Journal: Texila International Journal of Public Health
Publisher: Texila International Journal
ISSN: 2520-3134
Volume 14 Issue 1, 2026
DOI: 10.21522/TIJPH.2013.14.01.Art006

Associations between Wildfire Smoke Exposure and Chronic Cardiovascular and Respiratory Conditions in Selected Provinces in Canada: A Retrospective Ecological Study

Chukwubuikem Cornelius Okafor*, Afusat Adesina
Department of Public Health, Texila American University, Guyana

Abstract

Wildfire smoke (PM2.5) has been recognized as an environmental risk factor with severe adverse health outcomes. Exposure to PM 2.5 can lead to severe cardiovascular and respiratory health conditions. The study aims to assess and examine the ecological associations between wildfire smoke exposure and the burden of chronic cardiovascular and respiratory conditions in Canada from 2010 to 2023, by integrating health outcome data with wildfire activity and air quality indicators across provinces. The study used a retrospective study design to collect secondary data from the Canadian Chronic Disease Surveillance System (CCDSS) for health outcomes (acute myocardial infarction, asthma, chronic obstructive pulmonary disease (COPD), heart failure, stroke) across the selected provinces, from the Canadian Wildland Fire Information System (CWFIS), for wildfire perimeters and their causes, and from the National Air Pollution Surveillance Program (NAPS), for air quality using PM 2.5 concentration as a proxy for air pollution exposure. The correlation between average $PM_{2.5}$ concentrations and incidence rates was weakly negative ($r = –0.106$, $p = 0.238$), and the wide confidence interval (95% CI: –0.6357 to 0.1593). Similarly, the correlation between high-risk air quality days (HRD) and incidence rates was also weak and negative ($r = –0.042$, $p = 0.643$), again failing to reach statistical significance. The findings indicate that wildfire smoke exposure, though an important environmental health concern, was not a statistically significant predictor of chronic cardiovascular and respiratory disease incidence across the studied provinces. This does not negate the potential health risks of wildfire smoke.

Keywords: *Cardiovascular Diseases, Disease Surveillance, PM2.5, Respiratory Diseases, Wildfire Smoke.*

Introduction

Wildland fire smoke increasingly has been recognized as an environmental risk factor of serious impact, leading to acute and chronic illness, particularly to the respiratory and cardiovascular systems [1]. Canada has the privilege of owning one of the world's largest forest coverages, with nearly 40% of its land mass dominated by forest [2]. British Columbia, Alberta, Saskatchewan, and Ontario are the provinces most vulnerable to wildfires due to high forest cover and hot, dry weather during summer [2]. Wildfire smoke is made up of a complex blend of gases and fine particulate matter (PM2.5) that can pose serious health risks, even when the exposure has occurred far from the fire or at relatively low concentrations [3]. They can be categorized as atmospheric particles, which consist of suspended particulate matter, including thoracic and respirable particles. These are coarse and inhalable particles with a diameter of 10 micrometers, which is why they are designated

Received: 22.12.2025 ***Accepted: 11.02.2026*** ***Published on: 31.03.2026***
Corresponding Author: okaforchukwubuikem@gmail.com

PM10, while the particles with a smaller diameter are designated PM2.5 [4]. Particulate matter (PM) or particulates are microscopic particles of solid or liquid matter suspended in the air, and the sources of particulate matter can be natural or man-made [5].

Fine particles (PM2.5), with diameters less than 2.5 micrometers, are of particular concern because these microscopic particles can penetrate deep into the lungs, reaching the bronchioles and alveoli and enter the bloodstream, potentially impacting almost every organ in the body [3]. The wildfire smoke also contains gases such as carbon monoxide, carbon dioxide, nitrogen oxides, sulfur dioxide, and volatile organic compounds (VOCs). Additionally, hazardous air pollutants (HAPs) like benzene, formaldehyde, and polycyclic aromatic hydrocarbons (PAHs), known for their irritant and carcinogenic properties, are also composite of wildfire smoke. Other substances often detected in wildfire smoke include water vapor, black carbon (soot), and trace metals such as lead, copper, and zinc, especially when the fire is anthropogenic in nature [3]. Wildfire smoke contains high levels of fine particulate matter (PM2.5), and it is deeply in the lungs and can reach the bloodstream, leading to systemic inflammation, oxidative stress, and vascular dysfunction [6]. All these biological processes are strongly associated with the etiology and aggravation of chronic respiratory and cardiovascular diseases [7]. Notwithstanding this, there is a paucity of retrospective studies from Canada exploring how repeated or prolonged exposure to wildfire smoke exacerbates chronic disease incidence, hospitalization, and death [8].

Wildfires are no longer a new phenomenon in Canada; however, the number and intensity of recent wildfires have increased. For example, in 2023, Canada saw its largest-ever wildfire season, and smoke traversed North America, even extending to Europe [9].

This study addresses a critical gap in Canadian public health literature. While most studies have examined either acute respiratory events or cardiovascular diseases and their association with wildfire smoke as stand-alone investigations focused on short-term effects [10], few have integrated both disease categories to explore long-term associations with wildfire smoke exposure. This knowledge gap poses significant challenges for policy-making and public health preparedness. Without robust evidence on the long-term health implications of wildfire smoke, the development of evidence-based interventions, optimal resource allocation, and climate-resilient healthcare systems remains limited. Therefore, this study aims to address these research gaps by conducting a retrospective ecological analysis to assess the associations between wildfire smoke exposure and the burden of chronic cardiovascular and respiratory conditions in selected Canadian provinces from 2010 to 2023. The study integrates health outcome data with wildfire activity and air quality indicators to provide a comprehensive understanding of these relationships across provinces.

Materials and Methods

Research Design

This study employed a retrospective study design from 2010-2023 to examine the associations between exposure to wildfire smoke and chronic cardiovascular and respiratory diseases in selected provinces in Canada. The study integrated three primary data sources: wildfire activity indicators (area burned, number of fires), air quality measurements ($PM_{2.5}$ concentrations, high-risk air quality days), and health outcome incidence rates (acute myocardial infarction, asthma, COPD, heart failure, and stroke). Data were aggregated at the provincial level for each calendar year, enabling temporal trend analysis and ecological correlation assessment.

Study Area

This study was carried out in selected provinces in Canada, which are: Alberta, British Columbia, Ontario, Quebec, and Saskatchewan. These provinces are of particular interest because they are provinces with high and frequent wildfire activities, they possess an established and comprehensive air quality monitoring system, which will enhance the reliability of the retrospective exposure assessment, and demographically diverse populations, which will allow for the examination of health effects across socio-demographic strata [2].

Study Population

Secondary data were used for this study, including all health records of focus from the five selected provinces in Canada, air quality records from the same provinces, and wildfire activities within them. The inclusion criteria are: All health records of the five health conditions of focus from the selected provinces (acute myocardial infarction, asthma, chronic obstructive pulmonary disease (COPD), heart failure, and stroke); all records of PM2.5 concentration within the selected province; and all records within the selected years for the study. Those excluded from the study were: Individuals who reside outside the five selected provinces, data records that did not match the pre-specified list of respiratory or cardiovascular outcomes as a result of wildfire smoke, and incidents of wildfire that occurred outside the 2010–2023 timeframe.

Sample and Sampling Techniques

For the secondary data, a convenience sampling technique was employed to aggregate and collect a total of 125 cases from 5 selected provinces.

Data Sources and Collection

Wildfire Activity Data were obtained from the Canadian Wildland Fire Information System (CWFIS) [11, 12], providing detailed information on wildfire perimeters and causes. Only natural-origin, non-prescribed fires were included. Data were aggregated to estimate total area burned (hectares) and the number of wildfire events per province per year.

Air Quality Data were retrieved from the National Air Pollution Surveillance (NAPS) Program [13] using $PM_{2.5}$ concentrations as a proxy for air pollution exposure. Hourly $PM_{2.5}$ measurements were averaged to produce daily and annual provincial means. Days with $PM_{2.5}$ concentrations exceeding 25 $\mu g/m^3$ were classified as high-risk days, consistent with Air Quality Health Index values ≥7 under Canadian health guidelines.

Health Outcome Data were extracted from the Canadian Chronic Disease Surveillance System (CCDSS) [14] maintained by the Public Health Agency of Canada. Data provided by the fiscal year were harmonized to match the calendar years used in environmental datasets. Incidence rates were expressed per 100,000 population for standardized comparison across provinces and time periods.

Data Analysis Methods

Data were systematically coded, cleaned, and analyzed using Statistical Package for the Social Sciences (SPSS version 25) and R statistical software (version 4.4.1) for advanced visualization and regression modeling. Multiple analytical approaches were employed: Descriptive Statistics summarized wildfire activity, air quality indicators, and health outcomes through frequencies, percentages, means, standard deviations, medians, and interquartile ranges, while Temporal Trend Analysis employed time-series methods to assess changes in wildfire activity, air pollution, and chronic disease incidence from 2010 to 2023. Line graphs illustrated yearly variations, and percentage changes between baseline (2010) and endpoint (2023) quantified directional trends. Inferential Statistics included Analysis of Variance (ANOVA) to compare mean values across provinces, with

Kruskal-Wallis tests employed where data violated normality assumptions. Statistical significance was determined at $p \leq 0.05$. Furthermore, correlation analysis utilized Pearson's correlation coefficient to examine linear relationships between wildfire activity indicators and air quality measures, as well as associations between exposure variables and health outcomes. Correlation strength was interpreted using conventional thresholds (weak: $r < 0.3$, moderate: 0.3-0.6, strong: >0.6). Graphical Visualization included scatter plots with regression lines, heat maps illustrating spatiotemporal variations, and trend line graphs highlighting longitudinal shifts in incidence rates and air quality metrics.

Results

A total of 125 cases were included in the study, Table 1. Distribution by year showed an equal representation in 2010, 2011, 2012, and 2021, with 25 cases each (20.0%). The year 2022 contributed 20 cases (16.0%), while 2023 accounted for the least with only 5 cases (4.0%).

In terms of provincial distribution, each of the five provinces contributed equally to the study population. Alberta, British Columbia, Ontario, Quebec, and Saskatchewan all had 25 cases each (20.0%), ensuring balanced geographical representation.

With respect to health conditions, the study also maintained an even distribution. Each of the five conditions—acute myocardial infarction, asthma, chronic obstructive pulmonary disease (COPD), heart failure, and stroke—contributed 25 cases (20.0%), reflecting an intentional design to allow for balanced comparisons across disease groups. The age group analysis revealed that the largest proportion of cases was in the 20-34 years category (50; 40.0%). The remaining groups were equally distributed, with 25 cases each (20.0%) in the 1–19 years, 35-39 years, and ≥ 40 years categories. This indicates a skew towards early adulthood, while still capturing both younger and older populations.

Table 1. Socio-demographic Characteristics

Variables	Frequency	Percent (%)
Year		
2010	25	20.0
2011	25	20.0
2012	25	20.0
2021	25	20.0
2022	20	16.0
2023	5	4.0
Province		
Alberta	25	20.0
British Columbia	25	20.0
Ontario	25	20.0
Quebec	25	20.0
Saskatchewan	25	20.0
Condition		
Acute myocardial infarction	25	20.0
Asthma	25	20.0
Chronic obstructive pulmonary disease	25	20.0
Heart failure	25	20.0

Stroke	25	20.0
Age Group		
1-19	25	20.0
20-34	50	40.0
35-39	25	20.0
≥ 40	25	20.0

Table 2 shows the analysis of Temporal Trends in Chronic Cardiovascular and Respiratory Conditions. Across all five provinces, considerable variations were observed in the mean and median rates of the selected conditions. In Ontario, the highest mean incidence rate was recorded for chronic obstructive pulmonary disease (COPD) at 722.40 ± 246.05 per 100,000, with significant variation over time (ANOVA = 15.32, $p < 0.0001$; Kruskal-Wallis = 18.93, $p = 0.008$). Asthma also showed a relatively high incidence (494.60 ± 79.68), while heart failure (499.60 ± 14.60), stroke (302.60 ± 16.74), and acute myocardial infarction (188.40 ± 36.34) remained comparatively stable without statistically significant variation.

In Quebec, COPD similarly showed significant temporal variation (ANOVA = 53.02, $p < 0.00001$; Kruskal-Wallis = 22.40, $p = 0.0002$), with a mean incidence of 684.80 ± 101.57. Other conditions, such as asthma (397.40 ± 68.27), heart failure (506.00 ± 7.45), stroke (267.40 ± 9.61), and myocardial infarction (252.40 ± 11.28), did not show significant fluctuations over the study period.

In Alberta, COPD again presented the highest mean incidence rate at 863.80 ± 317.75, with strong statistical significance (ANOVA = 15.58, $p < 0.00001$; Kruskal-Wallis = 20.95, $p = 0.0003$). Asthma (474.20 ± 82.44) and heart failure (600.60 ± 35.91) followed closely, while myocardial infarction (193.00 ± 42.92) and stroke (294.20 ± 30.03) remained comparatively lower and non-significant. In British Columbia, COPD also dominated with a mean incidence of 896.60 ± 305.32 and significant variation (ANOVA = 19.26, $p < 0.00001$; Kruskal-Wallis = 21.97, $p = 0.0002$). Heart failure (604.60 ± 11.26) and asthma (466.60 ± 72.79) were common, while stroke (321.80 ± 18.38) and myocardial infarction (174.80 ± 22.42) exhibited comparatively lower rates.

In Saskatchewan, COPD again demonstrated significantly high variability with a mean rate of 837.80 ± 165.28 (ANOVA = 39.76, $p < 0.00001$; Kruskal-Wallis = 22.55, $p = 0.0002$). Other conditions, such as asthma (447.60 ± 67.89), heart failure (568.80 ± 69.61), stroke (295.40 ± 31.50), and myocardial infarction (203.60 ± 32.51), showed no significant changes across the study period.

Table 2. Temporal Trends and Statistical Significance of Incidence Rates of Chronic Cardiovascular and Respiratory Conditions Across Selected Canadian Provinces, 2010–2023

Condition	**Mean Rate (per 100,000)±SD**	**ANOVA (p-value)**	**Median Rate (IQR)**	**Kruskal-Wallis (p-value)**
Ontario				
Acute Myocardial Infarction	188.40 ± 36.34		207 (155–211)	
Asthma	494.60 ± 79.68		508 (500–539)	
Chronic Obstructive Pulmonary Dz	722.40 ± 246.05	15.32 **(<0.0001)***	868 (492–901)	18.93 **(0.008)***
Heart Failure	499.60 ± 14.60		498 (495–505)	

Stroke	302.60 ± 16.74		304 (287–313)	
Quebec				
Acute Myocardial Infarction	252.40 ± 11.28		256 (246–261)	
Asthma	397.40 ± 68.27		425 (343–446)	
Chronic Obstructive Pulmonary Dz	684.80 ± 101.57	53.02 **(<0.00001)***	707 (600–740)	22.40 **(0.0002)***
Heart Failure	506.00 ± 7.45		506 (502–508)	
Stroke	267.40 ± 9.61		271 (259–272)	
Alberta				
Acute Myocardial Infarction	193.00 ± 42.92		221 (155–224)	
Asthma	474.20 ± 82.44		519 (415–525)	
Chronic Obstructive Pulmonary Dz	863.80 ± 317.75	15.58 **(<0.00001)***	1061 (553–1087)	20.95 **(0.0003)***
Heart Failure	600.60 ± 35.91		608 (604–624)	
Stroke	294.20 ± 30.03		307 (267–312)	
British Columbia				
Acute Myocardial Infarction	174.80 ± 22.42		190 (155–191)	
Asthma	466.60 ± 72.79		474 (409–500)	
Chronic Obstructive Pulmonary Dz	896.60 ± 305.32	19.26 **(<0.00001)***	1023 (574–1094)	21.97 **(0.0002)***
Heart Failure	604.60 ± 11.26		608 (596–612)	
Stroke	321.80 ± 18.38		322 (304–337)	
Saskatchewan				
Acute Myocardial Infarction	203.60 ± 32.51		221 (177–224)	
Asthma	447.60 ± 67.89		446 (445–474)	
Chronic Obstructive Pulmonary Dz	837.80 ± 165.28	39.76 **(<0.00001)***	915 (715–931)	22.55 **(0.0002)***
Heart Failure	568.80 ± 69.61		583 (504–607)	
Stroke	295.40 ± 31.50		307 (264–317)	

Statistically Significant ($p<0.05$); **SD=Standard Deviations; **IQR**=Inter-quartile Range*

Figure 1 shows that overall, all five conditions demonstrated a general declining trend in incidence rates over the study period, although the magnitude and patterns of decline varied across conditions. Chronic obstructive pulmonary disease (COPD) consistently had the highest incidence rates throughout the study, starting at above 1,000 per 100,000 in 2010 and showing a marked reduction over time to below 600 per 100,000 by 2021. A slight increase was observed between 2022 and 2023, suggesting a recent uptick in COPD cases. Heart failure maintained relatively stable incidence rates across the years, with only a modest decline from around 580 per 100,000 in 2010 to approximately 540 per 100,000 in 2021. Similar to COPD, a minor increase was seen after 2021.

Asthma showed a steady decline from over 500 per 100,000 in 2010 to its lowest point

around 2021, followed by a rebound in 2022–2023. This suggests possible fluctuations in environmental or healthcare-related factors influencing asthma incidence.

Stroke incidence remained comparatively stable, with a gradual downward slope from about 300 per 100,000 in 2010 to approximately 270 per 100,000 in 2023, indicating slower changes relative to other conditions.

Acute myocardial infarction (AMI) recorded the lowest incidence rates among the five conditions. It showed a consistent downward trend, reducing from about 220 per 100,000 in 2010 to below 180 per 100,000 by 2023, with no evidence of major fluctuations.

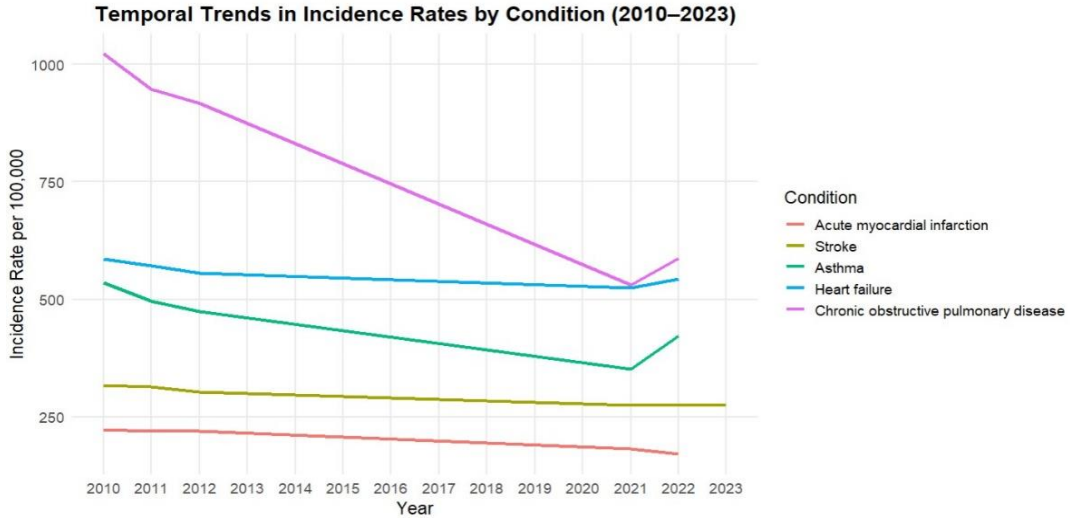

Figure 1. Temporal Trends in Incidence Rates of Chronic Cardiovascular and Respiratory Conditions, Canada, 2010–2023

The pattern in Figure 2 shows marked variability over time, with alternating periods of decline, stability, and sharp increases. Between 2010 and 2012, the total area burned dropped substantially, from over 350,000 hectares in 2010 to below 200,000 hectares in 2012, indicating a significant early decline. From 2013 to 2021, there was a gradual but steady increase, with total burned area rising from just under 200,000 hectares in 2012 to nearly 450,000 hectares in 2021.

A noticeable dip occurred in 2022, when the total area burned fell sharply to its lowest point in the observed period, under 150,000 hectares. However, this was immediately followed by a dramatic surge in 2023, when the total burned area exceeded 1.6 million hectares, the highest recorded across the entire study period.

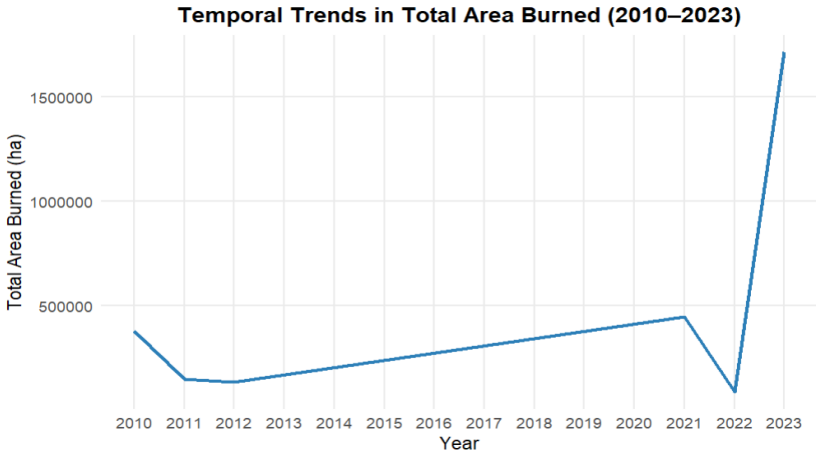

Figure 2. Temporal Trends in the Total Area Burned (2010-2023)

Figure 3 presents a heat map visualization of the total area burned across provinces between 2010 and 2023.

The colour intensity reflects the scale of burned area, ranging from lighter shades (smaller areas burned) to darker shades (larger areas burned).

The results show strong inter-provincial and temporal variation. Quebec stands out with the darkest shade in 2023, indicating the largest area burned nationally, surpassing 4 million hectares. British Columbia and Alberta also showed very dark shading in 2023, reflecting substantial wildfire activity exceeding 1 million hectares each. In contrast, Ontario and Saskatchewan exhibited lighter shades in 2023, indicating comparatively smaller but still significant burned areas.

Earlier years reveal more moderate wildfire patterns across provinces. For instance, Saskatchewan had relatively darker shading in 2010–2011, consistent with its historically higher burned areas during that period. Quebec displayed recurrent moderate-to-dark shading throughout the timeline, reflecting frequent large-scale wildfires, even before the 2023 spike. Ontario, in contrast, was characterized by lighter shades across most years, signifying smaller areas burned relative to western provinces.

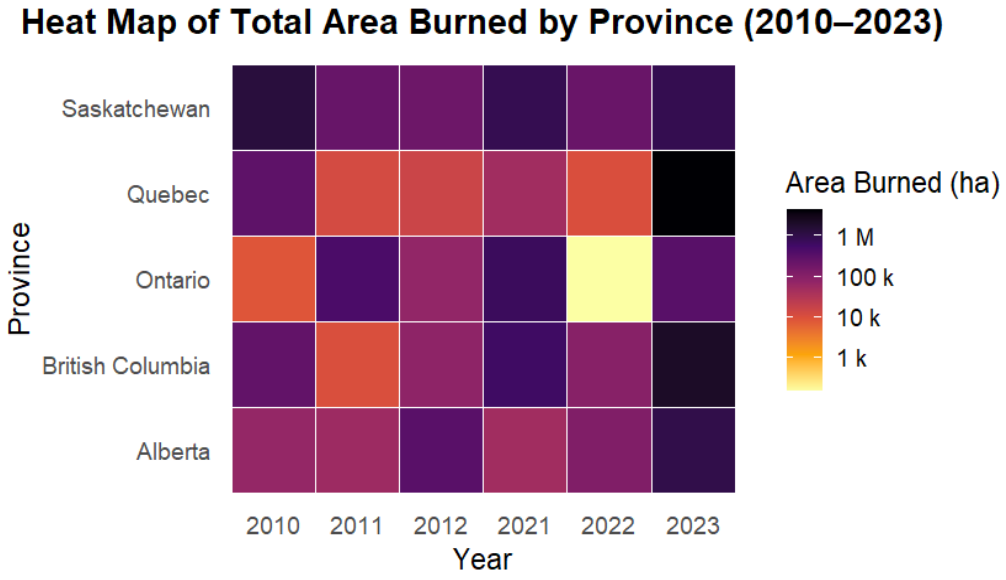

Figure 3. Heat Maps showing the Total Area Burned by Provinces (2010-2023)

Table 3 presents the correlation analysis between wildfire activity (measured as total area burned and number of fires) and high-risk air quality days (HRD) across Canadian provinces between 2010 and 2023.

The correlation between area burned and HRD was weakly positive (r = 0.214), indicating that larger burned areas were modestly associated with more high-risk days. However, this association did not reach statistical significance (p = 0.257). This suggests that while severe fire seasons tended to coincide with periods of poor air quality, the relationship was inconsistent, likely influenced by meteorological dispersion, topography, and smoke transport across provincial boundaries.

The relationship between the number of fires and HRD was similarly weak (r = 0.190) and statistically non-significant (p = 0.841). The wide confidence interval further illustrates the lack of precision in this association. This indicates that fire frequency alone was not a reliable predictor of the duration of poor air quality conditions. In other words, a high number of smaller or less intense fires did not necessarily translate into more high-risk days compared to a few but larger and more intense wildfire events.

Table 3. Correlation Between Number of Fires and High-Risk Days (HRD) (2010–2023)

Province	Pearson's Correlational Coefficient, r, (Area Burned vs. HRD [95%CI}	P-Value	Pearson's Correlational Coefficient, r, (Number of Fires vs. HRD [95%CI}	P-Value
All provinces	0.214 (weak positive) [0.00-0.00]	0.257	0.190 (weak positive) [-0.820-2.46]	0.841

Table 4. presents the provincial comparison of average fine particulate matter ($PM_{2.5}$) concentrations between 2010 and 2023.

In Alberta, the mean $PM_{2.5}$ concentration was 8.64 ± 3.64 μg/m³, with median values ranging between 6.88–8.37 μg/m³. Levels rose markedly from 8.37 μg/m³ in 2010 to 15.93 μg/m³ in 2023, representing the steepest proportional increase (+90%) among all provinces.

British Columbia recorded a relatively lower mean of 6.11 ± 0.90 μg/m³, with a modest increase from 5.81 μg/m³ in 2010 to 7.32 μg/m³ in 2023 (+26%). While lower in magnitude compared to Alberta and Saskatchewan, this still reflects a consistent upward trajectory, coinciding with the province's high wildfire frequency.

In Ontario, the average $PM_{2.5}$ was 6.69 ± 1.19 μg/m³, with concentrations increasing from 5.79 μg/m³ in 2010 to 8.93 μg/m³ in 2023 (+54%). Although the ANOVA and Kruskal–Wallis tests did not indicate statistically significant differences over time ($p>0.05$), the increase points to a gradual but steady deterioration in air quality.

Quebec exhibited a higher baseline, with a mean $PM_{2.5}$ of 7.68 ± 0.73 μg/m³, rising slightly from 7.83 μg/m³ in 2010 to 8.50 μg/m³ in 2023 (+8.5%). While the overall percentage change was modest compared to other provinces, Quebec remained one of the provinces with consistently elevated $PM_{2.5}$ levels throughout the period.

Saskatchewan recorded an average $PM_{2.5}$ concentration of 8.14 ± 3.82 μg/m³, increasing sharply from 6.19 μg/m³ in 2010 to 15.28 μg/m³ in 2023 (+147%), the largest relative increase observed.

Table 4. Provincial Comparison of Average PM25 (2010–2023)

Provinces	Mean Number of Fires (+SD)	ANOVA (p-value)	Median Number of Fires (IQR)	Kruskal-Wallis (p-value)	Number of Fires in 2010	Number of Fires in 2023	% Change (2010–2023)	Trend Direction
Alberta	8.64 ± 3.64		7.18 (6.88–8.37)		8.37	15.93	0.90	↑ Increasing
British Columbia	6.11 ± 0.90		6.19 (5.20–6.69)		5.81	7.32	0.26	↑ Increasing
Ontario	6.69 ± 1.19	1.06 (0.395)	6.25 (5.89–7.01)	7.02 (0.135)	5.79	8.93	0.54	↑ Increasing
Quebec	7.68 ± 0.73		7.90 (7.00–8.16)		7.83	8.50	0.085	↑ Increasing
Saskatchewan	8.14 ± 3.82		6.66 (5.59–9.47)		6.19	15.28	1.47	↑ Increasing

Statistically Significant ($p<0.05$); **SD=Standard Deviations; **IQR**=Inter-quartile Range*

Table 5 presents the results of the correlation analysis examining the relationship between wildfire smoke exposure indicators—average $PM_{2.5}$ concentrations and high-risk air quality days (HRD), and the incidence rates of cardiovascular and respiratory conditions across all Canadian provinces during the period 2010–2023. The correlation between average $PM_{2.5}$ concentrations and incidence rates was weakly negative (r = –0.106, p = 0.238), and the wide confidence interval (95% CI: –0.6357 to 0.1593).

Similarly, the correlation between high-risk air quality days (HRD) and incidence rates was also weak and negative (r = –0.042, p = 0.643), again failing to reach statistical significance.

Table 5. Correlation Between Wildfire Smoke Exposure Indicators (PM2.5, high-risk days) and Incidence Rates of Cardiovascular and Respiratory Conditions (2010–2023)

Province	**Pearson's Correlational Coefficient, r, ($PM_{2.5}$ vs. Incidence rates) [95%CI}**	**P-Value**	**Pearson's Correlational Coefficient, r, (High risk days vs. Incidence rates) [95%CI]**	**P-Value**
All provinces	-0.106 (weak negative) [-63.57-15.93]	0.238	-0.042 (weak negative) [-0.345-0.214]	0.643

Figure 4 illustrates the relationship between average $PM_{2.5}$ concentrations (µg/m³) and the incidence rates of cardiovascular and respiratory conditions across Canadian provinces between 2010 and 2023. Each point represents provincial-level observations over the study period, with the red dashed line depicting the fitted linear regression trend and the grey shaded area denoting the 95% confidence interval around the estimate. The scatter plot reveals a weak and slightly negative association between $PM_{2.5}$ concentrations and incidence rates. As $PM_{2.5}$ levels increase, the incidence rate of cardiorespiratory conditions shows a marginal downward trend. However, the dispersion of points around the regression line is wide, and there is no clear clustering pattern, suggesting substantial variability across provinces and years.

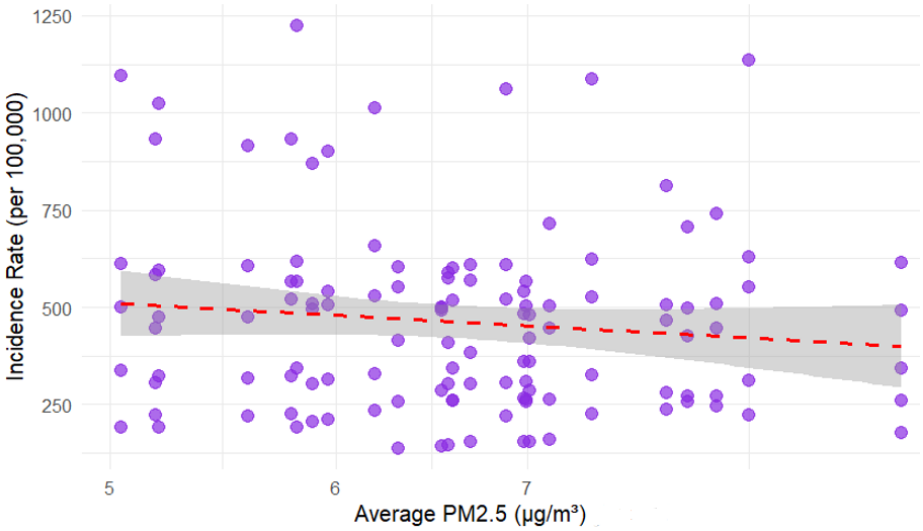

Figure 4. Scattered Plot of PM2.5 and the Incidence Rates of Cardiovascular and Respiratory Conditions in all Provinces (2010-2023)

Discussion

The sociodemographic distribution of this study indicated that the age category of 20+, which accounted for more than 40% of the study population, had the largest number of cases of exposure to wildfire smoke across the five selected provinces. This could be as a result of this age category being an active population that is more engaged in activities that expose them to wildfire smoke, such as bush burning, biomass burning, farming, etc. The sociodemographic gap plays a pivotal role in the formation of health complications, which aligns with previous research [15], revealing that repeated exposure to wildfire PM2.5 could have an adverse effect in the development of respiratory function in children, which suggests that infant exposure to ambient wildfire smoke correlates with significantly reduced lung functions later in adolescence, that is, early exposure to wildfire smoke is associated with immune dysregulation and lung function decrements in adolescence [15].

Across all provinces, the incidence rates of the five major conditions studied, acute myocardial infarction, stroke, asthma, chronic obstructive pulmonary disease (COPD), and heart failure, generally demonstrated a downward trend between 2010 and 2023. COPD consistently exhibited the highest incidence rate, followed by asthma, while myocardial infarction had the lowest. These declines, although varying by condition and province, suggest improvements in disease prevention, diagnosis, and management strategies over time [16]. The findings revealed that the decline was most prominent in COPD and asthma cases, both of which are highly sensitive to environmental triggers such as air pollution and wildfire smoke. The downward trajectory may reflect the cumulative effect of improved public awareness, smoking cessation policies, and healthcare interventions. The slight resurgence in COPD and asthma rates observed in 2022–2023 could, however, indicate renewed exposure to environmental pollutants following severe wildfire events during those years. Similar cyclical patterns have been reported in prior research, emphasizing that periods of intensified wildfire activity often correspond with temporary reversals in respiratory health gains [17, 18].

The analysis of wildfire activity revealed a complex and dynamic pattern across the provinces. Overall, wildfire events exhibited significant inter-annual variability, with both the total area burned and the number of fires fluctuating widely over the study period. Alberta, British Columbia, and Quebec recorded sharp increases in total area burned, particularly in 2023, which marked the most severe wildfire season within the observation window. Saskatchewan, in contrast, experienced a slight decline, while Ontario showed a moderate but steady increase. The findings support earlier observations [19], which emphasized that human activities and climate variability have significantly altered the temporal and spatial patterns of wildfire occurrence. The marked spikes in wildfire activity in 2023 align with documented national wildfire crises that produced transboundary smoke plumes, affecting not only local but also regional air quality. These patterns demonstrate the interplay between environmental, meteorological, and anthropogenic factors in shaping wildfire dynamics across Canada. All provinces demonstrated upward trends in $PM_{2.5}$ concentrations between 2010 and 2023, though with differing magnitudes. Alberta recorded the steepest rise, reaching the highest concentrations in 2023, while British Columbia and Ontario showed moderate increases. Saskatchewan's $PM_{2.5}$ levels nearly doubled within the same period, reflecting its vulnerability to large-scale wildfire smoke exposure. Conversely, Quebec exhibited relatively stable $PM_{2.5}$ levels with only modest increases. The findings further suggested that escalating wildfire activity is a key driver of deteriorating air quality, particularly in provinces with extensive forest coverage and

frequent fires. However, $PM_{2.5}$ levels are also influenced by industrial emissions and meteorological conditions, such as wind direction and temperature inversions, that affect pollutant dispersion. These results align with the conclusions of a previous report [18], which reported that wildfire-related $PM_{2.5}$ exposure varies significantly depending on topography and urban proximity.

High-risk air quality days also showed heterogeneous patterns across provinces. Ontario and British Columbia experienced significant increases in the number of such days, while Alberta and Saskatchewan recorded irregular fluctuations. The strong rise in high-risk days underscores the cumulative impact of recent extreme wildfire seasons. Nevertheless, the weak correlation between wildfire activity and air quality indicators suggests that the intensity and duration of fires, rather than their frequency alone, are more influential in shaping exposure levels [20]. The correlation analyses further showed weak and statistically non-significant associations between wildfire smoke exposure indicators ($PM_{2.5}$ and high-risk air quality days) and the incidence rates of cardiovascular and respiratory diseases. Specifically, the relationship between $PM_{2.5}$ and disease incidence was slightly negative ($r = –0.106$, $p = 0.238$), while the association between high-risk air quality days and incidence rates was also negative but negligible ($r = –0.042$, $p = 0.643$). These findings indicate that short-term variations in wildfire smoke exposure did not correspond to observable increases in annual disease incidence during the study period. This weak correlation suggests that the health impacts of wildfire smoke may be delayed, cumulative, or localized rather than immediately reflected in annual population-level statistics. Such temporal lags between exposure and disease manifestation have been highlighted in an earlier report [21], which agrees that short-term exposures tend to affect acute symptoms more than chronic incidence rates. The results also imply that other factors, such as aging, pre-existing conditions, occupational exposures, and healthcare disparities, may confound or obscure the direct association between wildfire smoke and chronic disease outcomes.

The findings highlight several implications for environmental health governance in Canada. The uneven distribution of wildfire impacts underscores the need for province-specific strategies that consider both environmental vulnerability and population density. While the overall disease incidence has declined, the increasing frequency of high-risk air quality days indicates growing exposure potential, particularly for vulnerable groups such as children, older adults, and individuals with pre-existing respiratory conditions.

The results also suggest that policy emphasis should shift from general surveillance to integrated environmental–health data systems capable of linking specific exposure events to health outcomes in real time. Enhanced predictive modeling using artificial intelligence and satellite-based monitoring could improve early warning systems for wildfire smoke episodes. Moreover, targeted health education, community preparedness, and equitable access to healthcare in remote and local communities remain critical to mitigating long-term impacts.

Future studies should explore the temporal lag effects between wildfire smoke exposure and disease manifestation using finer temporal resolution data (e.g., monthly or weekly). Incorporating meteorological variables, population mobility patterns, and socioeconomic indicators would enhance model precision. Additionally, employing spatial regression or exposure modeling approaches could help delineate localized health impacts more accurately. Such efforts would deepen understanding of the complex interplay between environmental hazards and population health in the context of climate change.

Conclusions

The findings indicate that wildfire smoke exposure, though an important environmental health concern, was not a statistically significant predictor of the incidence of chronic cardiovascular and respiratory diseases across the provinces studied. This does not negate the potential health risks of wildfire smoke but rather underscores the complexity of exposure–disease relationships in population-level data.

The study highlights that health outcomes are influenced by multiple interacting determinants, ranging from biological susceptibility and healthcare access to environmental policies and meteorological factors. The apparent absence of strong statistical associations may reflect data aggregation, temporal lags, and unmeasured confounding. Nonetheless, the evidence supports the need for proactive environmental monitoring and targeted interventions to reduce exposure during high-risk wildfire periods.

Recommendations

1. **Integration of Environmental and Health Data Systems:** Health and environmental agencies should establish interoperable systems linking health surveillance with environmental monitoring data. Such integration would enable the real-time tracking of health effects associated with specific exposure events and facilitate evidence-based interventions.
2. **Equity in Healthcare Access:** Governments should prioritize improving healthcare accessibility among vulnerable and rural populations, particularly Indigenous communities, who may experience disproportionate exposure and limited healthcare infrastructure during wildfire events.
3. **Enhancement of Air Quality Monitoring and Predictive Modeling:** Expansion of air quality monitoring networks and adoption of remote sensing, artificial intelligence, and geospatial modeling can enhance early detection of wildfire smoke and support targeted public health responses.
4. **Public Health Education and Risk Communication:** Health authorities should intensify public education campaigns emphasizing the risks of air pollution and the protective measures that can reduce exposure, including the use of air filtration systems and personal protective equipment.
5. **Investment in Research and Climate Adaptation Strategies:** Further research should focus on longitudinal, individual-level analyses to assess delayed and cumulative health effects of wildfire smoke exposure. Policy frameworks should incorporate climate adaptation measures aimed at mitigating wildfire risks through sustainable land management and urban planning. And also, there is a need for the government to strengthen regulations and implement more stringent guidelines to regulate the emission of this fine particulate (PM2.5).

Conflict of Interest

The authors hereby declare that there is no conflict of interest.

Financial Disclosure

This study has received no financial support.

Data Availability

The data for this study is available on direct request from the authors

Authors' Contribution

- Conceptualization: Chukwubuikem Cornelius Okafor, Afusat Adesina.
- Study Design: Chukwubuikem Cornelius Okafor, Afusat Adesina.
- Definition of intellectual content: Chukwubuikem Cornelius Okafor, Afusat Adesina.

- Literature Search: Chukwubuikem Cornelius Okafor, Afusat Adesina.
- Data Acquisition: Chukwubuikem Cornelius Okafor, Afusat Adesina.
- Data Analysis: Chukwubuikem Cornelius Okafor, Afusat Adesina.
- Manuscript Preparation: Chukwubuikem Cornelius Okafor, Afusat Adesina.
- Manuscript editing: Chukwubuikem Cornelius Okafor, Afusat Adesina.

Acknowledgement

The authors would like to thank the lecturers in the department of public health, Texila American University.

References

[1]. Franchini, M., & Mannucci, P. M., 2012, Air pollution and cardiovascular disease. *Thrombosis Research.* 129(3), 230–234. https://doi.org/10.1016/j.thromres.2011.10.030.

[2]. Canadian Interagency Forest Fire Centre. 2024, *Annual report 2024.* https://ciffc.ca.

[3]. Delaney, E. J., 2023, The chemistry of fires at the wildland–urban interface. *CHOICE: Current Reviews for Academic Libraries,* 60(10), 1014–1015.

[4]. United States Environmental Protection Agency, 2024, *Particulate matter (PM) basics.* https://www.epa.gov/pm-pollution.

[5]. Seinfeld, J. H., & Pandis, S. N., 1998, Atmospheric chemistry and physics: From air pollution to climate change (2nd ed.). *John Wiley & Sons.*

[6]. Liu, J. C., Pereira, G., Uhl, S. A., Bravo, M. A., & Bell, M. L., 2015, A systematic review of the physical health impacts from non-occupational exposure to wildfire smoke. *Environmental Research,* 136, 120–132. https://doi.org/10.1016/j.envres.2014.10.015.

[7]. Brook, R. D., Rajagopalan, S., Pope, C. A., Brook, J. R., Bhatnagar, A., Diez-Roux, A. V., et al., 2010, Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. *Circulation,* 121(21), 2331–2378. https://doi.org/10.1161/CIR.0b013e3181dbece.

[8]. Jones, C. G., Rappold, A. G., Vargo, J., Cascio, W. E., Kharrazi, M., McNally, B., et al., 2020, Out-of-hospital cardiac arrests and wildfire-related particulate matter during 2015–2017 California wildfires. *Journal of the American Heart Association,* 9(8), e014125. https://doi.org/10.1161/JAHA.119.014125

[9]. Jain, P., Barber, Q. E., Taylor, S. W., Whitman, E., Castellanos Acuna, D., Boulanger, Y., et al., 2024, Drivers and impacts of the record-breaking 2023 wildfire season in Canada. *Nature Communications, 15,* 6764. https://doi.org/10.1038/s41467-024-51154-7

[10]. Reid, P. T., & Innes, J. A., 2014, Respiratory diseases. In B. R. Walker, N. R. Colledge, S. H. Ralston, & I. Penman (Eds.), Davidson's principles and practice of medicine (22nd ed., pp. 661–730). *Elsevier.*

[11]. Canadian Wildland Fire Information System. (n.d.). *Data Mart.* https://cwfis.cfs.nrcan.gc.ca/datamart

[12]. [Canadian Wildland Fire Information System. (n.d.). NBAC Downloads. https://cwfis.cfs.nrcan.gc.ca/downloads/nbac/

[13]. Environment and Climate Change Canada. (n.d.). *Air quality indicators.* https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/air-quality.html

[14]. Public Health Agency of Canada. (n.d.). Chronic Disease and Surveillance System (CCDSS) data tool. https://health-infobase.canada.ca/ccdss/data-tool/

[15]. Black, C., Gerriets, J. E., Fontaine, J. H., Harper, R. W., Kenyon, N. J., Tablin, F., et al., 2017, Early life wildfire smoke exposure is associated with immune dysregulation and lung function decrements in adolescence. *American Journal of Respiratory Cell and Molecular Biology,* 56(5), 657–666. https://doi.org/10.1165/rcmb.2016-0380OC.

[16]. Haydon, E., Roerecke, M., Giesbrecht, N., Rehm, J., & Kobus-Matthews, M., 2006, Chronic disease in Ontario and Canada: Determinants, risk factors and prevention priorities. *Ontario Chronic Disease Prevention Alliance*.

[17]. Dai, H., Younis, A., Kong, J. D., Bragazzi, N. L., and Wu, J., 2021, Wildfire smoke exposure and health outcomes: A review. *Environmental Research*, 198, 111239. https://doi.org/10.1016/j.envres.2021.111239

[18]. Yu, M., Zhang, S., Ning, H., Li, Z., & Zhang, K., 2024, Assessing the 2023 Canadian wildfire smoke impact in the Northeastern US: Air quality, exposure, and environmental justice. *Science of the Total Environment*, 926, 171853. https://doi.org/10.1016/j.scitotenv.2024.171853

[19]. Campos-Ruiz, R., Parisien, M. A., & Flannigan, M. D., 2018, Temporal patterns of wildfire activity in areas of contrasting human influence in the Canadian boreal forest. *Forests*, 9(4), 159. https://doi.org/10.3390/f9040159

[20]. Renouf, R., 2021, Vancouver's air quality worst of any 'major city' in the world due to wildfire smoke, heat. *CityNews*. https://vancouver.citynews.ca/2021/08/13/vancouver-air-quality-wqorst-wildifres/

[21]. Henderson, S. B., Brauer, M., & Vedanthan, R., 2022, Wildfire smoke as a global health issue. *The Lancet Planetary Health*, 6(4), e302–e313. https://doi.org/10.1016/S2542-5196(22)00044-0.