Halifax Residential Air Quality: Public Perceptions and $PM_{2.5}$ Concentrations

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Abstract

Residents of Halifax's North End have raised concerns over air quality in their neighbourhood. Exposure to elevated levels of airborne particulate matter pose serious risks to human health and increases strain on local healthcare systems. This study sought to quantify local concentrations of $PM_{2.5}$ and compare them to Canadian Ambient Air Quality Standards (CAAQS). Additionally, it aimed to understand public perceptions of air quality and sources of pollution within their neighborhood. $PM_{2.5}$ concentrations were collected remotely from the 2600 block of Agricola Street from November 2022 and November 2023. A total of 276 usable days were recorded. The observed 24-hour 98th percentile $PM_{2.5}$ average is 50.1 µg/m^3 and the annual average is 12.6 µg/m^3. Averages exceeded the highest CAAQS threshold of both 24-hour and annual averages. Daily trends showed that the highest concentrations occurred between 8 am and 6 pm on weekdays and showed no variation from the downtown control site on weekends. The highest $PM_{2.5}$ concentrations were recorded in the presence of northwesterly winds. A local butcher shop and meat smoker to the northwest of the study site, was identified as a likely source of the local elevated air pollution A self-selecting, online survey was circulated by mail flyer and email. People who live or work within a 200 m radius of the air quality sensor were eligible to participate. Participants were asked to rate their perception of local air quality trends, level of concern, and perceived sources of pollution. Based on census population density, it is estimated that 900 respondents lived within the study area. Survey results were based upon 61 usable responses. Respondents to the survey confirmed that they perceived the nearby meat smoking operation to be one of the top three sources of air pollution within their community. *A Posteriori* coding of open-ended questions yielded numerous sentiments of frustration and reduced quality of life due to local air pollution. However, most respondents indicated that they perceived air quality to be at least acceptable. Regardless of perception, long-term exposure to elevated $PM_{2.5}$ levels pose health risks to the public in the immediate vicinity; especially seniors, children, and those with pre-existing medical conditions.

Key words: Halifax, $PM_{2.5}$, Low-Cost Sensor, Air Quality, Residential

List of Abbreviations

CAAQS	Canadian Ambient Air Quality Standards
CCME	Canadian Council of Ministers for the Environment
GDAD	Guidance Document for Achievement Determination
$PM_{2.5}$	Particulate Matter Under 2.5 microns
TEOM	Tapered Element Oscillating Microbalance
WHO	World Health Organization

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Introduction

Residents of Halifax's North End have raised concerns regarding air quality in their community. Exposure to fine particulate matter has been linked to acute and chronic health concerns, including cardiovascular disease, respiratory illnesses, metabolic syndrome, and shortened life expectancy (Krittanawong et al., 2023; Li et al., 2023; Manisalidis et al., 2020). These risks are heightened for vulnerable populations such as children, seniors, people who are pregnant, and individuals with pre-existing medical conditions (Xia & Yao, 2019; Kloog et al., 2012; Crouse et al., 2015). Beyond health impacts, elevated levels of $PM_{2.5}$ can impede quality of life by forcing residents to alter daily routines and by preventing enjoyment of the outdoors (Ścibor et al., 2019). Nova Scotia is currently facing a healthcare crisis with severe staff shortages causing significant delays in patient care (Nova Scotia, 2023). Addressing the air quality concerns of residents in Halifax could alleviate health symptoms and lessen economic costs and staffing burdens associated with patient treatment. This research aimed to characterize fine particulate matter ($PM_{2.5}$) concentrations and explore public perceptions of air quality in a hyperlocal neighborhood setting.

This research aimed to answer the following research questions:

1) In Halifax's North End, do measured levels of $PM_{2.5}$ exceed Canadian Ambient Air Quality Standards?
2) What is the perception of air quality of North End Residents?

The North End is a mixed use industrial and residential area. It is a mosaic of single and multi-unit homes, businesses, and commercial lots. It is bordered by numerous local and arterial roads. Residents in the area have reported visible smoke, smog, and strong smells. These issues are often found in areas with high concentrations of $PM_{2.5}$ (Jeensorn et al., 2018).

Particulate matter (PM) is liquid or solid particles that are suspended in the air (California Air Resource Board, 2024). These fine particles are produced either through primary emissions, where they enter the air directly from a source, or formed through secondary formation in which they result from reactions of chemicals already in the air (California Air Resource Board, 2024). Particles can have a range of chemical compositions depending on their source of origin. The primary components of PM are elemental carbon, organic carbon, ammonium, sulfate, and nitrate (Dominici et al, 2015). Rather than chemical composition, PM is classified by the diameter of particles measured in micrometers. 10 µm and 2.5 µm are the most common size classifications used in discussing particulate matter. However, due to its small diameter and ability to be inhaled deep into lung tissue, $PM_{2.5}$ has become the primary focus of contemporary research.

$PM_{2.5}$ is roughly 1/30th the width of a human hair and is small enough to pass through the alveoli of human lungs and enter the bloodstream (Olesiejuk & Chałubiński, 2022). As part of the bloodstream, particles are able to travel throughout the body, causing interruptions in organ function and damage to cell structures (Feng et al., 2016). Recent research has shown that $PM_{2.5}$ is able to pass through the blood-brain barrier (Li et al., 2022). Respiratory infections, cardiovascular disease, and mortality have all been linked to $PM_{2.5}$ exposure (Krittanawong et al, 2023; Zhang et al, 2019; Zhang et al., 2017). An increase in 10 $\mu g/m^3$ in annual averages has been associated with a 5% increase in all-cause mortality (Wang et al., 2020). The World Health Organization has named air pollution as the most significant environmental threat to human health (World Health Organization, 2021). In 2022, WHO reduced its annual average and 24-hour exposure limits to 5 $\mu g/m^3$ and 15 $\mu g/m^3$ respectively (World Health Organization, 2021). These new limits are half of what had been set in the 2006 WHO Air Quality Guidelines.

The severity of $PM_{2.5}$ exposure on health also has implications on healthcare systems. For example, an increase in $PM_{2.5}$ concentrations of 10 $\mu g/m^3$ has been shown to increase ER admissions of children with acute lower respiratory illness by 4.3% (Xia and Yao, 2019). Nova Scotia is currently facing a healthcare crisis. According to the 2023 Annual Accountability Report, emergency room wait times increased by 33.3% from the previous year (Nova Scotia, 2023). This is due, in part, to the decrease in the number of operating emergency departments in the province. By identifying areas of elevated $PM_{2.5}$ and sources with preventable or reducible emissions, mitigating actions can be taken to prevent health concerns from arising and eliminate undue pressure on the Nova Scotia healthcare system.

This research aimed to provide clarity on how air quality in Halifax's North End compares to the Canadian Ambient Air Quality Standards. While monitoring is conducted at provincial ambient air quality monitoring stations, it may not provide an accurate picture of air quality at a more granular scale. By providing residents with hyperlocal data on the air quality in the neighbourhood, they are empowered to make informed choice regarding the health of themselves and their families.

Literature Review

This literature review outlines the current body of research that has been conducted on the nature of $PM_{2.5}$ in Canadian urban settings, methods of monitoring, and public perceptions of air quality. The literature reviewed in this section was sourced through the National Institute of Health, California Air Resource Board Research Contracts Search Tool, and Novanet database. As awareness, concern, and technological abilities regarding particulate matter are continuously evolving, literature was limited to publications made within the last twenty years. Search terms included air pollution, air quality, health impacts, low-cost sensor/monitor, public perception, particulate matter, $PM_{2.5}$, quality of life, and spatial/temporal variability. Documents on air pollution and particulate matter published by Canadian federal and provincial health and environmental authorities, such as Canadian Council of Ministers for the Environment, Environment and Climate Change Canada, and Nova Scotia's Department of Environmental and Climate Change, were reviewed prior to the literature review to understand current nation air quality and policies which influence air pollution. Priority was given to studies conducted in Canada and the United States which involve similar params to this study but was expanded globally as the impact of $PM_{2.5}$ has been heavily studied in countries such as China and India (eg. Li et al., 2023; Sekar et al., 2023; Xia & Yao, 2019).

Urban Indoor and Outdoor Sources of $PM_{2.5}$

Increased population and building density in urban centers can create pockets of high $PM_{2.5}$ concentrations (Li et al., 2019). In urban settings road use, domestic combustion, and construction are the primary sources of $PM_{2.5}$. Traffic related air pollution was found to be responsible for 30% of ambient $PM_{2.5}$ in Toronto, Canada (Brook et al., 2007). $PM_{2.5}$ from vehicle use is generated by exhaust fumes, particularly diesel combustion engines, as well as deterioration of brake pads, tires, and resuspension of road dust (Dabek-Zlotorzynska et al., 2019). Construction sites are ranked as the second largest source of $PM_{2.5}$ nationally (Environment and Climate Change Canada, 2023a). The movement of earth and laying of building's foundations increase downwind 24-hour averages by10 $\mu g/m^3$ (Yan et al., 2023).

$PM_{2.5}$ is also generated in indoor environments which contributes to both indoor and outdoor concentrations (Martins & Carrilho da Graça, 2023). Nova Scotia has the third highest emissions of residential wood burning of any Canadian province. Heating and cooking with wood produces 5,565 tonnes of $PM_{2.5}$ emission annually (Environment and Climate Change Canada, 2023a). Fireplaces and standard woodstoves, which do not have channels to admit outside air, produce 58.0 mg and 21.6 mg of $PM_{2.5}$ per kg of firewood burned (Martins & Carrilho da Graça, 2023). Amongst the residential buildings of the North End are several well known breweries. During the grain drying process, approximately 46 mg $PM_{2.5}$ is emitted per kg of dry grain produced. (Environment and Climate Change Canada, 2023a). Additionally, breweries are a significant source of volatile organic compounds, especially during the bottling process. For every 10,000 hl of beer bottled, 154.614 kg VOCs are produced (Environment and Climate Change Canada, 2023a). VOCs are of interest in the study of $PM_{2.5}$ as they facilitate the secondary formation of particulate matter through the creation of secondary organic aerosols (Pye, 2021).

In Canada, people spend 67% to 73% of the time inside their own homes regardless of season (Matz et al., 2014). Without proper mechanical ventilation systems, outdoor $PM_{2.5}$ freely enters indoor environments through windows, natural ventilation, and unintended cracks or openings (Martins & Carrilho da Graça, 2023). Between indoor sources, and the infiltration of outdoor emissions, indoor $PM_{2.5}$ concentrations can exceed that of the surrounding outdoor areas (Martins & Carrilho da Graça, 2023). This means that indoor air quality can be worse than the ambient outdoor air quality in urban settings.

Spatial Variation in $PM_{2.5}$

Given the airborne nature of $PM_{2.5}$, it is subject to topographic and meteorological influences which affect its spatial distribution. Strong winds can carry particulate great distances (Zhang et al., 2017). This is especially true in coastal areas, such as Halifax, with high winds coming from fluctuations in ocean temperatures. Precipitation weighs down particulate matter and prevents future resuspension by washing it away (Cheng et al., 2015). Mountainous regions impede $PM_{2.5}$ flow through the physical barrier against winds, as well as higher rate precipitation due to elevation (Chow et al., 2006). In urban settings, tall buildings can create a similar canyon affect which channels the flow of PM. This can expediate or prevent its removal out of the area by wind (Mei et al., 2018).

Methods and Correction in Measuring $PM_{2.5}$ Concentrations

Measurement $PM_{2.5}$ of can be accomplished using several different methods. Regardless of the monitoring style used, measurements can be affected by unstable temperatures and high air moisture contents (Undavalli et Khandelwal, 2021). One method of measurement, gravimetric monitoring, uses filters to collect $PM_{2.5}$ and measures the change in weight to determine air pollutant concentrations. This is a widely used methods as it requires little training. However, in low-cost gravimetric systems, constant handling and physical monitoring of the site is needed to take continual measurements (Undavalli et Khandelwal, 2021). Near-real time monitoring can be achieved by gravimetric systems which employ tapered element oscillating microbalances (TEOM) technology which uses the frequency of magnetic oscillations to calculate the weight of the filter (Thermo Fisher Scientific Inc., 2024). This increases precision and minimizes handling, but TEOM technology is more expensive with each unit costing several thousand dollars CAD.

An alternative method of monitoring employs nephelometer systems. Nephelometers measure aerosol light scattering and calculate the aerosol mass concentrations from these measurements (Tryner et al., 2019). This monitor style has low associated costs and does not need physical monitoring as the measurements can be stored or uploaded remotely via Wi-fi. The nephelometer monitor used in this study, developed by Purple Air, has been shown to be an effective tool in measuring $PM_{2.5}$ concentrations in city environments (Delong-Maxey, 2022). Concerns of measurement accuracy in low-cost sensors are minimized through the use of corrective calculations (Nilson et al., 2022).

Perceptions of Air Quality By Demographic

While there is clear evidence that exposure to air pollutants can have numerous negative consequences to human health, the perception of poor air quality does not always lead to an increase in concern for one's personal health. In their study of the metropolitan area of Kansas City, USA, Reames and Bravo (2019) found no observed relationship between the level of air pollution and air quality perception or concern for one's health. Pignocchino et al. (2023) found differing results in a study of air quality perceptions in Italy and Sweden where the perceived levels of air pollution, and associated concerns for health impacts, increased when air pollution was experienced. Attitudes towards air quality can be influenced by age, education level, and health status of themselves and their children (Guo et al., 2016).

Methodology

Study and Control Sites

The North End air quality monitor, now referred to as the study site, was installed in the 2600 block of Belle Aire Terrace in Halifax. From the 2021 Canada Census, the population density of the area is 3,607.4 people/km^2 (Statistics Canada, 2021).

This site is contained within Nova Scotia's Central Air Zone. This air zone had two provincial ambient air quality monitoring stations. The Johnston Building location is in Halifax's downtown core at 1672 Granville St and is 2 km southeast from the study site location. The second monitoring station, Major Lake, is approximately 12 km east of the study site on the Dartmouth side. The Johnston Building Station was chosen as a control site due to its proximity to the study area and its similarities in population density and traffic patterns.

$PM_{2.5}$ Concentration Data

The monitor used to collect $PM_{2.5}$ concentrations was a *Purple Air Classics Style* model. This model has a base area of 72.25 cm^2 and is 12.5 cm tall. It is powered using a 5 V USB Micro and requires 0.18 Amps of continuous power (Purple Air, 2024). It was mounted approximately 1.5 m off the ground in a residential back yard. $PM_{2.5}$ concentrations were recorded every ten minutes using a dual laser nephelometer system. The station was dependent on uninterrupted wi-fi access as the monitor cannot store values internally. Recordings were uploaded via wi-fi to the Purple Air database where it was compiled and made available from the University of Northern British Columbia via the Cyclone UNBC air quality database.

The study site data were cleaned for any missing values, and days with less than 108 entries were removed. This was done in accordance with the CAAQS calculation guidelines in which each day must have at least 18 hours of recorded concentrations to produce 24-hour averages (Canadian Council of Ministers for The Environment, 2019). The Nova Scotia Tantalon Fire, which occurred between May 28th and June 4th, 2023, was located approximately 24 km away from the study site and was deemed to be an exceptional event which could influence ambient air quality results. The associated dates were removed before calculations occurred. All preliminary cleaning of data was done using Microsoft Excel.

The control site dataset was downloaded from the Nova Scotia Environment and Climate Change Ambient Air Quality Data website (Nova Scotia Environment and Climate Change, 2024). This data set had not yet been validated by the Department of Environment and Climate Change and was not yet available through Nova Scotia's Open

Data Portal. Due to construction, the Johnston Building station was offline from 11:00 April 17, 2023, and 17:00 July 21, 2023. Data for this period were supplemented from the Major Lake Station. Concentrations were provided in hourly values, where each timestamp was representative of the following hour (eg. 6:00 represents 6:00 to 6:59).

Statistical analysis of the dataset was compled using Rstudio package Dplyr (Wickham et al., 2023), Tidyverse (Wickham et al., 2019), Lubridate (Grolemund et Wickham., 2011), Ggplot(Wickham, 2016), and Openair (Carslaw et Ropkins, 2012).Hourly averages were analysed for temporal variations. Timestamps were changed into recognizable time variables using the as.POSIXct function. The time stamps of the study site were recorded in UTC was adjusted to AST to match the control data set. Each timestamp was rounded down to its corresponding hour (eg. 10:40 to 10:00). Months were extracted from this time variable. Monthly averages were calculated by $PM_{2.5}$ values by month and then grouping hourly blocks. Dates were separated into days of the week using the weekday function and then hourly averages were grouped for each unique day. Concentrations for each day were then plotted using ggplot().

Hourly blocks were categorized as either daytime (8 am to 8 pm) and nighttime (7 pm to 7 am). T tests were performed to compare daytime and nighttime hours independently between the two monitoring sites. The null hypothesis was that there was no difference between average $PM_{2.5}$ concentrations recorded at each site in either the daytime or nighttime period. The alternative hypothesis was that there was a significant difference between sites for either period. T tests and confidence intervals were completed at alpha = 0.05.

Local Wind Data

To understand movement of $PM_{2.5}$ within the study area, local wind direction, speed and frequency were investigated. Wind data collected at the Halifax Windsor Park Station were provided by the Climate Atlantic division of Environment and Climate Change Canada. This weather station is approximately 1.5 km from the study site monitor.

Wind direction and speed data were provided for each hour over the study period. Some values were not available due to missing flag readings. Hours with missing values were removed from the provided dataset. Wind direction was provided in angle degrees between 0 ^{o} and 359^{o}, with 0^{o} indicating north. The wind direction indicates the direction from which the wind originates.

Windroses were created using Rstudio Openair package (Carslaw et Ropkins, 2012). Daytime, nighttime, and monthly wind roses were created to visualize the temporal pattern of wind direction. Pollution roses of annual daily $PM_{2.5}$ averages was created, as were pollution roses by day of the week.

Canadian Ambient Air Quality Standards calculations

To compare $PM_{2.5}$ concentrations with CAAQS, the daily 24-hour average concentrations and the 98th percentile of the daily 24-hour average concentration were calculated following the equations given in the *Guidance Document on Achievement Determination Canadian Ambient Air Quality Standard for Fine Particulate Matter and Ozone* (GDAD) (Canadian Council of Ministers for the Environment, 2012). These equations are given as follows:

$$daily\ 24hr\ PM_{2.5} = \frac{x_1 + x_2 + x_3 + \cdots x_n}{N}$$

where, X_i is the hourly $PM_{2.5}$ concentration in μg/m^3 and N is the number of 1-hour $PM_{2.5}$ concentrations in the given day.

To find the 98th percentile, the GDAD suggests finding the observation in which 98% of the daily 24hr $PM_{2.5}$ fall above and then subtracting this from N to achieve the observation in which only 2% falls above. This is given as follows:

$$observation\ \# \ = \ 0.98 * N$$

$$98P = N - observation\ \#(rounded\ to\ nearest\ whole\ number)$$

where, observation # is the number of observations in descending concentration value. The 98Pth observation will give the 98th percentile concentration.

Public Perception Survey

A self-selection survey on public perceptions of air quality was circulated to residents within a 200 m radius of the study station. This covers approximately 0.25 km^2. Both residents and people who work within the area were invited to respond.

The survey included 15 questions (Appendix B) and was available to participants via Dalhousie's online survey platform, Opinio. The survey included questions about perception of recent air quality, perception of primary emitters, personal concerns, as well as demographic information. Questions regarding perceptions, concern, and nuisance were answered using Likert scales. Participants were offered the opportunity to enter a draw for one of five $20CAD gift card as an incentive to participate.

The survey followed a cross-sectional methodology, in which a sample of residents within the area of interest was polled once to understand current perceptions of air quality. Potential participants were notified by printed flyers (Figure A1) which were delivered to businesses and households. A total of 400 flyers were distributed over the course of 3 weeks. Flyers were delivered on foot by the research team and left in accessible mailboxes. Additionally, the survey was circulated via email and social media (Figure A2). Two emails were sent out approximately two weeks apart to a list of known residents who were concerned about local air quality. It is believed that the survey was also independently circulated by residents on personal social media accounts.

A text box provided to list perceived primary emitters. Text responses were analysed using qualitative coding. *A Priori* coding was used to tally sources of pollution listed by respondents. Emitter types were used as primary codes: Industry, Construction, Vehicle, Residential, and Environment. These codes were based of the primary sources of $PM_{2.5}$ in Canada as outline in the literature review. Subcodes were created for specific sources mentioned under the umbrella codes. One tally was added to a code if it was mentioned in a participant's response. One tally was added to each subcode mentioned. For example, if a respondent stated industry as a primary source of pollution and listed three specific examples, one count would be added to industry code and one count would be added to each of the specific subcodes. Therefore, the total count of umbrella codes may not be equal to the sum of their subcodes.

A Posteriori coding was used to code sentiments, concerns, and other themes which arose within the open-ended responses. Each response was read and coded to indicate the underlying concern raised by the respondent. A primary and secondary reading of each response was completed to ensure that accurate coding was completed.

Results

Canadian Ambient Air Quality Standards

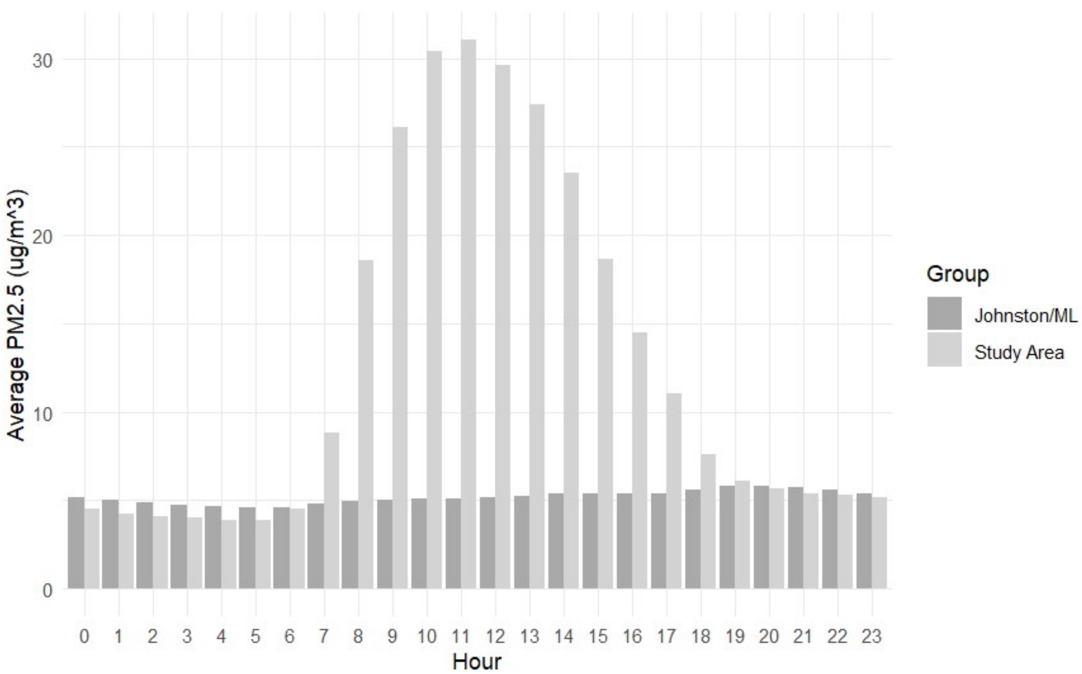
The calculated 24-hour average of the study site was 12.6 μg/m^3. The annual 98th percentile of the daily 24-hour average concentrations was 50.3 μg/m^3. The 24-hour average and 98th percentile thresholds for the CAAQS "red" management level are 8.8 μg/m^3 and 27 μg/m^3 respectively.

Characteristics of $PM_{2.5}$ Concentrations

The average hourly mean of the study site exceeded that of the control site in 12 of the one-hour intervals at alpha = 0.05. The remaining 12 hours showed no difference in mean concentrations between the two sites within 95% certainty (Table B1). Exceedance took place between 8 am and 6 pm inclusively. Figure 1 shows a side-by-side comparison of the hourly averages found in each dataset. Concentrations at the study site reach the highest averages between 11 am and 12 pm. This average exceeds 30.0 μg/m^3.

Figure 1

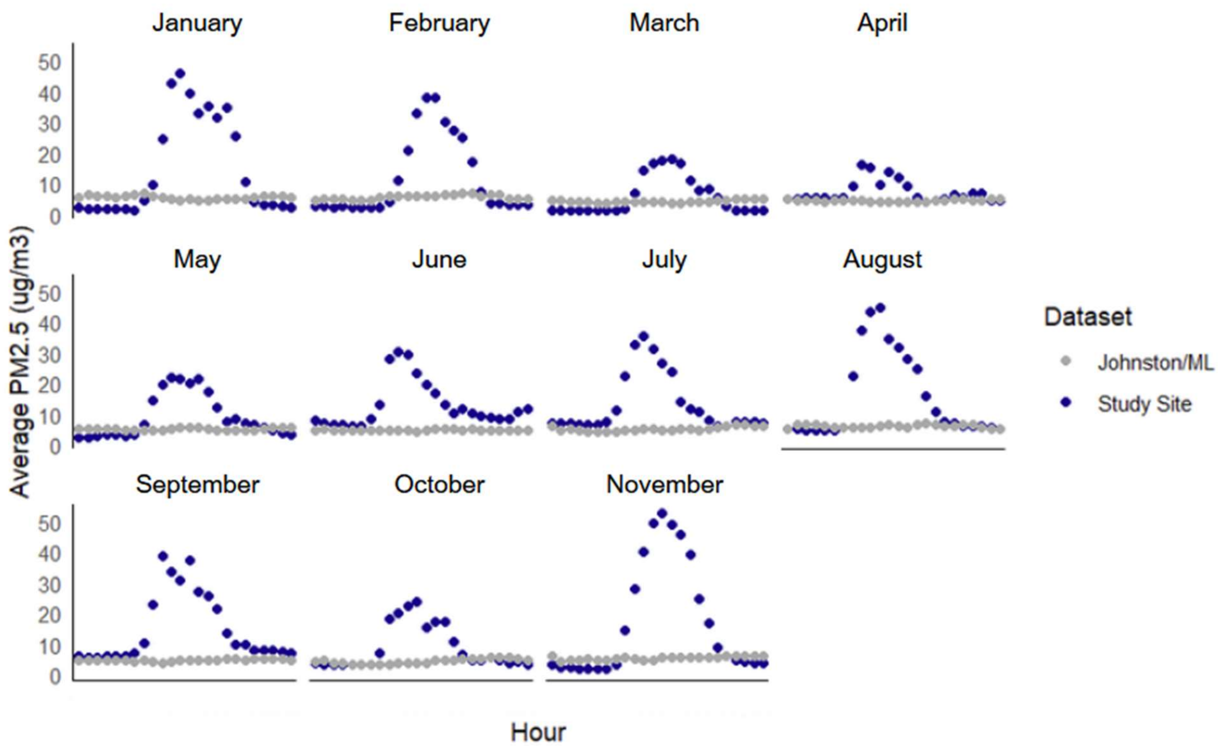
Hourly $PM_{2.5}$ Averages of Study Site and Johnston/Major Lake Stations



Peak concentrations between 8 am and 6 pm were found in every month as seen in Figure 2. Descriptive statistics of hourly concentrations of $PM_{2.5}$ for both the study site and control site for daytime and nighttime in each month can be found in Table E2. In all months, hourly concentrations are significantly greater at the study site during daytime hours than the control site at alpha = 0.05, Evening hours (7 am to 7 pm) appear to be roughly equal between the two sites. There was a mix of three months with no significant difference between sites during evening hours, four months with higher concentrations at the study site and four months higher concentrations found at the control site. The highest estimated difference at a 95% confidence during evening hours was found to be 5.5 μg/m³ during the month of June. Daily peak concentrations decreased in March, April and May, but maintained the concentration distinction between daytime and nighttime.

Figure 2

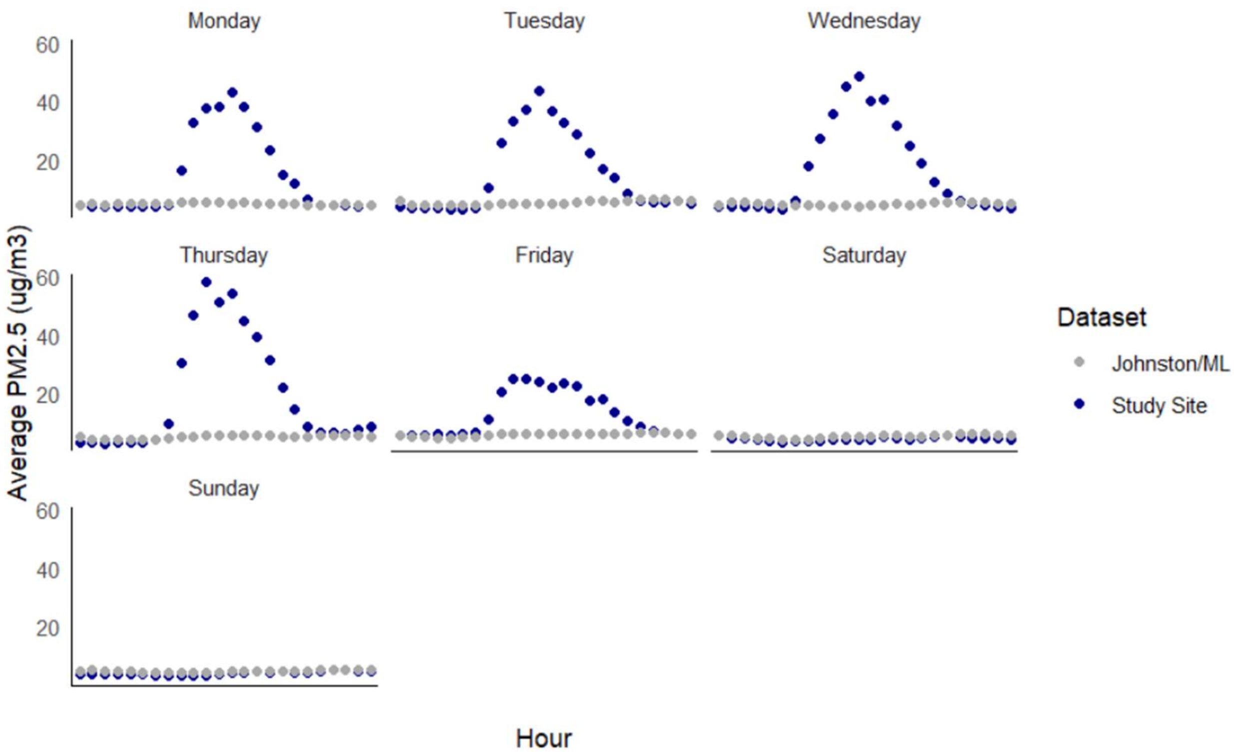
Hourly $PM_{2.5}$ Averages by Month for Study Site and Johnston/Major Lake Station



Weekdays (Monday to Friday) see the same daytime trend that was seen in each of the months (Figure 3). Daily averages exceed 45 μg/m³ Monday through Thursday. Thursday peak averages reach 60 μg/m³. Friday averages see a slight decrease in concentrations at the study site with average midday peaks reaching only approximately 30 μg/m³. During weekends (Saturday and Sunday), concentrations trends at the study site show no daytime peak. The control site sees no significant fluctuation in concentrations in any day of the week. Control site concentrations remain at approximately 5 μg/m³.

Figure 3

Hourly $PM_{2.5}$ Averages by Day of the Week for Study Site and Johnston/Major Lake Station



Local Wind Influences

Wind characteristics from the Windsor Park weather station, as displayed in Figure 4, show that almost 70% of study site wind comes from the north, northwest, and southwest directions. Northwesterly wind was the most frequent. Most wind blows between 2.5 m/s and 5 m/s, with the highest wind speeds reaching 10 m/s. Southeasterly winds saw the highest frequencies of top wind speeds. Wind characteristics did not vary greatly between day and night as seen in Figure 5. Slight variation was seen as daytime winds increase from the southeasterly direction while northly winds decrease.

Figure 4

Average Wind Direction, Speed, and Frequency Over Entire Study Period

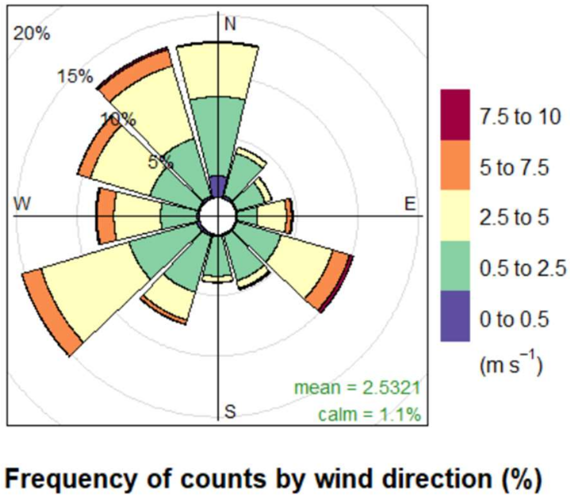
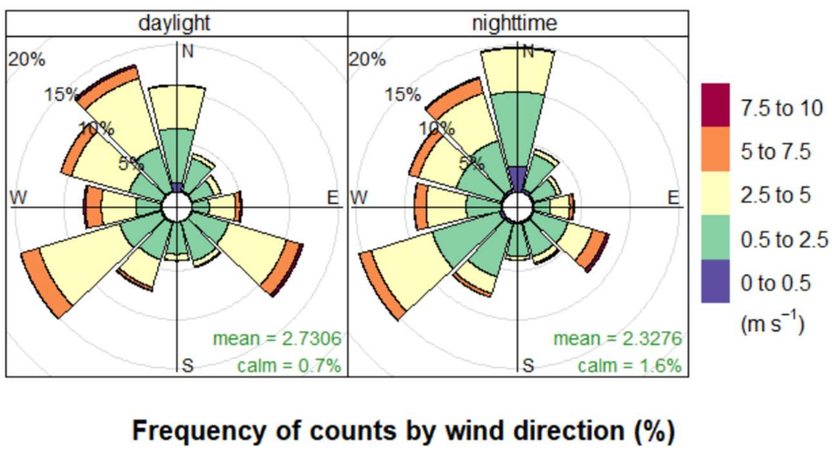


Figure 5

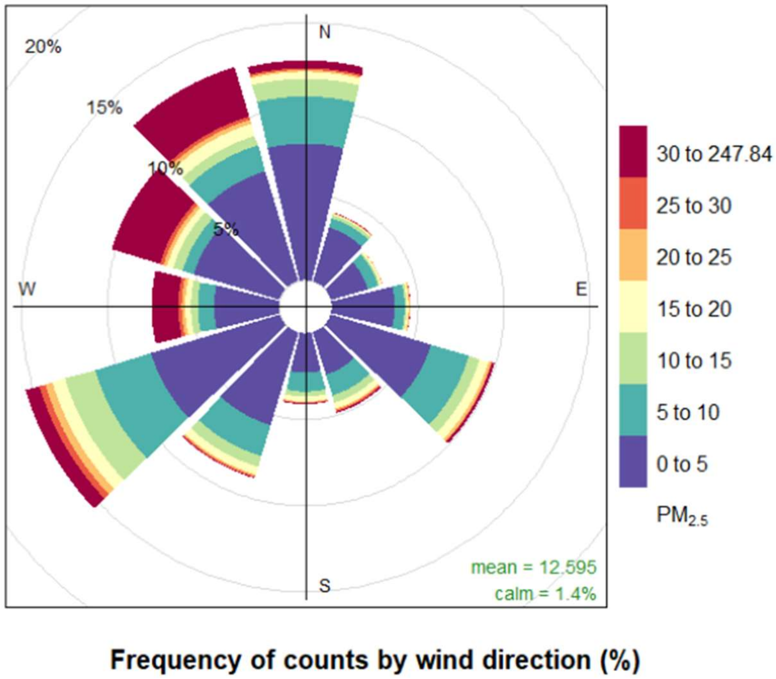
Average Wind Direction, Speed, and Frequency by Daytime and Nighttime



Observed $PM_{2.5}$ concentrations are compared to wind directions in the pollution rose in Figure 6. $PM_{2.5}$ concentrations above 30 μg/m^3 were most frequently recorded at the study site when wind was blowing from the northwesterly and westerly direction. The relationship between northwesterly wind and elevated concentrations of $PM_{2.5}$ was seen in every weekday (Figure 7), regardless of the frequency of winds from that direction. This relationship was not observed on weekends. Negligible concentrations above 30 μg/m^3 are recorded from the northwesterly direction on Saturday or Sunday. Less than 1% of concentrations recorded on weekend days exceeded 30 μg/m^3 regardless of wind direction.

Figure 6

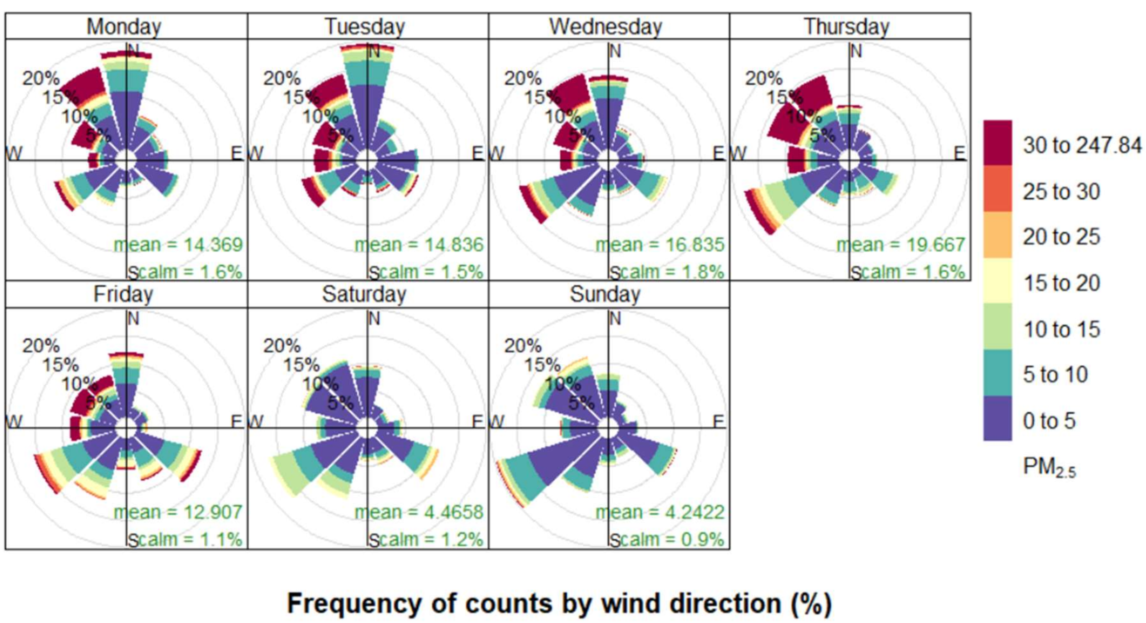
Wind Direction, Frequency, and Associated $PM_{2.5}$ Concentrations



Note. $PM_{2.5}$ concentrations are in μg/m³.

Figure 7

Wind Direction, Frequency, and Associated $PM_{2.5}$ Concentrations by Day of Week



Note. $PM_{2.5}$ concentrations are in μg/m³

Air Quality Perception Results

The survey was accessed 79 times. A total of 60 usable responses were included in the survey analysis. Survey responses were disqualified if no questions were answered beyond the ethics confirmation and the age confirmation. The tallied results from each question are listed in Appendix D. The average age of participants was 46 (+/- 14.6 years) with respondent age ranging between 22 and 80 years old. 39 participants responded that over the last year they perceived air quality to be at least acceptable in their neighbourhood. However, 37 respondents indicated that they perceived daily fluctuations in air quality at least sometimes. Only 25 respondents reported that they were moderately, very, or extremely bothered by the quality of the air. However, 33 respondents reported that they were at least moderately worried about the impact of air quality on their health. A total of 18% of respondents stated that they have previously raised their concerns for air quality to municipal or provincial authorities.

Participants were asked to write the top three sources of pollution they perceived to influence air quality in their neighbourhood. Many participants went beyond only listing three sources and included insights into other factors which exacerbate pollution, their feelings towards the perceived polluters, how air quality has impacted their quality of life and mitigation actions they have taken. The results from this survey question were analyzed both using *A Priori* coding, which solely identified listed sources of pollution, and *A Posteriori* coding, which accounted for overall sentiments, concerns, and actions listed by participants.

Table 1 displays the rate of mention of each source of pollution. The majority of the respondents indicated that industry, such as local businesses or manufacturers, were among the primary sources of polluters. A local meat smoking business, known for using wood burning to in their operations, was named directly by most participants who listed industry as a cause. Woodburning was also mentioned as a residential cause by a few participants. Within the responses coded as 'Industry,' a nearby major commercial brewery site was another business which was specifically named. Additionally, vehicles were listed by most participants. Increasing traffic congestion was specifically mentioned by many participants who identified vehicles as a primary source.

Table 1

Primary Sources of Air Pollution Named by Residents

Code	Subcode	Rate	Code	Subcode	Total
Industry		0.73	Vehicles		0.57
	Meat Smoking	0.52		Traffic Congestion	0.30
	Commercial Brewery	0.32		Transport Trucks	0.05
	Power site	0.08		Idling	0.02
	Coffee Roaster	0.05			
	Crematorium	0.02			
	Gas Station	0.02			
Environment		0.13	Construction		0.17
	Wildfire	0.17		Dust	0.07
	Lack of Trees	0.03			
Residential		0.05			
	Smoking	0.03			
	Woodburning	0.02			

The *A Posteriori* results uncovered more nuance in how air quality impacted the lives of residents. Many participants cited a persistent bad smell in the area. Some were unsure if bad smells constitute air pollution, but named breweries, woodburning, and gas stations as sources. Notably, many responses included strong feelings of frustration and angering regarding the state of the air quality in and around the homes and places of work. Participant #41 stated that they “had to purchase air filtration appliances to try to mitigate the situation, and [...] have decided to sell and move due to this unresolved issue.” The issue of emissions entering homes was echoed by several participants with some even recounting health impacts such as headaches, nausea, and worsening respiratory conditions. Participant 7 wrote:

> We can see the smoke coming from their stacks and wafting through our yard. We have to stay inside and close all of the windows. We get headaches outside and can't use our backyard. We get headaches inside if the windows in the back of the house are open. We can't dry clothes on the laundry line because they smell like campfire.

The *A Posteriori* results show that this issue evokes sentiments of anger, frustration, and dismay for the loss of quality of life and personal impacts caused by local air pollution.

Discussion

In collecting $PM_{2.5}$ and public perception data, this study sought to provide insight into the ambient air quality of a single neighborhood in Halifax's North End. By analysing both qualitive survey responses and quantitative $PM_{2.5}$ concentrations, local sources of air pollution identified by residents were corroborated using air quality and meteorological data. The air quality data were analyzed in context to current Nova Scotia CAAQS management levels. The goal was to provide quantitative $PM_{2.5}$ concentrations to both residents and provincial agencies to promote evidence-based decision making in regard to community air quality and health outcomes.

Identified Local Sources of $PM_{2.5}$

$PM_{2.5}$ concentrations recorded in the North End indicate a local emission which is not present in the downtown core. The consistent daytime peaks observed across all months indicated that the source was not impacted by seasonal variation and was not related to residential heating in colder months. These peaks seen on weekdays were consistent with typical business hours. Slightly lower average concentrations on Fridays may be attributed to long weekends when businesses tend to be closed on Fridays.

The concentrations recorded in the downtown Halifax control site remained stable around 5.0 μg/m³. Despite consistent vehicle use along Barrington St, high business and residential density, and its proximity to the active Halifax harbor and cruise ship terminals, the control site showed no temporal variation. The annual average recorded at the study site, 12.6 μg/m³, exceeds annual averages found in other major cities such as Toronto (7 μg/m³), New York (7 μg/m³) and Vancouver (6.1 μg/m³) (IQAir, 2024a; Ontario, 2021; IQAir 2024b). It also exceeds Canadian national annual averages of 8.8 μg/m³ (Environment and Climate Change Canada, 2023b). The averages observed at the study site are similar to those of Tokyo, Japan (IQAir, 2024c).

Identification of industrial woodburning and vehicle use as primary sources of urban air pollution is consistent with the modelled sector contributions of $PM_{2.5}$ published in the Air Pollutant Emissions Inventory (2023). However, daily peaks did not line up with morning or evening rush hours traffic and there was E in weekend concentrations from the control site. Therefore, traffic related air pollutants are not a significantly greater factor of air pollution within the study area than at the control site. Elevated $PM_{2.5}$ concentrations from woodburning are consistent with the findings of Martins & Carrilho da Graça (2023). It is also inline with the findings of Health Canada (2023) that wood burning contributes significant $PM_{2.5}$ emissions in Nova Scotia.

The woodburning conducted at the local meat smoking operation was the most named source of air pollution by survey participants. The identified operation is to the northwest of the study site monitor. This is consistent with the findings of $PM_{2.5}$ concentrations being elevated by northwesterly winds.

Many participants named this meat smoking operation even in response boxes for unrelated questions such as “when did they perceive changes in air quality during the day?”. Participants used the text space in the ‘other’ option, to specify that they perceived air quality specifically when the wood fires were in operation. The *A Priori* and *A Posteriori* coding of responses show a resounding concern of local residents of the impact that the commercial wood burning was causing to their lives.

Survey responses proved air quality to be an issue important to dozens of individuals within a relatively small area of 0.25 km^2. The dense intermingling of residential and commercial lots raises questions about zoning regulations when it comes to emission mitigation practices. Current development plans for the Halifax peninsula include increasing housing density for all residential zones in the urban center as part of the Housing Accelerator Fund (Halifax Regional Municipality, 2024). There should be a review of enforceable requirements for residential or small-scale industrial smokestacks to use scrubbers in areas of increasing population density.

Nova Scotia Air Zone Management

Air zone management levels are set by the station with the highest recorded pollutant concentration within each zone (Canadian Council of Ministers for the Environment, 2019). The data collected at the study site did not meet the three-year criteria required by CAAQS to create validated 24-hour and 98^{th} percentile averages. However, if the recorded trend of $PM_{2.5}$ concentrations continue, it would increase the air zone management level in Nova Scotia’s Central Air Zone from “yellow” to “red” for $PM_{2.5}$ as it would be the highest recorded averages within the central zone. Inconsistent air quality throughout urban setting mean that government monitoring networks may not provide accurate portrayals of pollutant concentrations on a neighbourhood scale (Delong-Maxey, 2022). Increasing the density of low-cost air monitoring stations could identify hot spots of air pollutants that would otherwise be overlooked in the implementation of mitigation measures.

Local Health Burden

Given the recorded concentrations of $PM_{2.5}$, there is greater health risks to residents within the study area than residents who live in the downtown core. There is a 7.5 $\mu g/m^3$ difference between the annual averages of each site. As found by Wang et al.

(2024), a 10 μg/m³ increase in ambient $PM_{2.5}$ is associated with a 5% increase in all-cause mortality. There are at least four senior-oriented living facilities and day programs operating within the study area. Acute hospitalizations of seniors for cardiovascular disease and other heart related issues increases by 1% when $PM_{2.5}$ concentrations increase from 5 μg/m³ to 10 μg/m³ (Wei, 2024). This is consistent with the concentrations found at the downtown control site and North End study site, respectively. Additionally, there are two elementary schools found within the study area, Joseph Howe Elementary School and Shambala School. Emergency room admissions for children with acute lower respiratory illnesses increase 4.3% with a 10 μg/m³ increase in $PM_{2.5}$ concentrations (Xia and Yao, 2019). Nova Scotia emergency room wait times are at an all time high, and most Nova Scotian do not have access to a primary care physician (Nova Scotia, 2023). The observed North End $PM_{2.5}$ concentrations pose health risks to the area's residents and create greater burdens to a health care system already at its limits.

Limitations

Recording of $PM_{2.5}$ concentrations was limited by the style of monitor used. Wi-Fi and power connection proved caused interference in the collection of data. Power outages disrupted connection and the monitor had to be manually reconnected. There were several prolonged periods where the disconnection went unnoticed before it was able to be restored. Only 75% of days within the study period have sufficient recording to calculate daily 24-hour average. However, the analysis meets the 75% CAAQS requirement to calculate annual averages (Canadian Council of Ministers of The Environment, 2019).

It is understood that people who feel strongly about air pollution within the study area were more likely to participate in the survey and that this creates an inherent bias in the levels of perceived air pollution recorded. The delivery of flyers to each business and residences aimed to counteract some of this bias. During delivery, business owners, employees, and residents were specifically sought out to speak with and encouraged Ato share their experiences even if they had not previously considered local air quality.

The sampled population of residents who responded to the survey was not enough to conclude significant results descriptive of the entire population of the study area. Distribution of the survey flyers was impeded due to heavy snowfall throughout the three-week period of circulation. Some sidewalks and stairways were inaccessible due to snow piles and ice buildup which posed hazardous conditions for the research team. Apartment buildings or multi-unit residents with locked lobby entrances also restricted the deliverance of survey flyers as mailboxes were not accessible. Future iterations of air quality surveys should use postal services to access multi-unit buildings and time the circulation of the survey to minimize seasonal barriers.

Conclusion

This research aimed to characterize $PM_{2.5}$ in relations to the Canadian Ambient Air Quality Standards set out by the Canadian Council of Minister's for the Environment. Results found that $PM_{2.5}$ concentrations within Halifax's North End exceeded the Canadian Ambient Air Quality Standard's highest threshold, the "red" management level. Evidence found in this study points towards the on-site smoking operations of a local business to be the source of local elevated emissions. Additionally, this research sought to understand the perception of air quality among North End residents. There was no single consensus of the perceived air quality, however, among respondents, industry was perceived to be the largest source of pollutants.

Due to recorded levels of $PM_{2.5}$ within the study area, people who spend a significant amount of time around the 2600 block of Agricola and adjacent streets should take precautions to limit exposure to fine particulate matter and associated pollutants. This may include limiting time outdoors and installing mechanical filtration systems inside buildings. Taller smokestacks or scrubbers should be installed within commercial wood burning operation sites to reduce point source emissions if they are not already present. If $PM_{2.5}$ emissions cannot be reduced to acceptable levels, smoking operations should be moved outside of the urban core to a location with lower residential density.

Further research should be conducted by the provincial government into residential air pollution in the North End. A provincial ambient air quality station should be set up within the defined study area to measure $PM_{2.5}$ concentrations and collect particulate matter for analysis of its chemical composition. Subsidizing low-cost air monitors for Nova Scotian residents could provide greater insight into $PM_{2.5}$ concentrations in urban areas with high spatial variability. Using citizen-led platforms with publicly available data, such as Purple Air, allows residents to make informed decisions using real-time air quality data and provides government bodies with more information of the spatial distribution of air pollutants.

I recommend that provincial and municipal governments collaborate to find zoning solutions which minimize health risks and quality of life impacts in dense urban settings. While air quality does fall under provincial jurisdictions, the Guidance Document on Air Zone Management states that "all orders of government have a responsibility to ensure that pollutant levels do not increase and that CAAQS are not exceeded" (Canadian Council of Ministers for the Environment, 2019, p. 9). The Halifax Regional Municipal Government is responsible for issuing building permits and business licences. Ensuring local businesses comply with provincial government ambient air quality goals should be part of the permit and licencing processes. Municipal governments also manage city planning and zoning bylaws. Areas with high population density should include zoning restrictions which limit emissions generated by businesses and require appropriate air pollutant mitigation measures. Provincial governments already work with the Canadian federal government to set out ambient air quality goals, and municipal governments hold jurisdiction over many of avenues with make implementation and enforcement possible.

References Cited

Brook, J. R., Poirot, R. L., Dann, T. F., Lee, P. K. H., Lillyman, C. D., & Ip, T. (2007). Assessing sources of PM2.5 in cities influenced by regional transport. *Journal of Toxicology and Environmental Health. Part A*, *70*(3–4), 191–199. https://doi.org/10.1080/15287390600883000

California Air Resources Board. (2024) *Inhalable Particulate Matter and Health (PM2.5 and PM10) | California Air Resources Board*. Retrieved December 3, 2023, from https://ww2.arb.ca.gov/resources/inhalable-particulate-matter-and-health

Canadian Council of the Ministers of the Environment. (2012). *Guidance Document on Achievement Documentation Canadian Ambient Air Quality Standards for Fine Particulate Matter and Ozone*. https://www.ccme.ca/en/res/gdadforcaaqsforsulphurdioxide_en1.0.pdf

Canadian Council of Ministers of the Environment. (2019). *Guidance Document on Air Zone Management (1593)*. https://ccme.ca/en/res/guidancedocumentonairzonemanagement_secured.pdf

Carslaw, D.C., Ropkin, K. (2012). "Openair – An R package for air quality analysis." *Environmental Modelling & Software,* 27-28(0), 52-61. ISSN 1364-8152 doi:10.1016/j.envsoft.2011.09.008.

Cheng, Y., He, K., Du, Z., Zheng, M., Duan, F., & Ma, Y. (2015). Humidity plays an important role in the PM2.5 pollution in Beijing. *Environmental Pollution*, *197*, 68–75. https://doi.org/10.1016/j.envpol.2014.11.028

Chow, J. C., Chen, L.-W. A., Watson, J. G., Lowenthal, D. H., Magliano, K. A., Turkiewicz, K., & Lehrman, D. E. (2006). PM2.5 chemical composition and spatiotemporal variability during the California Regional PM10/PM2.5 Air Quality Study (CRPAQS). *Journal of Geophysical Research: Atmospheres*, *111*(D10). https://doi.org/10.1029/2005JD006457

Crouse, D. L., Peters, P. A., Hystad, P., Brook, J. R., van Donkelaar, A., Martin, R. V., Villeneuve, P. J., Jerrett, M., Goldberg, M. S., Pope, C. A., Brauer, M., Brook, R. D., Robichaud, A., Menard, R., & Burnett, R. T. (2015). Ambient PM2.5, O_3, and NO_2 Exposures and Associations with Mortality over 16 Years of Follow-Up in the Canadian Census Health and Environment Cohort (CanCHEC). *Environmental Health Perspectives*, *123*(11), 1180–1186. https://doi.org/10.1289/ehp.1409276

Dabek-Zlotorzynska, E., Celo, V., Ding, L., Herod, D., Jeong, C.-H., Evans, G., & Hilker, N. (2019). Characteristics and sources of PM2.5 and reactive gases near roadways in two metropolitan areas in Canada. *Atmospheric Environment*, *218*, 116980. https://doi.org/10.1016/j.atmosenv.2019.116980

Delong-Maxey, M. D. (2022). PurpleAir Sensors as Effective Indicators of PM Exposure in Urban Areas (LLNL-TR-838504). Lawrence Livermore National Laboratory (LLNL), Livermore, CA (United States). https://doi.org/10.2172/1880935

Dominici, F., Wang, Y., Correia, A. W., Ezzati, M., Pope, C. A., & Dockery, D. W. (2015). Chemical Composition of Fine Particulate Matter and Life Expectancy. *Epidemiology (Cambridge, Mass.)*, *26*(4), 556–564. https://doi.org/10.1097/EDE.0000000000000297

Environment and Climate Change Canada. (2023a). *Canada's Air Pollutant Emissions Inventory Report 2023: Chapter 2.1*. https://publications.gc.ca/collections/collection_2023/eccc/En81-30-2021-eng.pdf

Environment and Climate Change Canada (2023) *Canadian Environmental Sustainability Indicators: Air Quality*. Consulted on April 3, 2024. www.canada.ca/en/environment-climate-change/services/environmental-indicators/air-quality.html.

Feng, S., Gao, D., Liao, F., Zhou, F., & Wang, X. (2016). The health effects of ambient PM2.5 and potential mechanisms. *Ecotoxicology and Environmental Safety*, *128*, 67–74. https://doi.org/10.1016/j.ecoenv.2016.01.030

Grolemund G, Wickham H (2011). "Dates and Times Made Easy with lubridate." Journal of Statistical Software, 40(3), 1–25. https://www.jstatsoft.org/v40/i03/.

Guo, Y., Liu, F., Lu, Y., Mao, Z., Hanson, L., Wu, Y., Chu, Y., Yu, L., Liu, Y., Ren, M., Li, N., Chen, X., & Xiang, H. (2016). Factors Affecting Parent's Perception on Air Quality—From the Individual to the Community Level. *International Journal of Environmental Research and Public Health*, *13*(5), 493. https://doi.org/10.3390/ijerph13050493

IQAir. (2024a). *Air Quality in Vancouver BC*. IQAir. https://www.iqair.com/ca/canada/british-columbia/vancouver-bc

IQAir. (2024b). *Air Quality in New York City*. IQAir. https://www.iqair.com/ca/usa/new-york/new-york-city

IQAir. (2024c). *Air Quality in Tokyo*. IQAir. https://www.iqair.com/ca/japan/tokyo

Jeensorn, T., Apichartwiwat, P., & Jinsart, W. (2018). PM10 and PM2.5 from Haze Smog and Visibility Effect in Chiang Mai Province Thailand. *Applied Environmental Research*, *40*, 1–10. https://doi.org/10.35762/AER.2018.40.3.1

Kloog, I., Melly, S. J., Ridgway, W. L., Coull, B. A., & Schwartz, J. (2012). Using new satellite based exposure methods to study the association between pregnancy $PM_{2.5}$ exposure, premature birth and birth weight in Massachusetts. *Environmental Health: A Global Access Science Source*, *11*, 40. https://doi.org/10.1186/1476-069X-11-40

Krittanawong, C., Qadeer, Y. K., Hayes, R. B., Wang, Z., Virani, S., Thurston, G. D., & Lavie, C. J. (2023). PM2.5 and Cardiovascular Health Risks. *Current Problems in Cardiology*, *48*(6), 101670. https://doi.org/10.1016/j.cpcardiol.2023.101670

Li, H. Z., Gu, P., Ye, Q., Zimmerman, N., Robinson, E. S., Subramanian, R., Apte, J. S., Robinson, A. L., & Presto, A. A. (2019). Spatially dense air pollutant sampling: Implications of spatial variability on the representativeness of stationary air pollutant monitors. *Atmospheric Environment: X*, *2*, 100012. https://doi.org/10.1016/j.aeaoa.2019.100012

Li, J., Song, Y., Shi, L., Jiang, J., Wan, X., Wang, Y., Ma, Y., Dong, Y., Zou, Z., & Ma, J. (2023). Long-term effects of ambient PM2.5 constituents on metabolic syndrome in Chinese children and adolescents. *Environmental Research*, *220*, 115238. https://doi.org/10.1016/j.envres.2023.115238

Li, W., Lin, G., Xiao, Z., Zhang, Y., Li, B., Zhou, Y., Ma, Y., & Chai, E. (2022). A review of respirable fine particulate matter (PM2.5)-induced brain damage. *Frontiers in Molecular Neuroscience*, *15*, 967174. https://doi.org/10.3389/fnmol.2022.967174

Nova Scotia Environment and Climate Change. (2024). *Nova Scotia Environment and Climate Change Ambient Air Quality Data*. Ambient Air Quality. https://novascotia.ca/nse/airdata/

Manisalidis, I., Stavropoulou, E., Stavropoulos, A., & Bezirtzoglou, E. (2020). Environmental and Health Impacts of Air Pollution: A Review. *Frontiers in Public Health*, *8*. https://www.frontiersin.org/articles/10.3389/fpubh.2020.00014

Martins, N. R., & Carrilho da Graça, G. (2023). Health effects of PM2.5 emissions from woodstoves and fireplaces in living spaces. *Journal of Building Engineering*, *79*, 107848. https://doi.org/10.1016/j.jobe.2023.107848

Matz, C. J., Stieb, D. M., Davis, K., Egyed, M., Rose, A., Chou, B., & Brion, O. (2014). Effects of Age, Season, Gender and Urban-Rural Status on Time-Activity: Canadian Human Activity Pattern Survey 2 (CHAPS 2). *International Journal of Environmental Research and Public Health*, *11*(2), 2108–2124. https://doi.org/10.3390/ijerph110202108

Mei, D., Wen, M., Xu, X., Zhu, Y., & Xing, F. (2018). The influence of wind speed on airflow and fine particle transport within different building layouts of an industrial city. *Journal of the Air & Waste Management Association*, *68*(10), 1038–1050. https://doi.org/10.1080/10962247.2018.1465487

Nilson, B., Jackson, P. L., Schiller, C. L., & Parsons, M. T. (2022). Development and evaluation of correction models for a low-cost fine particulate matter monitor. *Atmospheric Measurement Techniques*, *15*(11), 3315–3328. https://doi.org/10.5194/amt-15-3315-2022

Nova Scotia. (2023). *Annual Accountability Report on Emergency Departments*. https://novascotia.ca/dhw/publications/emergency-departments-accountability-report-2022-23.pdf

Olesiejuk, K., & Chałubiński, M. (2023). How does particulate air pollution affect barrier functions and inflammatory activity of lung vascular endothelium? *Allergy*, *78*(3), 629–638. https://doi.org/10.1111/all.15630

Ontario. (2021). *Air Quality in Ontario 2020 Report*. https://www.ontario.ca/document/air-quality-ontario-2020-report#

Pignocchino, G., Di Baldassarre, G., Mondino, E., & Raffetti, E. (2023). Public risk perception of air pollution in the general population of Italy and Sweden during the COVID-19 pandemic: Environmental and socio-demographic drivers. *Preventive Medicine*, *173*, 107601. https://doi.org/10.1016/j.ypmed.2023.107601

Reames, T. G., & Bravo, M. A. (2019). People, place and pollution: Investigating relationships between air quality perceptions, health concerns, exposure, and individual- and area-level characteristics. *Environment International*, *122*, 244–255. https://doi.org/10.1016/j.envint.2018.11.013

Ścibor, M., Galbarczyk, A., & Jasienska, G. (2019). Living well with pollution? the impact of the concentration of PM2.5 on the quality of life of patients with asthma. *International Journal of Environmental Research and Public Health*, *16*(14), 2502. https://doi.org/10.3390/ijerph16142502

Sekar, A., Jasna, R. S., Binoy, B. V., Mohan, P., & Kuttiparichel Varghese, G. (2023). Air quality change and public perception during the COVID-19 lockdown in India. *Gondwana Research*, *114*, 15–29. https://doi.org/10.1016/j.gr.2022.04.023

Statistics Canada (2022, February 9). *Profile table, Census Profile, 2021 Census of Population—2050020.00 [Census tract], Nova Scotia*. https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/index.cfm?Lang=E

ThermoFisher Scientific. (2024). *TEOM Technology for Particulate Matter Measurement—CA*. Retrieved March 20, 2024, from https://www.thermofisher.com/ca/en/home/industrial/environmental/environmentallearning-center/air-quality-analysis-information/teom-technology-particulate-matter-measurement.html

Tryner, J., Good, N., Wilson, A., Clark, M. L., Peel, J. L., & Volckens, J. (2019). VARIATION IN GRAVIMETRIC CORRECTION FACTORS FOR NEPHELOMETER-DERIVED ESTIMATES OF PERSONAL EXPOSURE TO PM2.5. *Environmental Pollution (Barking, Essex: 1987)*, *250*, 251–261. https://doi.org/10.1016/j.envpol.2019.03.121

Undavalli, V. K., & Khandelwal, B. (2021). Chapter 5—Impact of alternative fuels and fuel properties on PM emissions. In B. Khandelwal (Ed.), *Aviation Fuels* (pp. 71–111). Academic Press. https://doi.org/10.1016/B978-0-12-818314-4.00012-1

Wang, B., Eum, K.-D., Kazemiparkouhi, F., Li, C., Manjourides, J., Pavlu, V., & Suh, H. (2020). The impact of long-term PM2.5 exposure on specific causes of death: Exposure-response curves and effect modification among 53 million U.S. Medicare beneficiaries. *Environmental Health*, *19*(1), 20. https://doi.org/10.1186/s12940-020-00575-0

Wei, Y., Feng, Y., Danesh Yazdi, M., Yin, K., Castro, E., Shtein, A., Qiu, X., Peralta, A. A., Coull, B. A., Dominici, F., & Schwartz, J. D. (2024). Exposure-response associations between chronic exposure to fine particulate matter and risks of hospital admission for major cardiovascular diseases: Population based cohort study. *BMJ (Clinical Research Ed.)*, *384*, e076939. https://doi.org/10.1136/bmj-2023-076939

Wickham H (2016). *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag New York. ISBN 978-3-319-24277-4, https://ggplot2.tidyverse.org.

Wickham H, Averick M, Bryan J, Chang W, McGowan LD, François R, Grolemund G, Hayes A, Henry L, Hester J, Kuhn M, Pedersen TL, Miller E, Bache SM, Müller K, Ooms J, Robinson D, Seidel DP, Spinu V, Takahashi K, Vaughan D, Wilke C, Woo K, Yutani H (2019). "Welcome to the tidyverse." Journal of Open Source Software, 4(43), 1686. doi:10.21105/joss.01686

Wickham H, François R, Henry L, Müller K, Vaughan D (2023). *dplyr: A Grammar of Data Manipulation*. R package version 1.1.4, https://github.com/tidyverse/dplyr, https://dplyr.tidyverse.org

World Health Organization (2021). *WHO global air quality guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. World Health Organization. https://www.who.int/publications/i/item/9789240034228

Xia, X., & Yao, L. (2019). Spatio-Temporal Differences in Health Effect of Ambient PM2.5 Pollution on Acute Respiratory Infection Between Children and Adults. *IEEE Access*, *7*, 25718–25726. https://doi.org/10.1109/ACCESS.2019.2900539

Yan, H., Li, Q., Feng, K., & Zhang, L. (2023). The characteristics of PM emissions from construction sites during the earthwork and foundation stages: An empirical study evidence. *Environmental Science and Pollution Research International*, *30*(22), 62716–62732. https://doi.org/10.1007/s11356-023-26494-4

Zhang, L., Yang, Y., Li, Y., Qian, Z. M., Xiao, W., Wang, X., Rolling, C. A., Liu, E., Xiao, J., Zeng, W., Liu, T., Li, X., Yao, Z., Wang, H., Ma, W., & Lin, H. (2019). Short-term and long-term effects of PM2.5 on acute nasopharyngitis in 10 communities of Guangdong, China. *The Science of the Total Environment*, *688*, 136–142. https://doi.org/10.1016/j.scitotenv.2019.05.470

Zhang, Q., Jiang, X., Tong, D., Davis, S. J., Zhao, H., Geng, G., Feng, T., Zheng, B., Lu, Z., Streets, D. G., Ni, R., Brauer, M., van Donkelaar, A., Martin, R. V., Huo, H., Liu, Z., Pan, D., Kan, H., Yan, Y., … Guan, D. (2017). Transboundary health impacts of transported global air pollution and international trade. *Nature*, *543*(7647), 705-709I. https://doi.org/10.1038/nature21712

Appendix A
Survey Distribution Materials

Figure A1

Flyer Used for Circulation via Mail

Figure A2

Flyer Used for Circulation via Email and Social Media

Appendix B
Ethics Agreement

North End Air Quality Survey

You are invited to take part in a research study being conducted by Sadie Russell, an undergraduate student in Environmental Science, and Dr. Daniel Rainham, a professor in the School of Health and Human Performance at Dalhousie University. The purpose of this research is to investigate your perception of air quality in your neighbourhood. An online survey will be used to assess perception of air quality and how perception is related to place of residence, demographic information and time of the day or week.

If you choose to participate in this research, you will be asked to complete a short online survey approximately 8-10 minutes in length on your perceptions of neighbourhood air quality, changes in air quality, and demographic characteristics including your age, sex, gender and household characteristics. The survey should take approximately 10-12 minutes.

Your participation in this research is entirely your choice. You do not have to answer questions that you do not want to answer (by selecting prefer not to answer), and you are welcome to stop the survey at any time if you no longer want to participate. All you need to do is close your browser. Incomplete surveys will not be included in any analyses. If you do complete your survey and you change your mind later, your information cannot be removed as it will not be possible to know which response is yours.

Your responses to the survey will be anonymous. This means that there are no questions in the survey that ask for identifying details such as your name or email address. All responses will be saved on a secure Dalhousie server. Only Sadie Russell and Daniel Rainham will have access to the survey results.

General findings from the research will be published on the form of an honours thesis. A summary of the results will also be available online at: http://danielrainham.ca.

The risk associated with your participation in this study are minimal. Given the small size and population of the study area and that we are collecting demographic information, there is a small possibility that one of the researchers may identify a respondent. However, only the researchers will have access to survey data and are bound to hold all data in strict confidentiality.

There will be no direct benefit to you in participating in this research. The research, however, might contribute to new knowledge that will be extremely valuable for municipal planners, decision makers and public health researchers who require input on how best to create healthy and viable communities.

To thank you for your time you can choose to enter a draw for a chance to win a $20 gift card at the end of the survey. Your contact information for the draw will not be linked in any way to your survey responses.

You should discuss any questions you have about this study with Sadie Russell (sadierussell@dal.ca) or Daniel Rainham (dr@dal.ca). Please ask as many questions as you like before or after participating.

If you have any ethical concerns about your participation in this research, you may contact Research Ethics, Dalhousie University at (902) 494-3423, or email ethics@dal.ca (and reference REB file # 2023-6962).

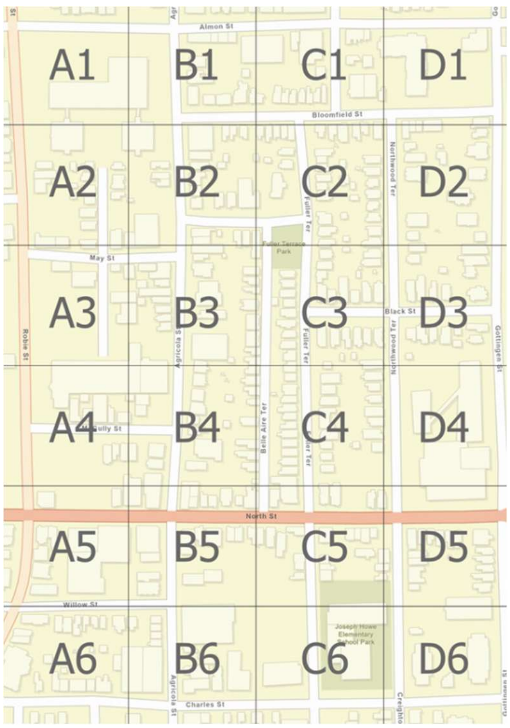
Appendix C
Survey Questions

Eligibility

1. You are required to be at least 18 years of age to complete this survey. Please confirm this below in order to continue.

Study Area

2. Within the study area, where best describes where you live or work? Please indicate (1) quadrant which best describes where you spend the most amount of your time in the text box below.



Air Quality Perception

3. The quality of the air in the neighbourhood where I live is:

Very bad Bad Acceptable Good Excellent

4. When you go outside from your home, do you pay attention to the quality of the air?

Never Rarely Sometimes Always

5. Air quality can change throughout the day. How often do you perceive changes in the air quality in your neighbourhood throughout the day?

Never Rarely Sometimes Always

6. If you indicated that you do perceive changes in air quality throughout the day, when during the day to you perceive the air quality to be worse than usual?

6:01am - 10:00am 10:01am - 2:00pm 2:01pm - 6:00pm I do not perceive changes during the day

Other:

7. Thinking about the last 12 months or so, when you are at home or work, how much does outdoor air pollution bother you?

Not at all Slightly Moderately Very much Extremely

9. What do you think are the top three sources of air pollution that change the air quality in your neighbourhood?

Demographics

10. Have you ever raised concerns air quality in your neighbourhood to municipal or provincial authorities

11. What is the year of your birth (e.g. 1973)?

12. What was your sex at birth? (please select one)

13. What is your gender? (please select any that apply)

Female (cisgender or transgender)

Male (cisgender or transgender)

Nonbinary

Gender Fluid

Two-spirit

Other; please specify

14. How many people (including yourself) live in your household?

15. Of the total number of people living in your household, how many are under the age of 12 and/or over the age of 65?

Appendix D

Survey Results from Likert Scale Questions and Demographic Characteristics

Perception of Air Quality		Variations		Time Periods of Variation		Level of bother		Level of Worry		Has Raised Concerns	
Very bad	6	Always	12	No changes	19	Extremely	6	Extremely	9	Yes	11
Bad	14	Sometimes	25	2:01pm to 6:00pm	17	Very much	9	Very	8	No	47
Acceptable	19	Rarely	17	10:01am - 2:00pm	11	Moderately	10	Moderately	17		
Good	17	Never	5	Daytime Hours*	10	Slightly	18	Slightly	17		
Excellent	3					Not at all	16	Not at all	12		

Age		Sex at birth		Gender		Household Total		Seniors and Children in Household	
Average	46.39	Male	20	Male	21	1	13	0	36
StDev	14.6	Female	36	Female	32	2	24	1	12
		Intersex	1	Non-binary	3	3	7	2	9
						4	12		
						5	1		

* Daytime Hours was not a response offered it the multiple-choice selection but was indicated in the open text box

Appendix E

Table E1

Average PM2.5 Concentrations of Study Site v. Johnston/Major Lake Station

Study Site					Johnston/ Major Lake				
Hour	PM2.5 (μg/m³)	StDev	95% CI	Observations	Hour	PM2.5 (μg/m³)	StDev	95% CI	Observations
0	4.52	5.24	(3.88, 5.14)	269	0	5.19	3.46	(4.83, 5.53)	376
1	4.21	4.89	(3.62, 4.80)	268	1	5.04	3.09	(4.72, 5.35)	375
2	4.05	4.87	(3.46, 4.63)	269	2	4.91	3.07	(4.59, 5.21)	375
3	4.04	4.96	(3.44, 4.63)	268	3	4.76	3.02	(4.44, 5.06)	374
4	3.90	4.57	(3.35, 4.45)	268	4	4.63	2.98	(4.32, 4.92)	374
5	3.86	4.47	(3.32, 4.39)	268	5	4.57	3.01	(4.26, 4.87)	373
6	4.49	6.14	(3.74, 5.22)	268	6	4.62	3.10	(4.29, 4.93)	372
7	8.82	18.52	(6.59, 11.04)	268	7	4.77	3.23	(4.44, 5.10)	373
8	18.56	31.97	(14.71, 22.40)	268	8	4.96	3.37	(4.61, 5.29)	373
9	26.08	41.73	(21.06, 31.09)	268	9	5.05	3.33	(4.70, 5.38)	372
10	30.43	45.78	(24.92, 35.93)	268	10	5.08	3.30	(4.74, 5.41)	372
11	31.03	48.83	(25.16, 36.89)	269	11	5.11	3.56	(4.74, 5.46)	372
12	29.61	47.70	(23.88, 35.33)	269	12	5.16	3.51	(4.80, 5.52)	374
13	27.36	43.85	(22.10, 32.61)	270	13	5.26	3.54	(4.89, 5.61)	373
14	23.50	38.44	(18.89, 28.10)	270	14	5.40	3.81	(5.01, 5.78)	373
15	18.66	30.19	(15.03, 22.28)	269	15	5.36	3.81	(4.97, 5.75)	371
16	14.47	26.30	(11.31, 17.63)	269	16	5.38	4.12	(4.95, 5.79)	374
17	11.01	18.46	(8.79, 13.22)	269	17	5.40	3.98	(4.99, 5.80)	373
18	7.57	8.71	(6.52, 8.61)	271	18	5.56	4.54	(5.09, 6.02)	372
19	6.08	6.60	(5.28, 6.86)	270	19	5.80	4.83	(5.30, 6.29)	372
20	5.66	6.03	(4.93, 6.38)	269	20	5.81	4.32	(5.36, 6.25)	373
21	5.37	5.86	(4.66, 6.06)	270	21	5.72	4.15	(5.29, 6.14)	372
22	5.32	8.10	(4.35, 6.29)	269	22	5.57	3.94	(5.16, 5.96)	375
23	5.14	9.78	(3.96, 6.31)	269	23	5.37	3.86	(4.97, 5.75)	376

Table E2

Monthly Daytime and Nighttime Average $PM_{2.5}$ Concentrations of Study Area v. Johnston/Major Lake Station

Month	Time of Day	P-value	Mean of Study Site	Mean of Control Site	95 CI
January	Daytime	<0.05	32.30	5.31	19.46, 34.52
	Nighttime	0.087	3.04	5.79	-3.82, 1.69
February	Daytime	<0.05	24.43	6.01	13.11, 23.73
	Nighttime	<0.05	3.06	5.13	-2.79, -1.35
March	Daytime	<0.05	11.78	6.01	13.11, 23.72
	Nighttime	<0.05	1.66	4.50	-3.41, -2.27
April	Daytime	<0.05	9.20	4.32	1.69, 8.06
	Nighttime	<0.05	5.82	4.73	0.32, 1.86
May	Daytime	<0.05	16.42	4.98	8.24, 14.66
	Nighttime	<0.05	4.15	5.14	-1.74, -0.24
June	Daytime	<0.05	19.17	4.77	10.49, 18.32
	Nighttime	<0.05	8.58	4.74	2.52, 5.15
July	Daytime	<0.05	21.52	4.78	13.22, 20.24
	Nighttime	<0.05	7.25	5.52	1.04, 2.42
August	Daytime	<0.05	27.81	6.06	16.68, 26.81
	Nighttime	0.346	6.68	6.04	-0.69, 1.96
September	Daytime	<0.05	26.24	4.75	15.44, 27.52
	Nighttime	<0.05	7.38	5.01	1.44, 3.30
October	Daytime	<0.05	15.75	4.28	8.47, 14.49
	Nighttime	0.087	4.27	4.83	-1.20, 0.08
November	Daytime	<0.05	36.18	5.51	25.13, 36.21
	Nighttime	<0.05	3.04	5.79	-3.82, -1.69

Note. Due to connection issues and lack of days with sufficient concentrations recordings, there is no data available for December 2022.