The Relationship between Wildfires and Respiratory Health: AQHI Data in Southern Saskatchewan and Its Potential Respiratory Implications

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Abstract

Wildfires have been increasing in length and frequency since the mid-1980s, which emit pollutant matter that can adversely impact human health, specifically exacerbating negative respiratory impacts (Lipner et al., 2019). Although many studies examine the respiratory impacts of worsened wildfire conditions, a limited number take place outside of the western United States, occur over prolonged periods, and look at how air quality is changing due to warming climates. The objective of this study is to investigate how air quality health index (AQHI) values have changed over a period of two decades (January 1, 2001 to December 31, 2021) in the Great Plains Air Zone (GPAZ) in southern Saskatchewan and the potential respiratory implications of AQHI changes. The study uses a mixed methods approach: time series analysis, correlation analysis, and regression analysis to analyze AQHI and a literature review to study respiratory implications of AQHI increases. We found a significant increase in AQHI over time of 19.3% ($p < 0.0001$, $n = 7308$) and three main outcomes for respiratory data: (1) individuals with respiratory conditions have increased susceptibility to worsened air conditions, (2) elevated AQHI values cause increases in healthcare admittances for respiratory conditions such as asthma and COPD, and (3) women and individuals in the age ranges of 15-65 are particularly susceptible to respiratory outcomes from wildfire smoke. The study provides areas for future research, including the implementation of apps to track respiratory outcomes, the impact of other risk factors on respiratory health, and the effects of AQHI on Indigenous populations.

Keywords: AQHI, respiratory health, GPAZ, wildfires

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1. Introduction and Background

Since the mid-1980s, wildfire activity has been increasing, causing larger and longer-lasting fires, and longer wildfire seasons (Lipner et al., 2019). Lipner et al. (2019) suggests that the size and severity of wildfires is expected to increase as the climate warms and that wildfires are known to emit particulate matter and other air pollutants that can adversely impact human health, with strong evidence for negative respiratory outcomes. Several studies found positive associations between landscape-, fire-, smoke-, and asthma-related outcomes and suggest that wildfire smoke may have a broad effect on people with asthma, including increasing their need for medical attention, inhaler rescue medication, and physician office visits (Borchers Arrigada et al., 2019; Gan et al., 2020). There are three major gaps in research examining the effects of wildfire smoke on respiratory health. First, there are a limited number of studies that take place outside of the western United States. Second, a research gap also exists when looking at epidemiological data on the impacts of wildfires on respiratory health over prolonged periods. A third research gap relates to how air quality is changing due to wildfires in the context of warming climates.

Three main themes are found in the current literature: first, wildfires and asthma resource utilization; second, vulnerable populations, asthma, and wildfire exposure; and third, measuring environmental impacts. These common themes were used to develop a theoretical context for this study. The theoretical framework drawn from the literature review emphasizes the measurement of exposure data. Numerous studies used fine particulate matter (PM2.5) as a basis for wildfire smoke concentrations (Borchers Arriagada et al., 2019; Gan et al., 2020; Gowda et al., 2016a, 2016b; Haikerwal et al., 2015; Lipner et al., 2019; Yao et al., 2020). Other studies used AQHI and AQI data, which is derived from PM2.5 to determine wildfire smoke exposure (Yao et al., 2020; Gowda et al., 2016a, 2016b). Other methods such as satellite imagery data (Lipner et al., 2019; Mazdiyansi and AghaKouchhak, 2019; Gan et al., 2020) were used, however these studies are less common. This research project will follow the majority of studies by using PM2.5 values to calculate AQHI in order to assess wildfire smoke exposures over time. The study will evaluate air quality over time to assess the potential impact of climate change (see (Borchers Arriagada et al., 2019; Mazdiyasni & AghaKouchak, 2019).

The first main theme found in the literature review investigates asthma resource utilization. The studies that focus on asthma resource utilization and wildfires discuss the impact of wildfire smoke on asthma outcomes and utilization of healthcare resources during wildfire seasons. Study findings include that overall short-term exposure to landscape fire smoke (PM2.5) levels were positively associated with asthma-related outcomes, specifically asthma hospitalizations and emergency department visits with higher effects on females and the elderly (Borchers Arriagada et al., 2019). Futher, Gan et al. (2020) found that wildfire smoke may have a broad effect on people with asthma demonstrating an increasing need for medical attention, inhaler rescue medication, and physician office visits. A concern raised by literature relating to this theme is that wildfires are likely to become an increasing problem worldwide in the context of a warming climate which can cause increased environmental triggers of asthma and other respiratory conditions, which are likely to result in more severe and frequent disease exacerbations (Haikerwal et al., 2015). The main conclusion that this major theme discusses is that there is importance to finding methods of predicting and quantifying peaks in healthcare needs during wildfires, both by location and diagnosis to ensure efficient and effective healthcare resources for those in need (Strickland, 2008).

The second main theme found in the literature review investigates vulnerable populations, asthma, and wildfire exposure. These studies, however, are limited in number and focus on three population subgroups: pediatrics (Lipner et al., 2019; Tse et al., 2015), African American populations (Mazdiyasni & AghaKouchak, 2019), and senior populations (Mazdiyasni & AghaKouchak, 2019). Lipner et al. (2019) found that patients aged 12-21 experienced below normal lung function on the day after wildfire smoke exposure. This study also discusses that behavioural or age-related vulnerability factors play a substantial role in mediating the impact of wildfire smoke exposure on lung function in asthmatic children (Lipner et al., 2019). Another pediatric study looked at the relationship between obesity, asthma, and wildfire smoke (Tse et al., 2015). The Tse et al. (2015) study found that patients with higher BMIs may be particularly susceptible to increased pollutant levels during a wildfire and that the link between obesity and asthma severity suggests that air pollutants released during wildfires can have substantially detrimental effects on asthma control in this population. Again, this study emphasizes the fact that pediatric patients may be impacted by other external factors including the possibility that asthmatic patients may have taken more preventative actions, such as wearing a mask or staying indoors, or fled the wildfire areas due to local government warnings to evacuate high risk areas (Tse et al., 2015). Mazdiyasni and AghaKouchak (2019) looked at senior and African American subgroups and found that African American populations had 70% higher likelihood of having above average asthma rates during above average wildfires and that senior populations had twice the probability of having above average asthma rates during above average wildfire years. The authors discuss the need to study the impact of natural disasters on individual demographic groups in order to protect more vulnerable populations in the face of climate change (Mazdiyasni & AghaKouchak, 2019). The study concludes with the urgent need to make high-resolution health-related data publicly available for in-depth analyses of climate change impacts on society and disadvantaged communities (Mazdiyasni & AghaKouchak, 2019).

The third main theme in the literature review relates to measuring the environmental impacts of wildfires. Yao et al. (2020) focused on the assessment of the Air Quality Health Index (AQHI) for wildfire seasons on a number of health outcomes. Researchers found that AQHI was the best fit to all-cause mortality and circulatory visits, but AQHI in conjunction with PM2.5 was specifically recommended for asthma-related outcomes (Yao et al., 2020). The significance of this is that individuals with common respiratory conditions such as asthma and COPD are particularly susceptible to wildfire smoke, so PM2.5 AQHI is recommended for communicating about potential effects of air quality during wildfire seasons (Yao et al., 2020).

Our study has the potential to advance knowledge of AQHI impacts on respiratory health in a number of ways based on the gaps and future research suggestions outlined in the current literature. The first research gap is a lack of studies in Canada about wildfires and asthma-related outcomes (Borchers Arriagada, 2019). The second research gap relates to the recommendation of linking multiple medical events over time by following a cohort through sequential wildfire exposures to see the effects of repeat or prolonged exposure (Gan et al., 2020, Tse et al., 2015, and Lipner et al., 2019). The third research gap discusses the urgent need to make high-resolution health-related data publicly available for in-depth analyses of climate change impacts on society (Haikerwal et al., 2015, Mazdiyasni & AghaKouchak, 2019 and Strickland, 2008). These suggestions show an overall need for more research in the field regarding the impacts of wildfire smoke on respiratory outcomes, more Canadian research, and understanding how air quality is changing due to wildfires in the context of warming climates. These research gaps provide the basis for the main aims of this paper.

This paper looks to answer two research questions: 1) how has air quality health index (AQHI) changed from January 1, 2001, to December 31, 2021, in the Great Plains Air Zone (GPAZ)? and 2) what are the potential implications of AQHI increases on respiratory health, specifically on asthma and chronic obstructive pulmonary disease (COPD)? The study will follow a mixed methods approach, employing archival air quality data and retrospective quantitative data analysis to assess trends and periodic cycles of AQHI values. The AQHI values will be used to determine the presence of wildfire smoke in the airshed. The study will also use a literature review to discuss potential implications of increased AQHI values (which assumes increased wildfire smoke) on respiratory health, specifically asthma and COPD. The study is significant because it aims to fill the above gaps in the research and its results could potentially help promote awareness of climate change and its impacts on human health.

2. Methods

2.1 Study Location

This study will focus on the Great Plains Air Zone (GPAZ), specifically with long term AQHI values from the Environment and Climate Change Canada air monitoring station in Regina, SK. The location of this study was chosen based on anecdotal evidence for this region of worsening wildfires and respiratory health outcomes over the last few decades. This study location was also chosen to help fill gaps in the current literature where there is minimal research done in the Canadian Prairies. This study will look at air quality data from the GPAZ in order to contribute to filling that gap in the research, which encompasses the area surrounding and including the cities of Regina, Moose Jaw, and Yorkton (Government of Saskatchewan, n.d.). The study will look at archival data to assess trends in AQHI over the study period.

2.2 Methodology

The current study will follow a mixed methods approach through the use of retrospective quantitative data analysis of archival air quality data and a literature review that examines the potential implications of wildfire smoke exposure on respiratory health outcomes. Quantitative data analysis is a method of inquiry in which statistical testing of hypotheses is done by collecting measurements and comparing groups (Bassil & Zabkiewicz, 2014). Statistical analysis of AQHI values includes time series and regression analyses. Time series analysis is a variety of statistically objective approaches to describe the nature of a time series, which is a collection of observations taken sequentially in time (Palma, 2016). Time series analysis is used to assess trends in AQHI over time. Regression analysis describes the relationship between variables (Rogerson, 2015). The null hypothesis for the quantitative data analysis assumes that there is no change in AQHI over the study period ($H_0 = 0$) and the alternative hypothesis assumes that changes in AQHI over the study period will be greater or less than 0 ($H_a \neq 0$).

2.3 Evaluating Respiratory Implications

Respiratory implications are drawn from the initial literature review and will focus specifically on impacts on asthma and COPD. Asthma and COPD are defined based on the Primary International Classification of Diseases version 11 (World Health Organization, 2021a, 2021b). Asthma is defined as a chronic inflammatory disorder of the airways, characterised by an increased responsiveness of the trachea and bronchi to various stimuli and is manifested by a widespread narrowing of the airways that change in severity either spontaneously or as a result of therapy with symptoms such as recurrent episodes of wheezing, breathlessness, chest tightness, and coughing (World Health Organization, 2021). COPD is defined as a common, preventable, and treatable disease characterised by persistent airflow limitation that is usually progressive and associated with an enhanced chronic inflammatory response in the airways and the lung to noxious particles or gases, in which exacerbations and comorbidities contribute to the overall severity in individual patients (World Health Organization, 2021). The literature review consists of relevant journal articles in the field. Articles were systematically searched for using USearch from the University of Saskatchewan, and included databases such as Scopus, ScienceDirect, ProQuest, Wiley Online Library, and Nature. Keywords included in the search are asthma, COPD, respiratory health, wildfires, and fine particulate matter. The search did not include studies published before the year 2000 in order to maintain relevance to current research. These studies were used in a literature review to find theoretical context for this study, including parameters for air quality data, to help define the research questions, and to find potential implications of wildfire smoke on respiratory outcomes.

2.4 Wildfire Smoke Data Measurements

Air pollution parameters were obtained from Environment and Climate Change Canada database and used as a proxy measure of air quality degradation due to wildfire smoke. The parameters for wildfire smoke exposure data will encompass fine particulate matter (PM2.5, measured in $\mu g/m^3$), ozone (O_3, measured in parts per billion), and nitrogen dioxide

Figure 1: Saskatchewan air zones, with the Great Plains Air Zone highlighted in blue. Regina, where the air quality monitoring station is located, is also shown in the GPAZ.

(NO_2, measured in parts per billion), which were used to calculate the air quality health index (AQHI) (Eq. 1).

$$AQHI = \frac{1000}{10.4} \times (e^{0.000537 \times O_3} - 1) + (e^{0.000871 \times NO_2} - 1) + (e^{0.000487 \times PM2.5} - 1) \quad (1)$$

Wildfire smoke data was obtained from January 1, 2001, to December 31, 2021. Statistical analysis focused primarily on time series analysis with the intention of determining observable trends over time. The first step in statistical analysis begins with the calculation of AQHI from the provided air quality parameters (PM2.5, O_3, and NO_2). Any missing values where AQHI cannot be calculated are removed. Causes for missing AQHI values include the calculation missing any of the parameters for any given date/time set (i.e., one or more parameters may be missing). Hourly AQHI values will are assessed for quality assurance and to identify trends and/or annual cycles. Quality controlled hourly data are converted into daily values by averaging over 24 hours. Daily AQHI values are used to predict potential respiratory implications based on the literature review.

3. Results

3.1 Wildfire Smoke Data Results

Wildfire smoke data was based on three parameters: fine particulate matter (PM2.5), ozone (O_3), and nitrogen dioxide (NO_2). These parameters were used to calculate hourly AQHI data from Eq. 1 above. The dataset was pretreated to address missing and extreme values. Missing values occur when one or more of the individual parameters is/are missing for an individual hourly interval. Overall, 13861 of 184080 hourly observations were excluded due to missing one or more parameters needed to calculate AQHI, leaving 170219 observations to calculate hourly AQHI. Daily AQHI was calculated from the hourly values, resulting in 7383 daily observations . Extreme daily AQHI values were identified as those below the 0.5^{th} percentile and those exceeding the 99.5^{th} percentile. In total, 75 values were removed from the daily series. Ordinary least squares regression was used to identify the trend in the 2001-21 time series (Fig 2A), yielding the model:

$$AQHI = 0.0001179 \times day + 0.3332155 \quad (2)$$

Following the linear regression, the trend in the data was removed to allow for periodic regression. To remove negative values, the minimum detrended-AQHI (-3.71) was added to all of the values. Periodic regression is used to describe the regular cycles in the data (Fig 2B). The periodic model has the form:

$$AQHI = 3.71 + (9.45 \times \cos((0.0172 \times DOY) + 3.67)) \quad (3)$$

The last step was the removal of cycles from the detrended data. Figure 2C shows positive standardized residual values and has been formatted to show only those during wildfire seasons (May-September). These residuals represent unusually high AQHI days during the wildfire season and therefore likely relate to substantial wildfire events during each season, or unusual non-wildfire-related air quality degradation events (e.g., dust storms).

The slope of the linear trend is significantly different than 0 ($p < 0.0001$) showing that the increase in AQHI over the study period is significant and meaningful. Periodic regression results in an F-value of 138.7 and $p < 0.0001$, showing that the periodicity of the detrended series is significant and meaningful as well.

3.2 Respiratory Implications as a Result of Smoke Exposure

Several expected respiratory implications can be drawn from the results of the studies analysed in the above literature review. Because many of the studies follow a similar theoretical framework of air quality analysis as this study, a basis for expected respiratory implications in the Great Plains Air Zone can be developed. In the Borchers Arriagada et al. (2019) study, results indicated that landscape fire smoke PM2.5 was positively associated with asthma hospitalizations and emergency department visits, and that there were increased effects in women and seniors. The Gan et al. (2020) study found results of

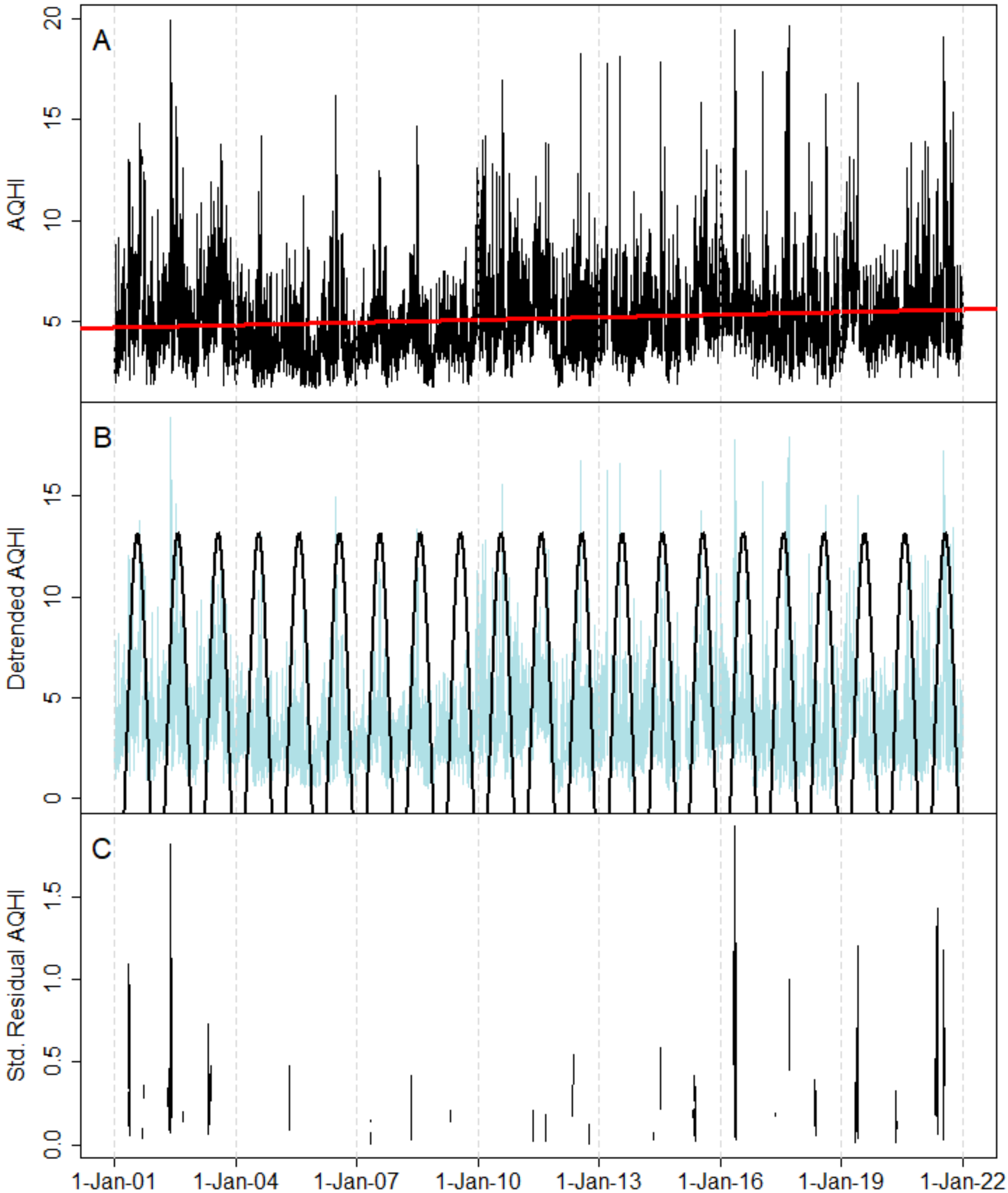

Figure 2: Time series analysis of daily AQHI data, 1 January 2001 through 31 December 2021: (A) AQHI daily time series (black) with linear regression model (red); (B) detrended AQHI daily time series (blue) with periodic regression (black); (C) positive standardized residuals during the May-September wildfire season after removing the seasonal cycle according to Environment and Climate Change Canada (2021). AQHI of 1-3 presents a low health risk, AQHI between 4-6 presents a moderate health risk, AQHI of 7-10 presents a high health risk and AQHI greater than 10 presents a very high health risk.

elevated office visits with elevations of wildfire smoke PM2.5 exposures and that these exposures had stronger impacts on females and those in the 15–65-year-old age category. The Gowda et al. (2016a, 2016b) studies demonstrated a close correlation between wildfire-induced air quality changes and users reporting air quality as an asthma trigger. Further, Haikerwal et al. (2015) showed positive associations between wildfire related PM2.5 exposures and emergency department attendances for asthma, again with increased risk found for adult women and in same day exposures to PM2.5. Strickland (2008) also found that asthma visits to clinics increased dramatically during and after fires. Tse et al. (2015) explain that catastrophic wildfires lead to worsening asthma outcomes and that air pollutants released during wildfires can have substantial detrimental effects on asthma control. Yao et al. (2020) emphasize that individuals with respiratory conditions such as asthma and COPD are particularly susceptible to wildfire smoke.

4. Discussion

4.1 Wildfire Trends and Patterns

Daily AQHI, a proxy for wildfire smoke, saw an increase of 19.3% over the study period of January 1, 2001, to December 31, 2021. Regression analysis shows an increasing trend in AQHI with a slope statistically different than 0. This significant trend in AQHI shows that AQHI is worsening over time in the GPAZ. Periodic regression shows AQHI peaks on average on July 30, in the middle of the typical May-September wildfire season. Positive AQHI standardized residuals can be matched to relatively large or significant wildfires. For example, the 2002 wildfires in California may have contributed to the spikes seen in 2002 (Fig. 4C) (Wikimedia Foundation, 2022a). Another example is the high daily average AQHI in August 2003 and subsequent high daily average AQHI into September 2003, which occurred at the same time as the Okanagan Mountain Park and the McLure fires in British Columbia (BC Wildfire Service, 2018), upwind of the GPAZ. Spikes in AQHI seen in late July and early August in 2009 can potentially be attributed to the West Kelowna wildfires in 2009 (BC Wildfire Service, 2018). Peaks in early to mid-May in 2011 can potentially be attributed to the wildfires in Alberta (either the Slave Lake wildfire from May 14 to 16, 2011, or the Richardson Fire in mid-May 2011) (Wildfire Alberta, 2021). Spikes in summer 2016 may be attributed to the Fort McMurray Wildfire that began burning on May 1, 2016 (Wildfire Alberta, 2021). Wildfire spikes in 2017, 2018, and 2019 are likely to be attributed to numerous wildfires in British Columbia (2017 and 2019) and Alberta (2017 and 2018) (Wikimedia Foundation, 2022b). AQHI spikes seen in summer 2021 can be potentially attributed to the Lytton Creek Wildfire in British Columbia that started on June 30, 2021 (Wikimedia Foundation, 2022b). These wildfire events would cause higher amounts of particulate matter and other parameters that contribute to high AQHI in downwind areas and are seen as spikes in the residual data graph (Fig. 4C). Other peaks in AQHI may not be explained by wildfires, but by other events that may cause increased particulate matter, nitrogen dioxide, and/or ozone in the atmosphere that would result in elevated AQHI levels, dust as dust storms, or upwind sources of pollution. One instance of wildfire data that was removed from the data analysis due to extreme outliers were the AQHI data points from summer 2015. The spikes seen in late June and early July of 2015 are related to the La Ronge fire in Saskatchewan, which were the largest fires in Saskatchewan history (Adam, 2020). These fires extended south and southeast, with Regina on its southern edge, and saw AQHI jump from 9.7 on June 8 to 171.1 on June 30, and stayed above 10 until July 12 (Adam, 2020). This data was excluded from our analysis because it created an extreme outlier peak in our results, however it is important to note that this fire caused extreme jumps in AQHI in the GPAZ.

This research summarizes air quality data over the span of two recent decades, which allows for the observation of the reasonable effects of climate change in southern Saskatchewan. When residual air quality data was linked with anecdotal evidence of Canadian wildfires, the connection to climate change can be seen. First, there is an increase in frequency of wildfires shown in the anecdotal evidence. Second, there is an increase in AQHI of 19.3% over the study period in the GPAZ. Third, AQHI spikes in wildfire seasons in the AQHI data from the GPAZ can be linked to anecdotal wildfire incidence in the Canadian context. These three factors are able to link to climate change effects in the sense that wildfires increasing over time as seen in anecdotal evidence for frequency of fires in Canada, and wildfires are being exacerbated by warmer and drier conditions as reflected in increased AQHI values over time, both of which are key indicators of climate change. These results helped to answer the first research question: how has air quality health index (AQHI) data changed in the Great Plains Air Zone (GPAZ) over the study period (January 1, 2001, to December 31, 2021)? The increasing trend in AQHI by 19.3% suggests that wildfire impacts on air quality is increasing over the study period of January 1, 2001 to December 31, 2021. This is supported by the increased occurrence of major wildfires in the recent half of the study period found in western Canada. Combined, the increasing trend in AQHI and increased occurrence of major wildfires represent an ongoing degradation of air quality in the GPAZ which is likely to have impacts on human health.

4.2 Implications for Respiratory Health

Based on the findings in the literature review, it is expected that asthma and COPD outcomes as a result of elevated AQHI values are expected to worsen. By following the trends of results found in the literature review, it is expected that communities in the GPAZ would see increased emergency department admissions and hospitalizations for asthma and COPD during periods of increased fine particulate matter (PM2.5) in the air, which can be linked to the presence of wildfire smoke. Potential implications for respiratory outcomes due to elevated AQHI values based on the literature review suggest increased asthma hospitalizations and emergency department visits (Borchers Arrigada et al., 2019), elevated office visits (Gan et al., 2020), increased reporting of asthma triggers (Gowda et al., 2016a, 2016b), and increases in emergency department attendees for asthma on the same day of smoke exposure (Haikerwal et al., 2015). Other expected implications on respiratory health outcomes include increased asthma visits to clinics during and after wildfires (Strickland, 2008) and worsening asthma outcomes and asthma control during periods of elevated AQHI (Tse et al., 2015). A consensus in the studies point towards risk factors of age and gender: between the ages of 15-65 (Borchers Arrigada et al., 2019 and Gan et al., 2020) and being female (Borchers Arrigada et al., 2019 and Gan et al., 2020) have increased likelihood of being admitted to healthcare facilities due to asthma or COPD triggers from worsened air quality. Another key finding of these studies is that individuals with existing respiratory conditions such as asthma and COPD are particularly susceptible to wildfire smoke (Yan et al., 2020). Overall, there are a few key points raised in these studies: (1) individuals with respiratory conditions have increased susceptibility to worsened air conditions, (2) elevated AQHI values cause increases in healthcare admittances for respiratory conditions such as asthma and COPD, and (3) women and individuals in the age ranges of 15-65 are particularly susceptible to respiratory outcomes from wildfire smoke. This project provides an opportunity for more Canadian research about analysis of AQHI data over time and potential respiratory implications of increases in AQHI over time during wildfire seasons. A strength of this project is that it focuses on a geographic region that is not commonly studied in the literature – although the provincial government has parameters of AQHI accessible to the general public, it was difficult to find Canadian research, let alone research in the GPAZ on AQHI and wildfire smoke impacts on respiratory health.

This literature review summarizes potential respiratory outcomes of increased AQHI. The literature review came up with the following conclusions expected to occur in times of increased AQHI: individuals with respiratory conditions will have increased susceptibility to worsened air conditions, elevated AQHI values are expected to cause increased healthcare admittances for respiratory conditions such as asthma and COPD, and that women and individuals in the age ranges of 15-65 are particularly susceptible to respiratory outcomes due to wildfire smoke. These conclusions provide an answer to the second research question: what are the potential implications of AQHI increases on respiratory health, specifically on asthma and chronic obstructive pulmonary disease (COPD)? Given the increasing trend in air quality degradation over time and the consistent reporting of asthma and COPD-related illnesses associated with this degradation, it is reasonable to suggest that wildfires in and upwind of the GPAZ are of growing concern for the health of the general population.

A weakness of this project is that it did not directly track respiratory outcomes and their association with air quality data. Although the study does provide potential respiratory outcomes of elevated AQHI levels, it does not specifically look at the population of the GPAZ and to assess trends of hospital admittances for respiratory outcomes during periods of elevated AQHI. The original objective of this study was to assess hospital admittances from two cohorts (one from Fort Qu'Appelle and one from Balcarres) over the same study period (January 1, 2001, to December 31, 2021), however this data is not publicly available and the time to receive it from the Saskatchewan Health Authority was out of the scope of this project.

4.3 Effects of Wildfires on Indigenous Populations

A large population subset in southern Saskatchewan that is impacted by wildfires is the Indigenous population that lives in the GPAZ as a large number of Indigenous communities are located in areas that frequently experience wildfires (Mottershead et al., 2020). Studies find that Indigenous groups may have low levels of emergency preparedness due to individual, family, and community-wide challenges caused by intergenerational trauma from the ongoing effects of colonialism's legacy which may make it more difficult for Indigenous groups to cope with the disruptive nature of wildfires (Mottershead et al., 2020). Despite these challenges, Indigenous peoples and communities are beginning to recover from this intergenerational trauma, which highlights the resilience in these communities and research is being done on a community level to see how Indigenous communities avoid, reduce, or cope with damages from natural disasters such as wildfires with minimal social disruption (Mottershead et al., 2020). The Mottershead et al. (2020) study focused on the Dene Tha' and Taché First Nation's recovery from evacuating their communities due to wildfires in July 2012. Effects on the community include heavy smoke causing difficulties for residents to breathe and see, initial voluntary evacuation for those at high risk from smoke (small children, infants, pregnant women, people with respiratory problems, and Elders) through word of mouth, and then a declared state of emergency and mandatory evacuation (Mottershead et al., 2020). The study discussed the lack of media attention on the Indigenous group in reporting and that media reports focused coverage on non-Indigenous communities, which made it difficult for the community to define the risk of the wildfire and delayed evacuation (Mottershead et al., 2020). Mottershead et al. (2020) also discuss how most Indigenous communities do not have emergency preparedness plans, or if they do, these plans are generally incomplete or out of date, which created issues in efficiently evacuating community members (Mottershead et al., 2020). There are three positive outcomes that resulted from this study that demonstrate resilience in this community including local leadership, keeping families together, and having a selection of host communities for evacuees that provide individuals with stability, familiarity, security, predictability, and a sense of control (Mottershead et al., 2020).

Another study looked at coping mechanisms of Indigenous communities (such as Mikisew Cree First Nation, Athabasca Chipewyan First Nation, Fort McKay First Nation, Fort McMurray First Nation, and Chipewyan Prairie Dene First Nation, along with five local Metis organizations in the area) after the 2016 wildfires in northern Alberta (Montesanti et al., 2021). Effects of the wildfires on Indigenous communities include community devastation, destruction, loss of homes, job insecurity, financial loss, injuries, impacts on mental health, and displacement/separation from loved ones (Montesanti et al., 2021). The study found that methods of coping during wildfire exposures were impacted by heightened physical and emotional stress, existing structural inequities, and strong community cohesion and connection to culture (Montesanti et al., 2021). Montesanti et al. (2021) also found that Indigenous communities found successes with coping through the use of sharing circles which allowed individuals to contextualize their experience and share their lived realities of wildfire evacuation and recovery with others. Challenges faced by the community include physical and emotional stress, difficulty accessing services and supports for mental and physical health, inadequate support from governments, and poor communication during evacuation and recovery (Montesanti et al., 2021).

As seen by the above studies, these communities are particularly susceptible to wildfire impacts and impacts of elevated AQHI due to the location of their communities and reserves in which they live (Mottershead et al., 2020). This current study provides a basis for future Indigenous research as it provides baseline AQHI data for the region. Quantitative analysis of Indigenous hospitalizations and admittances of respiratory health issues during the study period could be compared to the AQHI data provided. Increased hospitalizations and/or healthcare admittances for respiratory conditions such as asthma and COPD during times of peak AQHI values could be indicative of correlations between AQHI and respiratory health in Indigenous communities in the area. This research could also be expanded to qualitative data analysis, such as interviews or case studies in communities to learn more about coping mechanisms that took place during periods of abnormally high AQHI and how increasing AQHI values have impacted Indigenous communities over time. The communities should be communicated with regarding increased AQHI values over time, as seen in the trend in the current study, so that they are able to better prepare for future events. Communities could also participate in research through the development or updating of emergency preparedness plans, by finding or creating resources and supports that the community can use during times of distress, and creation of more thorough evacuation plans that can be used in future wildfire events.

4.4 Areas for Future Research

There are several areas for future research that stem from this project. One focus for future research could look at other factors that impact respiratory health caused by elevated AQHI values and smoke exposure including biological, social, behavioural, socioeconomic, and cultural factors that would require more qualitative data analysis. There is also an increasing need for research studies in low- and middle-income communities as much of the current research occurs in high-income countries (Borchers Arriagada et al., 2019). There is also a research gap in how different groups access care (Gan et al., 2020), so future research could focus on the stratification of the population into different demographic groups.

Another area for future research could be the implementation of app software into the healthcare system and general population to assess how respiratory outcomes are impacted by poor air quality. The Asthma Mobile Health Study completed by Gowda et al. (2016a, 2016b) was an example of how apps can be used to provide health data, and future research can demonstrate the use of apps as a way of sending real-time advisories to at-risk populations when adverse environmental conditions develop, such as sending AQHI data to users with asthma during extreme wildfire conditions to help individuals better prepare for an exacerbation. Apps can also be used to help healthcare facilities optimize allocation of resources and can be used to provide users with resources to help them in adverse environmental conditions (Gowda et al., 2016a, 2016b). The Asthma Mobile Health Study (AMHS), which was developed as part of Apple's Research kit, used survey responses correlated with air quality data to measure the impact of wildfires on individuals with asthma in the community (Gowda et al., 2016a, 2016b). One part of the AMHS focused on fires in March 2015 and occurred from May to September 2015 in the Pacific Northwest of the United States (specifically in Oregon, Washington, California, and Idaho) and used an Asthma Health Application (AHA) to collect continuous prospective data on asthma status for users through a series of daily and weekly surveys (Gowda et al., 2016b). The study involved adults in the United States with iPhones who had an active asthma diagnosis and the application collected self-reported symptoms and management and GPS location data and compared it to logs of PM2.5 data and overall air quality index (AQI) (Gowda et al., 2016b). This section of the study found that air quality was an asthma trigger and that there was a non-statistically significant spike in asthma medication use with wildfire incidence (Gowda et al., 2016b). The second part of the study looked at the Sleepy Hollow and Wolverine Complex wildfires in the Pacific Northwest in Oregon and Washington, again following United States adults with an asthma diagnosis on asthma medications (Gowda et al., 2016a). This section of the study also used AHA survey responses, GPS location, and self-reported asthma triggers and compared them to AQI (Gowda et al., 2016a). A close correlation was found between wildfire induced air quality changes and concluded that users reporting air quality as an asthma trigger demonstrates the feasibility of using mobile apps for conducting research on the impact of the environmental triggers of asthma (Gowda et al., 2016a). Both sections of the study suggest that the ability to send AQI data to app users with asthma could be used in the future to provide real-time advisories to at-risk populations when adverse environmental conditions develop and this could help individuals better prepare for an exacerbation and for healthcare centers to optimize allocation of resources (Gowda et al., 2016a, 2016b). This could be applied in the GPAZ in order to track respiratory outcomes of communities living in the GPAZ during periods of increased AQHI. Apps are a potential area for future research in the GPAZ and can be used, similarly to the Gowda et al. (2016a, b) studies, to provide real-time advisories to at-risk members of the community during worsened AQHI conditions. Apps could also be implemented in the GPAZ to conduct research on specific respiratory outcomes on communities in the area as a result of worsened AQHI or to allow healthcare facilities in the GPAZ region to better allocate resources to assist at-risk individuals in the community during periods of worsened AQHI.

Another future research possibility looks at factors that cause risk and impact access to healthcare in extreme conditions, such as biological, social, economic, and environmental conditions as well as personal risk factors such as socioeconomic status, smoking, obesity, and underlying health conditions (Haikerwal et al. 2015). Behavioural and age-related vulnerability factors, for example, the amount of time spent outdoors during times of poor air quality, should also be considered as they play a substantial role in mediating the impact of wildfire smoke exposure on lung function (Lipner et al., 2019). Cellular and molecular responses to wildfire smoke and the toxicological effects of wildfire smoke are also factors that need to be considered in future research (Lipner et al., 2019).

Finally, future research could look at how the seasonality of wildfires and poor air quality has changed over time. This would involve an understanding of what smoke seasons look like on an annual basis and how they have changed over time, for example, if they have changed in length, if they have begun earlier in the year (in the spring), and if they have ended later in the year (into the fall season).

5. Conclusions

The objective of this study was to assess how AQHI changed from January 1, 2001, to December 31, 2021, in the GPAZ and to find potential implications of AQHI increases on respiratory health, specifically on asthma and COPD. This objective was used to fill research gaps of limited research outside of the western United States, limited long term research on AQHI data, and limited connections between AQHI, respiratory outcomes, and changing climates. The study filled these research gaps by taking place in a different geographic region, southern Saskatchewan (in the GPAZ), looked at AQHI over a period of two decades (January 1, 2001, to December 31, 2021), and provided connections of AQHI increasing over time, increased wildfire frequency over time, and the increased likelihood of negative respiratory outcomes as a result of AQHI increases over time to the effects of climate change. Effects of climate change include exacerbated wildfire conditions (as seen in anecdotal evidence of increased frequency of wildfires in Canada) and AQHI values (19.3% increase in the GPAZ from our AQHI data) as a result of warmer and drier climates, which are likely to cause worsened respiratory outcomes (exacerbated asthma and COPD conditions as seen in the results of studies in the literature review).

This paper argues that AQHI has worsened over the study period through an increase of 19.3% in the last two decades. Based off results from the literature review, it also argues that individuals with respiratory conditions have increased susceptibility to worsened air conditions; elevated AQHI values cause increases in healthcare admittances for respiratory conditions such as asthma and COPD; and women and individuals in the age ranges of 15-65 are particularly susceptible to respiratory outcomes from wildfire smoke. Key takeaways from this study are that warmer and drier climates due to climate change will exacerbate wildfire conditions and will continue to cause worsened AQHI values over time. These worsened AQHI values are likely to have negative respiratory health impacts on communities living in GPAZ, especially in individuals with previous respiratory conditions such as asthma and COPD, women, and individuals aged 15-65, which will have an overall impact on communities in the GPAZ and their healthcare systems.

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