ranking of Hall County, Nebraska | **Source** : NCBI

The model (Fig 2) behind these measures gives 10% weightage to Physical environment which takes into account the AQI (PM2.5 concentration).

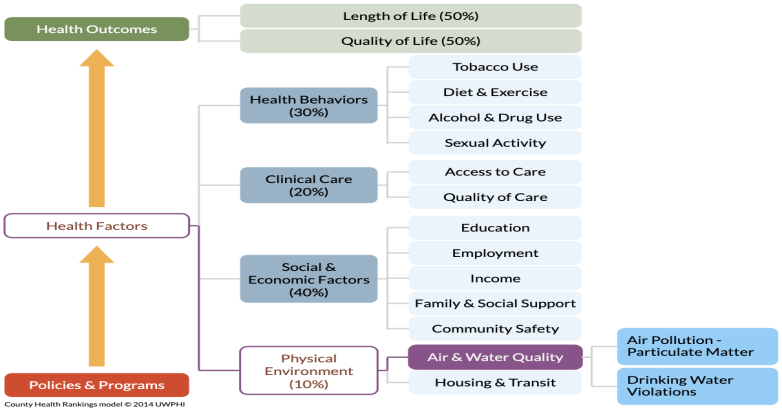


Fig 2: Features/factors of the Health outcomes and Health Factors model | **Source** : NCBI

This study will help inform the city council members about the correlation (if any) between wildfire smoke, Air Quality and respiratory illnesses and help them take steps to address issues in public health and thereby improve health rankings of Hall County.

III. RELATED STUDIES

Wildfire smoke is a large source of particulate matter, including fine inhalable particles with a diameter of 2.5 μm or less, known as PM2.5. Wildfire smoke, by recent estimates, has accounted for up to 25% of PM2.5 across the US, and up to half in some western regions (Burke et al., 2021). Exposure to wildfire-related PM2.5 can lead to negative impacts on human health, and is known to cause and/or exacerbate respiratory illness in particular (Chen et al., 2021; Johnston et al., 2012). Wildfire smoke pollution is associated with both respiratory morbidity and mortality (Aguilera, Corringham, Gershunov, & Benmarhnia, 2021; Aguilera, Corringham, Gershunov, Leibel, & Benmarhnia, 2021; Chen et al., 2021; Henderson & Johnston, 2012; Liu et al., 2015; O'Dell et al., 2021). Fine particles can induce respiratory issues through pulmonary inflammation and weakened pulmonary immune response (Hoek et al., 2013; Kurt et al., 2016). Repeated evidence supports the fact that smoke exposure can aggravate respiratory issues such as chronic obstructive pulmonary disorder (COPD) (Reid et al., 2016a, 2016b) and asthma (Arriagada et al., 2019; Malig et al., 2013; O'Dell et al., 2021; Ostro et al., 2016), and cause stress, especially oxidative, on the respiratory tract (Y. H. Kim et al., 2018; Wegesser et al., 2009).

As discussed above, there are many studies(see References) on the impact of wildfire smoke on public health and I have been most motivated by a research study [3] done by Darling et al : *The Burden of Wildfire Smoke on Respiratory Health in California at the Zip Code Level: Uncovering the Disproportionate Impacts of Differential Fine Particle Composition*. This study is aimed at quantifying the health burden of respiratory hospitalizations related to particulate matter (PM) exposure in California from 2006 to 2019, considering the differential impact of wildfire smoke. The findings suggest that previous estimates may have underestimated respiratory hospitalizations associated with PM exposure by approximately 13%, with higher underestimations in northern California and vulnerable areas. The study highlights the

importance of considering the specific health impact of wildfire smoke in air pollution guidelines to better protect at-risk communities.

I wanted to adopt the methodology and data sources discussed in this paper and apply the analyses to Grand Island, Hall County , Nebraska. Some of the data I found are at county level instead of city level , so we will be extending some of the analyses to Hall County.

The focus of this study will be based on the following:

- **Hypothesis** - There is a strong correlation between wildfire smoke (measured by AQI, Smoke Estimate) and incidence of respiratory diseases like COPD, Asthma (measured by ER Visits, Hospitalization, Mortality)
- **Analysis** - What is the demographics of Grand Island's population that is most likely to be affected by COPD and asthma caused due to wildfire smoke?

IV. METHODOLOGY

All the methodology described below can be found in the form of code in this repository: https://github.com/SayaniBoral/Human-Centered-Data-Science/tree/main/Wild-fire-smoke-estimation

Data Ingestion, Cleaning and Transformation

I have collected the **wildfire data** from USGS dataset (Combined wildland fire datasets for the United States and certain territories, 1800s-Present combined wildland fire polygons), specifically the file : USGS_Wildland_Fire_Combined_Dataset.json. The data has been filtered to 1963-2020 for Grand Island city in Nebraska. Using licensed code from Dr. David W. McDonald that included geodetic calculations, I was able to identify the fires that occurred within 1250 miles of Grand Island city.

The **data for AQI** (Air Quality Index) for PM2.5 was retrieved from US Environmental Protection Agency (EPA) Air Quality Service (AQS) API. This AQI data is a daily summary data from 3 Monitoring stations from Hall County, Nebraska(where Grand Island city is located) for PM2.5 concentration : JEFFERSON ELEMENTARY, Grand Island Senior High, Grand Island NDOT The data is available from 1999 - 2022. We will focus on PM2.5 concentration for AQI as this generally is more harmful than other forms of particulate matter.

The **public health data** for COPD and Asthma has been sourced from Centers of Disease Control and Prevention - US Chronic Disease Indicators tracking and is at the US state level granularity.

Both datasets share the same structure and has important measures like Emergency visits, Hospitalization rates and Mortality information. The data can be sliced by population demographics like Race/Ethnicity and Gender. I have filtered this data to Nebraska.
COPD:
https://data.cdc.gov/Chronic-Disease-Indicators/U-S-Chronic-Disease-Indicators-Chronic-Obstructive/aqr6-8kj8/about_data
Asthma:
https://data.cdc.gov/Chronic-Disease-Indicators/U-S-Chronic-Disease-Indicators-Asthma/us8e-ubyj/about_data
This dataset has been released by CDC as public and can be used for research in the public domain.

Formulating Wildfire Smoke Impact Estimate

As part of this study, I have defined a metric called Smoke Impact Estimate that measures the exposure to wildfire smoke. The metric considers the following features:
Distance of wildfire from Grand Island (fire_proximity)
Fire size as indicated by acres burnt by the fire (fire_size)
The formula for calculating smoke estimate is this:

```
Smoke Estimate=(fire_size_weight * normalized_fire_size + (proximity_weight * normalized_proximity)) * 100
– Where --
fire_size_weight = 0.7
proximity_weight = 0.3
normalized_fire_size = fire_acres / wf_size_max
normalized_proximity = (distance_max - distance_to_city) / distance_max
```

As seen in the formula above more weightage is given to fire_size based on the assumption that a large fire will produce more smoke than a smaller fire. Less weight is given to distance from the city as the farther the fire is from the city, less likely the smoke will be dispersed to Grand Island.

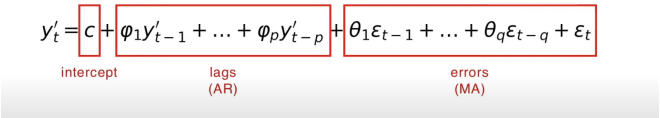
After I got the smoke estimate, I compared it to AQI data and determined if there is any positive or negative correlation between the calculated smoke estimate and the AQI. The Pearson correlation coefficient returned -0.049 suggesting a strong negative correlation between the 2 variables.

Forecasting Smoke Estimate for next 20 years

I wanted to assess what the smoke impact would look like in the next 20 years and used the ARIMA model to forecast the time series for the next 20 years. Briefly discussing about the methodology used:

- Determined time series stationarity of the “smoke estimate” using Augmented Dickey Fuller (ADF) test. The p-value came back 0.58 and ADF Statistic: -1.40. It shows the time series for this estimate is non-stationary and we will need differencing
- Determined the values of p(AR), d, q (MA) of the ARIMA formula using autocorrelation and partial auto correlation plots.
- Fitted the ARIMA model and extracted predictions
- Evaluated the ARIMA model to understand if this model is efficient or not

ARIMA Formula



COPD and Asthma data for Nebraska

Firstly, I checked that the data was devoid of any columns storing PII or PHI information . There was no such columns and CDC website also mentions that this data is ethically sourced through surveys where informed consent is taken from the survey participants for use of this data in research.

This data is at state level so I filtered it for Nebraska. Then I selected a subset of these columns:
'YearStart', – Year when this survey was taken
'Question', - Indicates whether response is for ER Visit, Hospitalization or Mortality
'DataValueType', - Indicates whether the data value is an absolute number or rate. I used absolute number for my analyses.
'DataValue',- Absolute number or metric
'StratificationCategory1',- Dimension to slice on: can be Gender or Race
'Stratification1' - If Category is Gender, then male/female. If Category is Race, then White, Black, Hispanic, etc.

V. FINDINGS

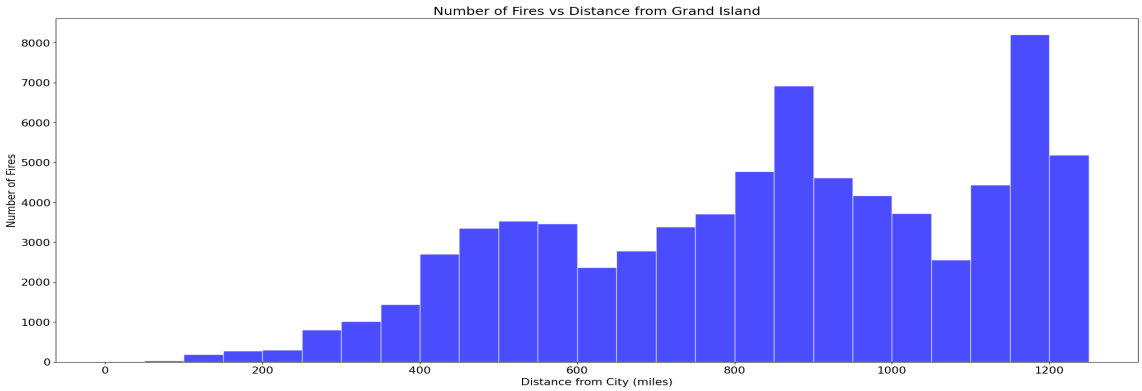


Fig 3: Proximity of wildfire from Grand Island, NE

From the wildfire data in Fig 3, it can be seen that most of the wildfires start from 150 to 200 miles away from Grand Island, with more wildfires occurring in the 800-1200 miles periphery. So **less wildfire is occurring very close to Grand Island** but smoke can travel very fast even if the fire is distant.

Due to its geographic location, Grand Island also receives smoke from wildfires from Canada. (article reference).

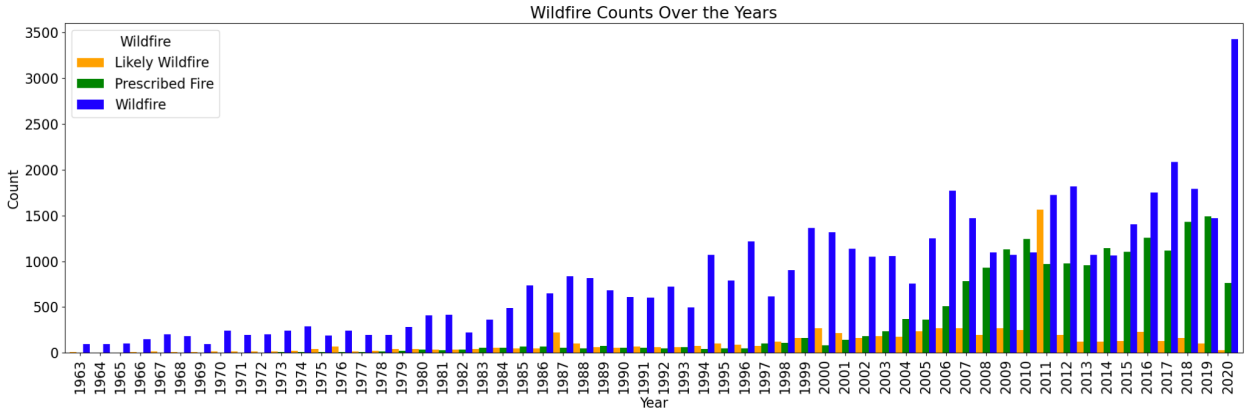
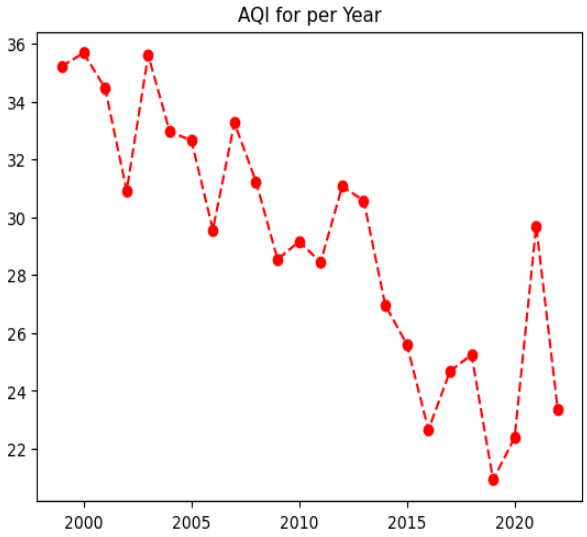


Fig 4: Wildfire count in last 60 years based on wildfire type

In Fig 4, we observe that the **number of wildfires have increased exponentially over the past decade**. US Forest Service in Nebraska has also started administering prescribed fires to control the damage caused by wildfire. Nevertheless smoke will also be caused by prescribed fires and can impact air quality.



AQI Basics for Ozone and Particle Pollution

Daily AQI Color	Levels of Concern	Values of Index	Description of Air Quality
Green	Good	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Yellow	Moderate	51 to 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Orange	Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
Red	Unhealthy	151 to 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Purple	Very Unhealthy	201 to 300	Health alert: The risk of health effects is increased for everyone.
Maroon	Hazardous	301 and higher	Health warning of emergency conditions: everyone is more likely to be affected.

Fig 5: AQI (PM2.5) for Hall County from 1999-2022 and the AQI scale for Air Quality

The trend AQI data for Hall County shows it has been improving in the last few years but had a peak in 2021 as seen in Fig 5. It is always below 50 and hence in the Green zone. **Thus air quality in Hall County indicates that is not harmful for public health.**

As discussed in the methodology section ,that I calculated the smoke estimate, forecasted smoke estimate for next 25 years and also found the correlation between this calculated smoke estimate and AQI.

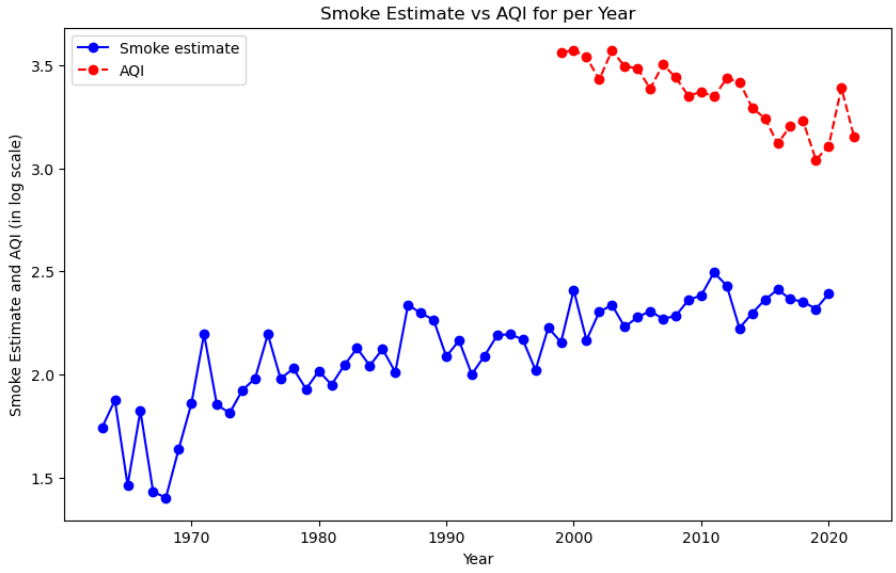


Fig 6: Comparing Calculated smoke estimate with AQI

In Fig 6, we can see that the trends of our smoke estimate and AQI are in opposite directions. This suggests that our calculated smoke estimates may not be correct. To corroborate this, I also performed the Pearson correlation test and we can see the results in Fig 7. We get a strong

negative correlation between our smoke estimate and AQI (-0.049). However the variables: proximity of fire and size of area burnt by fire have weak positive correlation with AQI . **This means that as the distance of the fire from the city increases or area burnt by fire increases, the AQI tends to increase slightly, but the correlation is weak**.

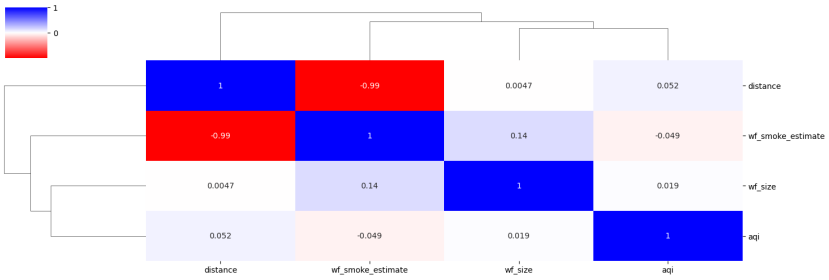


Fig 7: Correlation between AQI, smoke estimate, distance and size

How are the smoke estimate forecasts for next 20 years from our ARIMA model? In Figure 8 we note that the smoke estimate is non stationary and the predicted smoke

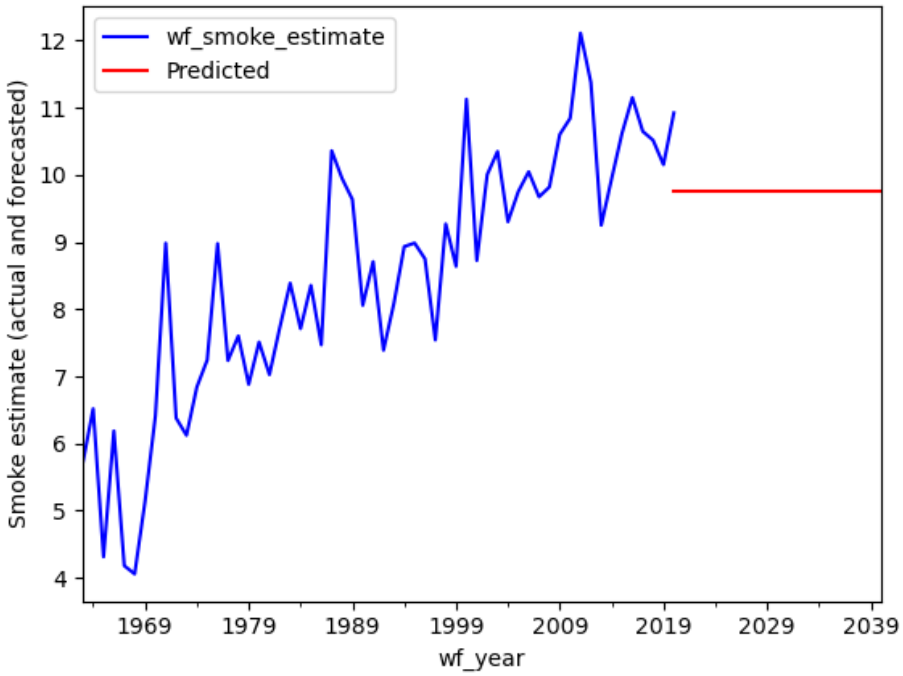


Fig 8: Time series analysis showing forecasted values from our ARIMA model

I have differenced our model once to make it stationary and used the p=4, q=1, d=1 for fitting the model. The SARIMAX (Seasonal Autoregressive Integrated Moving-Average with Exogenous Regressors) model details are below in Figure 9.

SARIMAX Results

Dep. Variable:	wf_smoke_estimate	No. Observations:	46
Model:	ARIMA(4, 1, 1)	Log Likelihood	−64.815
Date:	Mon, 11 Dec 2023	AIC	141.630
Time:	20:12:41	BIC	152.469
Sample:	01−31−1963	HQIC	145.671
	− 01−31−2008		
Covariance Type:	opg		

	coef	std err	z	P>|z|	[0.025	0.975]
ar.L1	−1.0822	0.346	−3.123	0.002	−1.761	−0.403
ar.L2	−0.4664	0.275	−1.699	0.089	−1.004	0.072
ar.L3	−0.4863	0.262	−1.854	0.064	−1.000	0.028
ar.L4	−0.4307	0.145	−2.974	0.003	−0.714	−0.147
ma.L1	0.5813	0.413	1.406	0.160	−0.229	1.392
sigma2	1.0191	0.270	3.776	0.000	0.490	1.548

Ljung−Box (L1) (Q):	0.17	Jarque−Bera (JB):	0.31
Prob(Q):	0.68	Prob(JB):	0.86
Heteroskedasticity (H):	0.56	Skew:	0.16
Prob(H) (two−sided):	0.27	Kurtosis:	2.75

Figure 9: SARIMAX model details

There is no trend in our forecast, no seasonality, and insufficient temporal dynamics to allow the future observations to have different conditional means.

Delving into the public health datasets for COPD and Asthma, we have the following findings:

We started with the hypothesis that wildfire smoke causes exacerbation of respiratory diseases like COPD and Asthma and increases mortality and hospitalization rates.

In the Fig 10 for COPD, we note that there is a strong negative correlation between AQI and ER Visit, Hospital Visit and Mortality. The strength of the negative relationship between AQI and COPD mortality is strong based on the magnitude of the correlation coefficient. This suggests that there is a notable inverse relationship between air quality and COPD mortality in your data . Although **this proves our hypothesis as incorrect for COPD, however it's important to note that correlation does not imply causation.** While a strong negative correlation suggests that there is a relationship between AQI and COPD mortality, it doesn't necessarily mean that changes in air quality directly cause changes in COPD mortality.

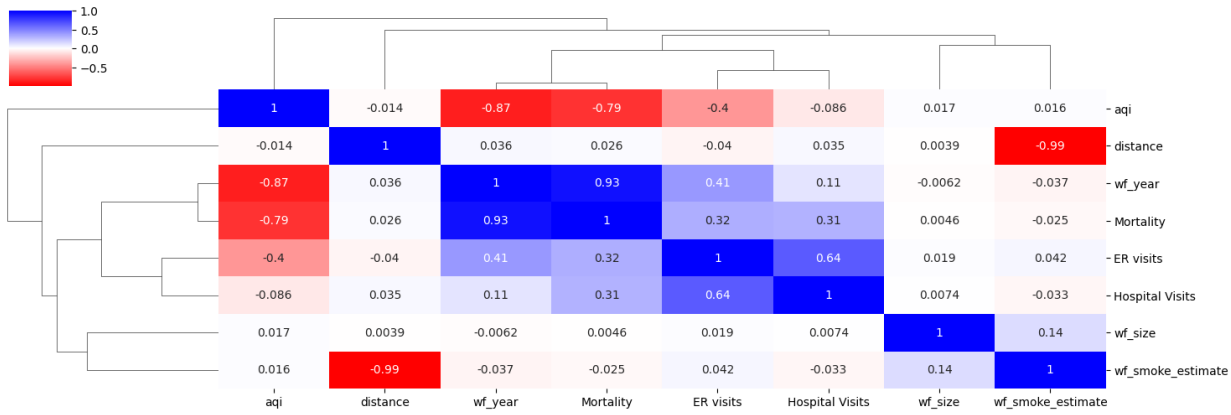


Fig 10 :Correlation between respiratory health metrics and AQI for Chronic Obstructive Pulmonary Disease

Doing the same study for Asthma in Fig 11, the correlation statistics gets interesting. We note that the AQI has a strong positive correlation with ER visits(0.59) and Hospitalizations(0.78). **This strong positive correlation between AQI and Hospitalizations implies that there is a notable association between higher AQI values and an increased likelihood of asthma hospitalizations. Poor air quality, as reflected in higher AQI values, may contribute to worsened respiratory conditions, such as asthma, leading to more hospitalizations.** This moderate positive correlation between AQI and ER visit suggests that higher AQI values are associated with a moderate increase in the likelihood of individuals seeking emergency medical care. Poor air quality can have a broader impact on health, leading to a rise in ER visits for various respiratory and cardiovascular issues

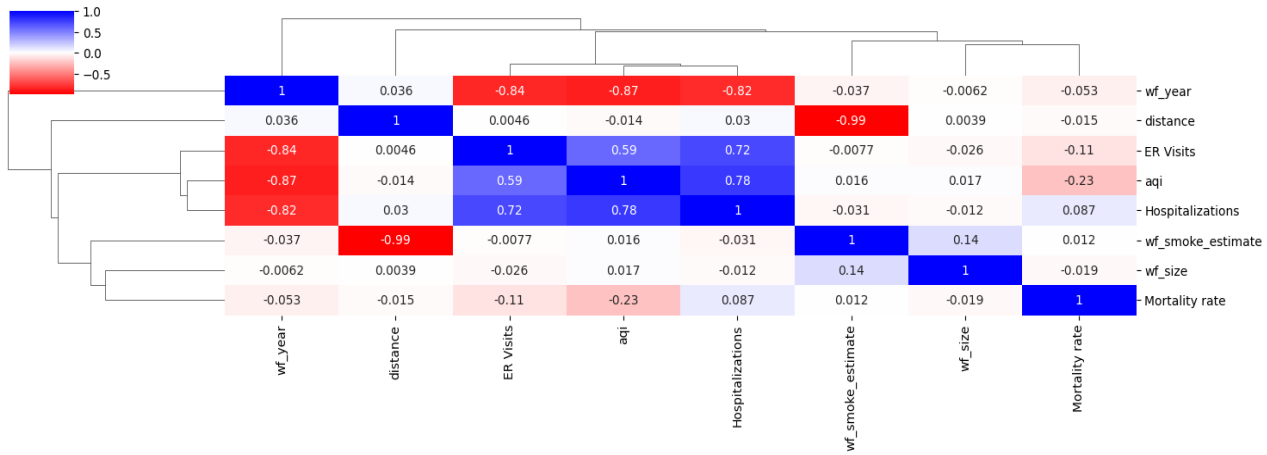


Fig 11: Correlation between respiratory health metrics and AQI for Asthma

Next I wanted to understand the demographics of Grand Island's population that is most likely to be affected by COPD and asthma. We note for COPD most impacted are White and Black populations. As we did not use the actual population data, we do not know what percentage of population do these numbers represent.

Question (group)	Year Start	American Indian or Alaska Native	Asian or Pacific Islander	Black, non-Hispanic	Hispanic	White, non-Hispanic
Hospital Visits	2010	68	29	347	28	12,552
	2011	71	26	440	26	14,969
	2012	97	33	451	43	14,083
	2013	77	25	425	46	13,903
	2014	81		413	46	13,317
	2015	110	23	480	57	14,310
	2016	112	24	564	63	14,613
	2017	131	27	629	73	15,637
	2018	155	36	606	79	15,506
	2019	149	32	593	72	15,659
	2020	120	42	528	69	12,314
Mortality	2010			48		2,812
	2011			64		2,963
	2012			89		2,937
	2013			41		2,971
	2014			83		3,100
	2015			93	21	3,238
	2016			91		3,164
	2017			93	27	3,435
	2018			105	21	3,303
	2019			92	21	3,267
	2020			122	30	3,382

Fig 12: COPD Hospitalization and Mortality by Race/Ethnicity

ASTHMA **COPD**

Question (group)	Year Start	Female	Male
Asthma mortality rate	2010		
	2011	20	
	2012		
	2013		
	2014	21	
	2015	20	
	2016	21	
	2017		
	2018		
	2019	22	
	2020		
Emergency department visit rate for asthma	2010	3,785	3,013
	2013	2,941	2,450
	2014	3,226	2,839
	2015	2,374	2,099
	2016	2,644	2,489
	2017	2,543	2,326
	2018	2,524	2,279
Hospitalizations for asthma	2010	837	508
	2013	672	389
	2014	688	423
	2015	554	287
	2016	288	168
	2017	569	353
	2018	275	199

Question (group)	Year Start	Female	Male
Mortality	2010	1,353	1,550
	2011	1,426	1,626
	2012	1,404	1,684
	2013	1,412	1,652
	2014	1,558	1,672
	2015	1,600	1,785
	2016	1,579	1,731
	2017	1,727	1,869
	2018	1,625	1,837
	2019	1,630	1,778
	2020	1,686	1,900
ER visits	2010	19,700	18,337
	2013	15,157	13,524
	2014	15,489	13,570
	2015	13,592	11,680
	2016	20,584	17,731
	2017	21,958	18,885
	2018	22,275	20,013
Hospital Visits	2010	18,384	18,150
	2011	7,776	7,928
	2012	7,218	7,676
	2013	17,696	17,653
	2014	16,433	16,755
	2015	16,404	16,371
	2016	21,706	21,236
	2017	37,186	35,392
	2018	22,577	22,791
	2019	8,465	8,347
	2020	6,594	6,695

In above diagram we can see the ER Visit,Hospitilization and Mortality rates by Gender for Asthma and COPD. We note that as an overall trend Females are more impacted by Asthma and males are more impacted by COPD.

VI. DISCUSSIONS

From our findings, we noticed that our smoke estimate formula needs to be improved so that it is at par with the AQI and we can start seeing a positive correlation. This also impacts our Smoke Estimate forecasting model.

Second we found that our hypothesis that Air quality impacts respiratory diseases holds true for Asthma hospitilization and ER visits. For COPD, we found weak negative correlations. While these findings are not conclusive, populations already suffering from Asthma need to be more careful during wildfire smoke season.

VII. LIMITATIONS OF THIS STUDY

This study has numerous limitations, the first one being , lack of public health data for Grand Island city or Hall County. Nebraska Health data is behind a paid service and not open for research , so I was unable to use that data.
https://www.nebraskahospitals.org/health_data/nhis.html

The second challenge was data sparsity or unavailability for certain granularity. The AQI data was at county level, public health data at state level and wildfire data at city level. If all data is at same geographic granularity, it ensures better results.

Also I joined the AQI data and Health data on “year” column, however the relationship is much more complex and should include more variables (for which we need domain expertise of environment and epidemiology experts).

VIII. CONCLUSIONS

As we note that there is a strong correlation between AQI and Asthma hospitalization and ER visit, We ask the city council members to focus on the following aspects :

- Children and individuals with asthma, COPD, heart disease, or those who are pregnant should take extra precautions when exposed to wildfire smoke due to heightened health risks.
- To reduce ash inhalation, especially for those with heart or lung conditions, wearing an N95 respirator is recommended. However, it is essential to wear it correctly and consult a doctor if one has pre-existing health issues. Monitoring health symptoms is advised, and seeking medical help if needed.
- Invest in an extensive air quality monitoring network to track and report real-time data during wildfire events. Enable residents to access this information easily through online platforms or community alerts. This empowers individuals to make informed decisions about outdoor activities based on current air quality conditions.
- Prepare for more healthcare workers to support asthma patients during fire season.

IX. REFERENCES

1. Assessing the social, economic impact of wildfires - https://yff.yale.edu/sites/default/files/files/wildfire_report(1).pdf
2. Wildfire, Smoke Exposure, Human Health, and Environmental Justice Need to be Integrated into Forest Restoration and Management https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9076366/
3. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2023GH000884
4. https://www.countyhealthrankings.org/explore-health-rankings/nebraska/hall?year=2023

X. LINKS TO DATA SOURCES

1. Wildfire data - Combined wildland fire datasets for the United States and certain territories, 1800s-Present combined wildland fire polygons)
2. AQI data - US Environmental Protection Agency (EPA) Air Quality Service (AQS) API.
3. COPD - https://data.cdc.gov/Chronic-Disease-Indicators/U-S-Chronic-Disease-Indicators-Chronic-Obstructive/aqr6-8kj8/about_data
4. Asthma - https://data.cdc.gov/Chronic-Disease-Indicators/U-S-Chronic-Disease-Indicators-Asthma/us8e-ubyj/about_data