Baseline Monitoring for Determining the Effects of Streetscaping on Particulate Matter Concentrations in the Downtown Area of Halifax, Nova Scotia

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Acknowledgements

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Abstract

Anthropogenic sources of air pollution in cities primarily originate from automobile traffic. Understanding the extent of air pollution from traffic is important for how governments plan cities, and for maximizing the benefits to human health and the environment. The main objectives of this project were to design an appropriate sampling strategy to measure air quality, to collect baseline data of air pollution concentrations from Spring Garden Road (SGR), Sackville Street (SVS) and Morris Street (MOS), and to compare pollution data collected among the sampling locations with a reference station monitored by Nova Scotia Environment (NSE). Measurements of fine particulate matter ($PM_{2.5}$) ($\mu g/m^3$) and ultrafine particle concentration ($count/cm^3$) were collected at three sites along SGR, SVS and MOS for three time periods, (7am-9am; 11am-1pm; 7pm-9pm) between October 10 and November 4, 2019. Statistically significant differences for particle concentration and $PM_{2.5}$ levels across sampling locations and time periods were found. $PM_{2.5}$ levels are significantly greater than those measured at the NSE station for the same months over a five-year period. The $PM_{2.5}$ levels observed generally are below the Canadian Ambient Air Quality maximum standards of 10 $\mu g/m^3$. Although the study is limited by temporal and spatial bounds, baseline data on air pollution levels is crucial to determining the impact of road enhancements on urban environments in the future. This air quality study can be repeated after construction is completed with the aim to inform the Halifax Regional Municipality on how to proceed with streetscaping projects in the future.

1.0 Introduction

As the human population has grown, humans have become a species that reside predominantly in cities. Today, 55 % of the world's population lives in cities (United Nations Department of Economic and Social Affairs, 2016). In Canada, over 80 % of the population reside in cities (Statistics Canada, 2011). As cities grow and become more densely populated, the question of how to design them with the environment in mind becomes challenging. An increase in population in a certain area may also result in an increase in corresponding anthropogenic air pollution, which can lead to adverse environmental and health effects (Brauer et al., 2013). Many anthropogenic sources of airborne particles in cities originate from automobile traffic (Brauer et al., 2013). Therefore, understanding the extent of traffic air pollution is important for governments to understand in order to plan their cities and design policies that will minimize pollutant releases and maximize health benefits for both humans and the environment.

Traffic related air pollution (TRAP) is air pollutants that are associated with vehicle emissions and include both gaseous substances and particulate matter (Brauer et al., 2013). Carbon dioxide (CO_2), carbon monoxide (CO), and ozone (O_3) gases are products of vehicle engine combustion (Davies et al., 2008). Particulate matter (PM) can include particles of a range of sizes. $PM_{2.5}$ are particles less than or equal to 2.5 μm in aerodiameter, and ultrafine particles (UFPs) are less than 0.1 μm in aerodiameter (United States Environmental Protection Agency, 2018). Both of these particulate sizes are also emitted from vehicles during the engine's combustion of fossil fuels (Zwack et al., 2011). There is evidence to suggest that these pollutants are detrimental to respiratory and cardiovascular systems in humans (Brauer et al., 2013; Gan et al., 2012). Many traffic related pollutants are also greenhouse gasses (GHGs), which contribute to the warming of the atmosphere causing adverse conditions for many ecosystems (Yuqin & Lam, 2011). Therefore, managing traffic levels in cities can help reduce overall TRAP and GHG emissions, which in turn will benefit both human health and the environment.

The Canadian Council of Ministers of the Environment have set Canadian Ambient Air Quality Standards (CAAQS) for $PM_{2.5}$ threshold levels. In 2015, $PM_{2.5}$ levels were set at 10 μg/m^3 for average annual and 28 μg/m^3 for an average over a 24-hour period (Canadian Council of Ministers of the Environment, 2012). The goal for 2020 is to bring these levels down to 8.8 μg/m^3 and 27 μg/m^3 respectively (Canadian Council of Ministers of the Environment, 2012). As part of the National Air Pollution Surveillance (NAPS) network, there are multiple air pollution monitoring stations around the country, including central Halifax. In 2012, the Canadian Council of Ministers of the Environment took the average of three years of $PM_{2.5}$ data (2010-2012) from Halifax, which showed it to be approximately 16 μg/m^3 (Canadian Council of Ministers of the Environment, 2012).

The effects of city air pollution on human health have previously been studied through exposure assessments and environmental epidemiology. Evidence from these studies concluded that air pollution, including particulate matter, negatively impacts human health primarily by affecting the cardiovascular and respiratory systems (Brauer et al., 2013; Gan et al., 2008). The particles can impact the function of these systems and are associated with diseases such as asthma, lung cancer and breast cancer (Brauer, et al., 2013).

There has been little research completed on how changing the streetscape of roads impacts ambient air pollution concentrations. One study executed by the University of Toronto, Ryerson University and the City of Toronto, investigated air pollution levels before and after prioritizing streetcars over vehicles between Bathurst Street and Jarvis Street, as well as changing the direction of traffic flow on Kings Street in downtown Toronto (Dekker, 2018). The study found that TRAP levels were reduced after the completion of the streetscaping project compared to TRAP concentrations prior to the streetscaping project

(Dekker, 2018). However, the study primarily focused on changes only to the street that was being altered (Dekker, 2018). Few studies have analysed how air pollution can cause changes on peripheral or adjacent streets when street altering occurs within a given road. Recording pollution levels in and around adjacent streets is also important for understanding the overall impact of streetscaping projects. Studying and recording these air quality levels will allow city planners to see if pollution levels could be impacted in areas beyond the developed street.

The present study focuses on recording $PM_{2.5}$ and UFP concentrations in the downtown district of Spring Garden Road (SGR) in Halifax, Nova Scotia. The Halifax Regional Municipality (HRM) has decided to change the layout of SGR, between South Park Street and Queen Street. This streetscaping plan is known as the “Spring Garden Road Enhancement Project” (SGREP). The goal of SGREP is to make the area more pedestrian friendly (City of Halifax, 2019). This will be achieved by increasing sidewalk widths, increasing foliage and changing traffic flows (City of Halifax, 2019). In addition to these changes, the air quality levels of the study area are of interest to the city to compare the before and after effects of the SGREP. In this thesis, baseline data of air quality parameters in the area of downtown Halifax that will be affected by the SGREP were collected. The research question was: What are the current air quality levels of areas likely to be impacted by the Spring Garden Project Enhancement? The objectives of this study were:

a) to design a sampling scheme to measure particulate matter concentrations;

b) to collect particulate matter data from SGR, Sackville Street and Morris Street;

c) to compare particulate matter data collected between the three streets; and,

d) to compare $PM_{2.5}$ data collected with data from Nova Scotia Environment (NSE).

Concentrations of $PM_{2.5}$ and UFP were collected using mobile collection devices on segments of SGR, Sackville Street and Morris Street during the months of October and November 2019.

2.0 Literature Review

2.1 Introduction

This literature review focused on research pertaining to traffic-related air pollution (TRAP) and urban modification, also known as streetscaping. The purpose of this literature review was to gain insight into the studies that have been completed on these two topics and to identify current knowledge gaps in the literature. Due to the amount of people now living in urban areas, it is important to understand urban air pollution and its effects on the population. Moreover, in order for cities to meet CAAQS, they need to address the sources of pollutants in cities. Therefore, understanding traffic related air pollutants and how they are associated with urban design is important in many regards. This literature review was expanded to include international case studies, as there are limited examples of urban modification and TRAP data collected and recorded for related to Canadian cities.

This literature review began by evaluating peer-reviewed literature, including journal articles and conference posters. Search terms that relate to TRAP, streetscaping, traffic flow, street trees, air quality monitoring and particulate matter were used in various combinations to acquire articles from several databases. Three databases were used to conduct the literature review for this thesis: Web of Science, Agriculture Environmental Science Collection and Dalhousie University's Novanet database.

2.2 Traffic Related Air Pollution (TRAP)

A significant proportion of outdoor ambient air pollution in cities is related to emissions from motor vehicles, and it is important to understand how these pollutants affect cities and their inhabitants (Brauer et al,, 2013). TRAP are important pollutants to study as they can be detrimental to both environmental and human health. TRAP have been described as the gases and particulate matter associated with vehicle emissions during engine combustion (Brugge et al., 2015).

There are several gasses that are considered to be traffic related air pollutants, as they are released during vehicle engine combustion and emit these contaminants into the atmosphere. One of these discharged gasses is nitrogen dioxide (NO_2). Several studies have sampled NO_2 to measure exposure to traffic related air pollutants. One study sampled NO_2 in the city of Toronto to assess the association between TRAP and mortality (Jerrett et al., 2009). The study found that there was an increased mortality rate associated with increased NO_2 exposure (Jarrett et al., 2009). Similarly, a study conducted in the Netherlands studied how distance from the road affects NO_2 presence (Roorda-Knape et al., 1999). Results from this study found that as distance from the roadside increased, NO_2 concentrations decreased (Roorda-Knape et al., 1999). Shu & Lam (2011) studied carbon dioxide (CO_2), another gas released through vehicle engine combustion. Their results showed that CO_2 is concentrated in areas of dense road networks (Shu & Lam, 2011). Other TRAP gasses that are often monitored are ground level ozone (O_3) and carbon monoxide (CO) (US EPA, 2015). O_3 is formed when fossil fuel pollution, such as emissions from vehicles, interacts with sunlight (US EPA, 2015). Ground level ozone can also be detrimental to human health when it enters the human body (US EPA, 2015). These above studies illustrate how certain gasses are related to vehicle emissions in different contexts. Furthermore, they demonstrate that these particular gasses are worthy indicators of TRAP. Despite this, it is difficult to sample gasses due to the intensive amount of analysis and inaccuracies associated with sampling techniques (Bari et al., 2015).

Particulate matter is also released during vehicle engine combustion and can be measured to show evidence of TRAP in an area in addition to gasses (Brugge et al., 2015). Particulate matter has been shown to have negative impacts on human health due to the properties and characteristics of the compounds being emitted. Fine particles such as $PM_{2.5}$ and ultrafine particles are small enough to bypass natural barriers in the human body and infiltrate cardiovascular and respiratory systems (Brauer et al., 2013). An increase in foreign particles and gasses in the body can lead to long term respiratory and cardiovascular issues such as asthma and coronary heart disease (Gan et al., 2012). Other health outcomes, such as breast cancer, have also been associated with TRAP, (Hystad et al., 2014; Crouse et al., 2010). Various studies have shown how TRAP are associated with many health issues as the particles and gasses can easily enter the respiratory pathway of humans, thus increasing the chances of acute and long term health impacts. These gasses and particulate matter can be studied when identifying TRAP; however, this thesis will focus on studying particulate matter.

2.3 Urban Modification (Streetscaping) and Traffic Related Air Pollution

Streetscaping, or urban modification, is employed by city planners and engineers to alter urban landscapes. The SGREP is modifying the streetscape of SGR to make the area more pedestrian friendly (City of Halifax, 2019). Some methods of urban modification include changing traffic flow, altering sidewalks, and increasing tree canopy (City of Halifax, 2019).

Pedestrians are exposed to TRAP when walking beside roadways, meaning small changes to streetscapes can significantly change an individual’s exposure to air pollution. Pedestrians are exposed to more pollutants on roads with higher traffic volumes (Hankey, Lindsey and

Marshall, 2017). Therefore, traffic volume can increase a pedestrian's risk of obtaining diseases related to air pollutants, when travelling on busier streets. Relocating the sources of pollution along a street, such as moving bus stop locations, can help reduce pedestrian exposure to TRAP (Hankey, Lindsey and Marshall, 2017). In one study, increasing the street width resulted in increased traffic flow and also increased pollutant concentrations in the area (Qiu & Li, 2015). These examples show how changing the street design, even slightly, can affect air pollution concentrations. Therefore, it is important to research how changing a streetscape may impact air pollution levels to determine what changes are the most beneficial when creating a healthy urban landscape.

Changing traffic flow has been shown to influence the levels of traffic related air pollution of the area. For example, during the 2008 Olympic Games in Beijing, air quality improved when traffic flow was restricted during a Traffic Restriction Scheme (TRS) (Cai & Xie, 2011). Concentrations of CO, PM_{10}, NO_2 and O_3 were recorded before and after the scheme (Cai & Xie, 2011). During the TRS, they restricted the traffic flow in areas around the city by assigning specific days that cars could drive depending on their licence plates, removing the worst polluting vehicles from the road, and only allowing necessary government vehicles to be on the street (Cai & Xie, 2011). Although this was not a permanent change in traffic restriction, they saw an overall decrease in air pollutants by approximately 30% for particulate matter when restricting and changing the traffic flow (Cai & Xie, 2011). This demonstrates how traffic flow can determine pollutant concentrations in a city.

Similarly, a 3.6 km single carriageway traffic tunnel was constructed in Sydney, Australia to reduce traffic congestion along the main roadway (Cowie et al., 2012). The tunnel linked two major roads with an aim to reduce vehicular traffic on the main highway (Cowie et al., 2012). The researchers wanted to see if the creation of this tunnel would lead to a redistribution of TRAP in the surrounding area. The implementation of this tunnel changed the layout of the streets area. Results showed a decrease in NO_2, NO_x and PM_{10} in some spaces within the study area, after the tunnel was constructed (Cowie, et al., 2012). Although different methods and modifications of traffic flow were applied to each of the scenarios, through traffic restriction or the introduction of a tunnel, the two case studies showed a reduction in air pollution levels when traffic flows were restricted.

Tree canopy coverage can also aid in the reduction of TRAP in the atmosphere with the canopy leaves providing natural filtering of the air (Moreira et al., 2018). Trees located near streets with high traffic volumes had high levels of TRAP trapped in the their bark (Moreira et al., 2018). Leaves both filter and act as passive deposits for air pollutants, however certain species of trees are better at air pollution absorption than others (Moreira et al., 2018). Tree canopy, other foliage, and grasses around schools may be associated with a reduction in exposure to traffic related air pollution (Dadvand et al., 2015). The overall presence of trees may reduce the amount of TRAP that is in the atmosphere due to the filtration properties of trees.

To gain the most insight into how altering street design affects air quality, measurements should be taken before and after the modifications occur. A novel study conducted in Toronto by the University of Toronto, Ryerson University and the City of Toronto assessed air quality in the downtown core before and after modifying traffic flow on Kings Street between Bathurst Street and Jarvis Street (Dekker et al., 2018). They aimed to assess the current pollution levels of the street and then after modifying the street, it would then give priority to street cars over individual vehicles (Dekker et al., 2018). They believed giving priority to streetcars would improve human health and environmental health as well as improving transit reliability (Dekker et al., 2018). The results from the study revealed a decrease in NO_2 concentrations in the western and northern parts of Kings Street (Dekker et al., 2018). The study additionally found UFPs decreased, but not by a statistically significant amount (Dekker et al., 2018). This study illustrates the importance of having a baseline in order to compare the after effects to the current levels of air pollution and as well as to gain accurate results of how streetscaping may impact air quality of an area.

2.4 Estimating Air Pollution Concentrations

There are several approaches to measuring levels of air pollution within a study area. Techniques can include using validated air quality machinery, handheld instruments, or technological models to estimate air pollution concentrations. Sophisticated equipment that has been validated, such as the Teledyne API Model T640, can be used to take air pollution measurements continuously and with a high degree of accuracy (Teledyne Advanced Pollution Instruments, 2018). This is what the National Air Pollution Surveillance Program (NAPS) in Canada uses in Halifax to measure particulate matter concentrations (C. Barrett, personal communication, March 12, 2020). The data are frequently validated by also sending samples to labs at Environment and Climate Change Canada to make sure the equipment is displaying accurate information (Government of Canada, 2019).

Handheld monitoring instruments can be used for fixed sampling or mobile measuring strategies. For example, one study used passive NO_2 samplers, an example of fixed sampling, to measure NO_2 before and after implementing a tunnel (Cowie et al., 2012). They used passive NO_2 gas samplers, which were fixed at 41 sites within the study, to consistently measure NO_2 levels for the duration of the sampling period (Cowie et al., 2012). The sites ranged from busy to quiet roads and residential regions to parklands, in order to obtain a wide distribution of sampling areas (Cowie et al., 2012). The study found that after the tunnel was implemented there were decreases in NO_2 concentrations for the eastern area of the study (Cowie, et al., 2012).

An alternative to a fixed site-sampling scheme is to use portable monitoring, which can be used to sample particulate matter within a study area without permanently setting up the equipment. An example of a study that used mobile measuring of air pollutants took place in a study that measured the before and after effects of changing the layout of a street to allow more access for streetcars on Kings St. in Toronto (Dekker, 2018). They employed a portable sampling approach and measured air quality along Kings Street, during two-hour time intervals and, for different times, dates and time of the day (Dekker, 2018). Through the mobile monitoring, they found some decreases in NO_2 levels across the study area (Dekker, 2018).

Pollutant concentrations can also be estimated through models. Examples of modelling air pollution levels include Land Use Regressions (LUR) and satellite image estimations. LUR models an area using specific inputs to estimate exposure to air pollutants by land use (Hankey, Lindsey, & Marshall, 2017). This technique has been used in various studies, but can only estimate pollutant levels through the constraints of the model (Hankey, Lindsey & Marshall, 2017). Satellite derived estimates are another strategy to model air pollutant exposure. Satellite images can be used to estimate ground level concentrations of pollutants, and have been used in Canada to predict exposure to TRAP (Hystad et al., 2014). There are uncertainties associated with models as they only represent estimate pollutant levels. Models are most often employed to make inferences about air pollution levels for areas where you cannot directly take measurements.

Although some of these studies incorporate the use of models and estimates of exposure, many of them state that in order to have the most accurate measurements of air pollution, physical pollutant measurements of the area must be collected. Whether it is through fixed or mobile monitoring, measuring the data directly from the given area of interest is suggested in order to yield the most accurate air pollution levels.

2.5 Knowledge Gaps

Within the studies that measure ambient air quality in areas of modification, there are few that show how streetscaping affects air quality in areas adjacent to the area of interest. Furthermore, few Canadian city air pollution and streetscaping studies exist with before and after measurements. Many studies showed how single changes, such as traffic flow or tree canopy, affect traffic related air pollution levels. However, few studies have shown how all these changes together as a full street re-design can impact traffic related air pollutants; especially in the context of Canadian cities.

2.6 Conclusion

The literature review has presented case studies related to TRAP with various study designs and monitoring methods examined. TRAP is made up of both gaseous and particulate matter. TRAP has been monitored through a variety of exposure related studies, however, most studies incorporate physical measurements of air pollutants to estimate exposure to obtain the most accurate data. Traffic flow, tree canopy and street layout can influence the levels of TRAP meaning modification of these factors can alter air pollution levels in cities. The literature review has identified knowledge gaps in the areas of urban modification and the effects on TRAP.

3.0 Methods

3.1 Study Area

The study area included three locations along Spring Garden Rd. (SGR), Sackville St. and Morris St. between, South Park Rd. and Queen St., in downtown Halifax, Nova Scotia (Figure 1). Due to the modifications that will be imposed on SGR during the SGREP, SGR was chosen as the main street of interest. However, when changes are imposed on a road they could divert traffic to alternative routes. Therefore, Sackville St. and Morris St. were also included in the study as they may experience an increase in traffic after the SGREP has been completed. They are also the nearer streets to SGR that connect South Park Street to Queen Street. Therefore, it was important for this project to track pollutant levels on all three streets.

Figure 1. Red dots indicate sampling locations, with corresponding site numbers, for traffic related air pollutants along Sackville Street, Spring Garden Road and Morris Street, Halifax. Figure created in ArcMap by Julia Walker on September 15, 2019.

This study focused on pollutants from traffic and aimed to minimize measuring external pollutant sources. Consequently, the sites on each road were specifically chosen in order avoid known pollution sources, such as bus stops and construction sites as they could influence the data collected. Although Clyde St. is also adjacent to SGR, it currently has multiple construction sites and road closures that could impact the measurement of TRAP. It was also anticipated that Clyde St. would not be an alternative thoroughfare to SGR for individuals commuting to downtown Halifax. In this study, all of the nine sampling sites are located at street intersections and in front of buildings. The buildings near the sites on Sackville St and SGR are primarily commercial buildings while the buildings on Morris St are mainly residential. The difference in land use amongst the streets could also impact how much TRAP is present in those areas. The data were collected between October 10th and November 4th 2019 (Table 3).

3.2 Sampling Approach

To meet the first and second objective of this study, air quality parameters were measured at each of the sites along the three streets, in intervals of two hours at three different time periods throughout the day (Table 1; Table 2; Table 3). The equipment was not permanently set up at these locations, but rather brought to and from the sites for each sampling session. The time periods of data collection include 7am-9am, 11am-1pm, and 7pm-9pm (Table 1; Table 2). These time periods were chosen to represent peak and non-peak times for traffic in the city to achieve fully representative air quality levels. Two-hour sampling time periods were chosen, as other studies had used this sampling length and found it successful (Dekker et al., 2018). Six volunteers were required for each sampling session as parallel sites on the three streets were sampled at the same date and time in order to obtain comparative results.

Table 1. Site locations and sampling time periods for ultrafine particle concentrations

Location	7-9am	11am-1pm	7-9pm
Sackville Street			
Site 7			x
Site 8		x	x
Site 9		x	x
Spring Garden Road			
Site 4	x		x
Site 5	x	x	x
Site 6	x		x
Morris Street			
Site 10			x
Site 11			x
Site 12		x	

Table 2. Site locations and sampling time periods for $PM_{2.5}$ measurements

Location	7-9am	11am-1pm	7-9pm
Sackville Street			
Site 7			x
Site 8		x	x
Site 9		x	x
Spring Garden Road			
Site 4	x		x
Site 5	x	x	x
Site 6	x	x	x
Morris Street			
Site 10			x
Site 11		x	x
Site 12		x	x

Table 3. Dates, day of the week, and time sampled for this study.

Date (dd/mm/yy)	Day of Week	Time (approx.)
10/10/19	Thursday	7-9pm
16/10/19	Wednesday	7-9pm
20/10/19	Sunday	11am-1pm
30/10/19	Wednesday	11am-1pm
2/11/19	Saturday	7-9am
4/11/19	Monday	7-9pm

3.3 Air Quality Measurements and Equipment Used

The measurements that were taken at each sampling site were concentrations of particles between 0.01-1 µm and particulate matter (PM) 2.5 µm in aerodiameter (TSI Incorporated, 2001; TSI Incorporated, 2019). Ultrafine particle concentrations were measured using a condensation particle counter (CPC) (Model 3007 TSI Inc.) (TSI Incorporated, 2001). $PM_{2.5}$ concentrations were measured using a DustTrak (Model DRX 8533 Desktop TSI Inc.) (TSI Incorporated, 2019). The operation of the machinery adhered to the guidelines set in each of the respective instructional manuals.

Immediately following each sampling session, the recorded data were downloaded from each of the machines onto the TSI Aerosol Instrument Manager Software Version 9.0 software (TSI Incorporated, 2001; TSI Incorporated, 2019). Then the recorded measurements were then exported as both software and text files and copied to Google Drive to be stored until data analysis.

3.4 Data Analysis

After each sampling session, each pollutant parameter data set were exported from the TSI software and imported into Microsoft Excel after each sampling session. These multiple data sets from each sampling session were then aggregated into one dataset to represent the different streets and time periods. Next, the spreadsheet was exported to the IBM statistical software SPSS Version 25, for data analysis. In conjunction with the third objective of this study, the data analysis compared the streets and time periods of data collection. Significant difference in air pollution levels between the three streets and between time periods were examined.

The data were analyzed using descriptive statistics. The descriptive statistics included examining median of various data comparisons, and skewness of the two pollutant parameters. The skewness for particle concentration and $PM_{2.5}$ data sets were 3.24 (SE=0.009) and 12.17 (SE=0.007) respectively. The kurtosis values for particle concentration was 28.68 (SE=0.0170 and 527.20 (SE=0.014) for $PM_{2.5}$. The skewness and kurtosis values indicate that the data for both pollutant parameters were not normally distributed. Therefore, median values were chosen to compare the data as they are less likely to be impacted by skewness, kurtosis and possible outliers in the data set. When data are not distributed normally, non-parametric analytical tests are more appropriate to use when determining significance. Therefore, for this study a Kruskal-Wallis statistical test was computed in SPSS in order to test pollution concentration differences between the streets and time periods. A Kruskal-Wallis test assesses whether or not the medians between groups are significantly different. The $PM_{2.5}$ data included 354 negative values between all of the sampling sites. Calibrating the equipment to zero occurred before each sampling session for both pieces of equipment. Negative values appear when improper calibration of the machine has occurred causing the DustTrak to read the measurement inaccurately (TSI Incorporated, 2019).

Therefore, negative values were removed from the $PM_{2.5}$ datasets before data analysis occurred.

To meet the fourth objective of the study, hourly means of the $PM_{2.5}$ concentrations collected in this study were compared to data collected at the Johnson Building on Granville Street, by Nova Scotia Environment, on the same dates and times for the years 2014-2019. The data were then displayed on a bar graph and boxplot to demonstrate the trend of $PM_{2.5}$ across the years.

4.0 Results

4.1 Overview

Several descriptive statistics were computed on various comparisons of the data. Each comparison is listed in its own section (4.2-4.3) within the results section of this thesis. A comparison between data collected for this study and data from NSE is reported in section 4.4.

Table 4. Summary descriptive statistics of the entire data set for particle concentration and $PM_{2.5}$ concentrations by street and time period

	Particle concentration (# particles/ cm^3)				$PM_{2.5}$ ($\mu g/m^3$)			
Street	Number of data points collected	Median	Min	Max	Number of data points collected	Median	Min	Max
Sackville St.	36374	13046	1	214741	35971	7	1	1130
Spring Garden Rd.	43465	17684	1	279029	43246	7	1	679
Morris St.	363	11608	3238	119248	35101	8	1	197
Time Period								
Morning	14433	13604	4661	265749	14519	5	1	212
Afternoon	22236	6507	1328	230793	42079	4	1	1130
Evening	43532	19329	1	279029	57720	10	3	981

Table 5. Summary descriptive statistics of SGR data for particle counts and $PM_{2.5}$ concentrations by time period

	Particle concentration (# particles/ cm^3)				$PM_{2.5}$ ($\mu g/m^3$)			
Street	Number of data points collected	Median	Min	Max	Number of data points collected	Median	Min	Max
Time Period								
Morning	14419	13604	4661	265749	14519	5	1	212
Afternoon	7535	18330	5517	230793	14207	9	1	679
Evening	14383	15172	0	279029	14520	8	3	178

Table 6. Summary descriptive statistics evening data for particle counts and $PM_{2.5}$ concentrations by street.

	Particle concentration (# particles/ cm^3)				$PM_{2.5}$ ($\mu g/m^3$)			
Street	Number of data points collected	Median	Min	Max	Number of data points collected	Median	Min	Max
Sackville St.	21805	19553	0	211767	21600	10	3	981
Spring Garden Rd.	14383	15172	0	279029	14520	8	3	178
Morris St.	119	42184	34083	119248	21600	12	1	196

4.2 Comparison of particle concentration and $PM_{2.5}$ data between streets

Data were aggregated into one data set and analyses were conducted on the entire data set for both particle concentration and $PM_{2.5}$. SGR had the greatest median particle concentration (17684.5 particle count/cm^3) compared to Sackville Street (13046.5 particle count/cm^3) and Morris Street (11608 particle count/cm^3) (Figure 2). Morris Street had a higher median $PM_{2.5}$ (8 $\mu g/m^3$) compared to Sackville Street and SGR presented the same value (7 $\mu g/m^3$) (Figure 3). Results from the Kruskil-Wallis test found significant differences for both particle concentration ($H=5068$, $p<0.000$, $df=2$) and $PM_{2.5}$ ($H=412$, $p<0.000$, $df=2$). The p-values are lower that the alpha value of 0.05, therefore the null hypothesis of no significant difference between the three streets, for both $PM_{2.5}$, and particle concentration is rejected.

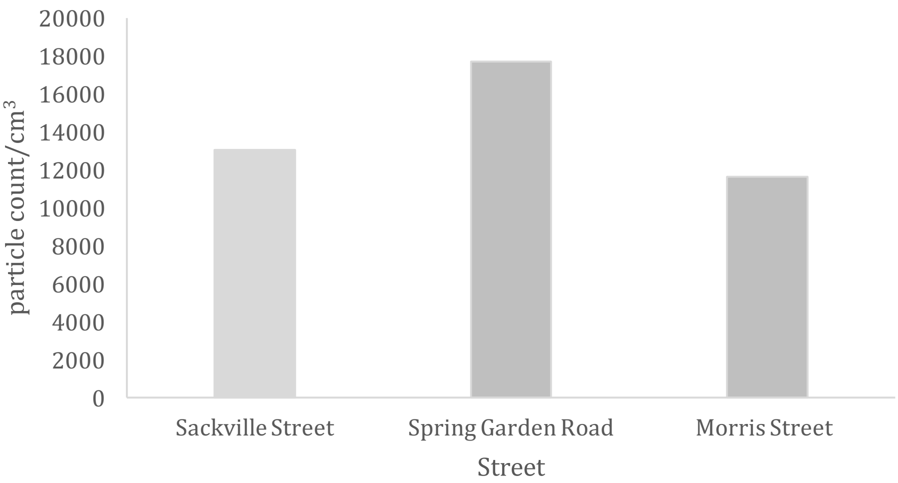

Figure 2. Median particle concentration (particle count/cm^3) of all data collected for Sackville Street, Spring Garden Road and Morris Street. Data collected during October and November 2019 by Dalhousie University undergraduate students.

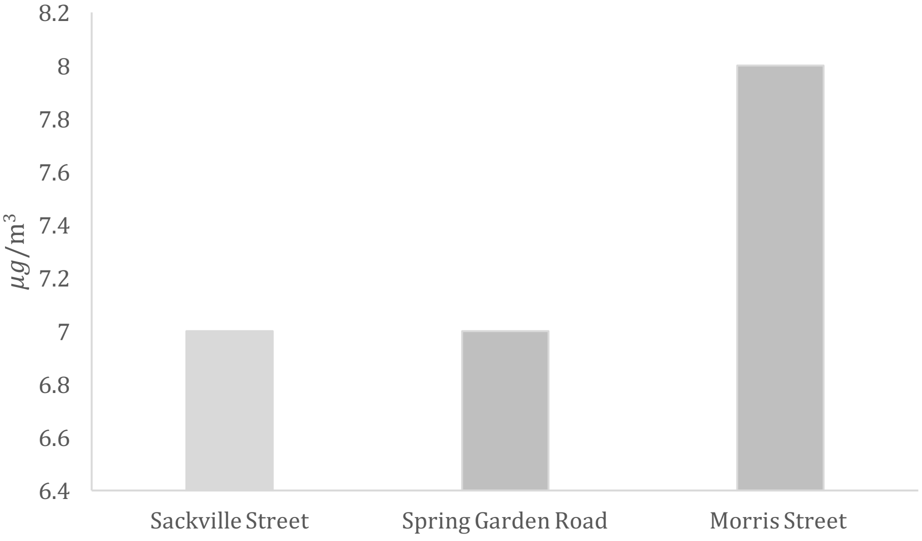

Figure 3. Median $PM_{2.5}$ (μg/m³) of all data collected for Sackville Street, Spring Garden Road and Morris Street. Data collected during October and November 2019 by Dalhousie University undergraduate students.

Evening measurements were aggregated and compared to test the difference in pollutant medians between streets for the evening period (7-9pm). For particle concentrations, Morris Street had the highest median value (42184 particle count/cm^3) compared to Sackville Street (19553 particle count/cm^3) and Spring Garden Road (19060 particle count/cm^3) (Figure 4). Morris Street also indicated the highest median values (12 μg/m^3) for $PM_{2.5}$ data collected compared to Sackville Street (10 μg/m^3) and SGR (8 μg/m^3) (Figure 5). Results from the Kruskil-Wallis test found significant differences for both particle concentration ($H=281$, $p<0.000$, $df=2$) and $PM_{2.5}$ ($H=4171$, $p<0.000$, $df=2$). The p-value is less than the alpha value (0.05), therefore the null hypothesis indicating that there is no significance between streets during the evening time period is rejected.

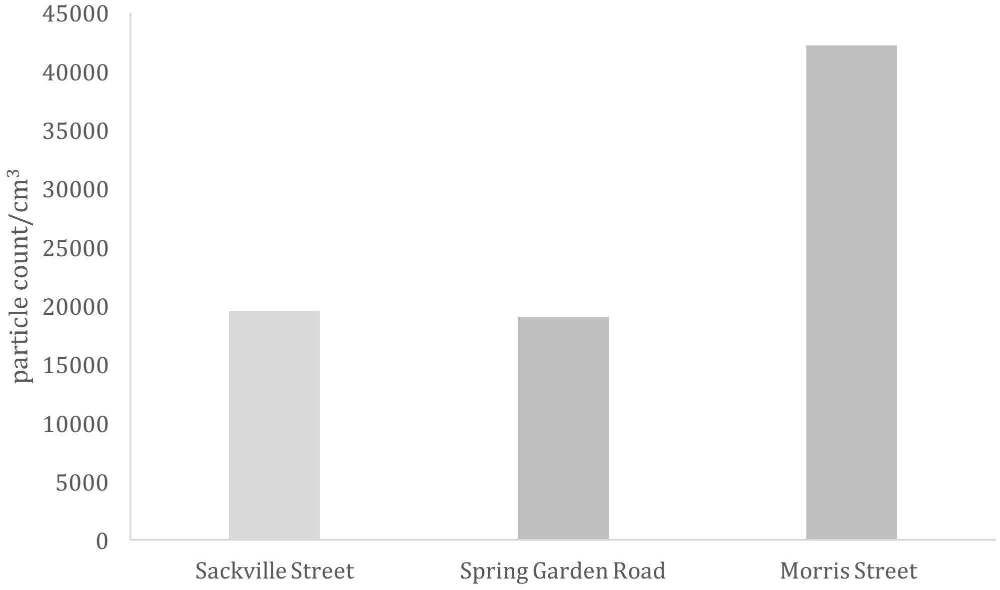

Figure 4. Median particle concentration (particle count/cm^3) of evening data for Sackville Street, Spring Garden Road and Morris Street. Data collected during October and November 2019 by Dalhousie University undergraduate students.

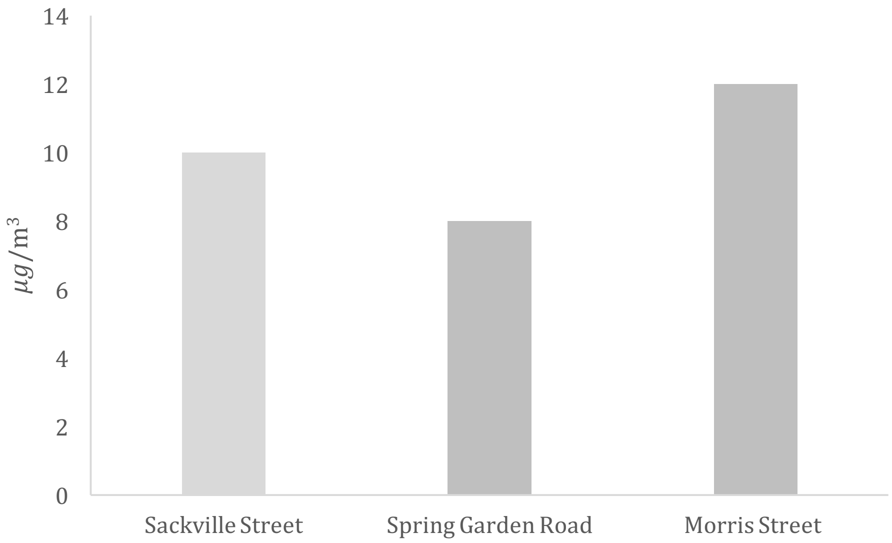

Figure 5. Median $PM_{2.5}$ (μg/m^3) of evening data for Sackville Street, Spring Garden Road and Morris Street. Data collected during October and November 2019 by Dalhousie University undergraduate students.

4.3 Comparisons of particle concentration and $PM_{2.5}$ data between time periods

Ultrafine and fine particulate air pollution data were aggregated to calculate the three measurement periods for data analysis. The highest median particle concentration was measured in the evening period (19329 particle count/cm^3) compared to morning (13640 particle count/cm^3) and afternoon (6307.5 particle count/cm^3) periods (Figure 6). The evening time period also showed to have the highest median value for $PM_{2.5}$ (10 μg/m^3) compared to morning (5 μg/m^3) and afternoon (4 μg/m^3) periods (Figure 7). Results from the Kruskil-Wallis test found significant differences for both particle concentration (H=20616, p<0.000, df=2) and $PM_{2.5}$ (H=33076, p<0.000, df=2). The results of the tests for both pollutants showed p-values less than alpha (0.05). Therefore, the null hypothesis is rejected because there is no significant difference between time periods for both particle concentration and $PM_{2.5}$.

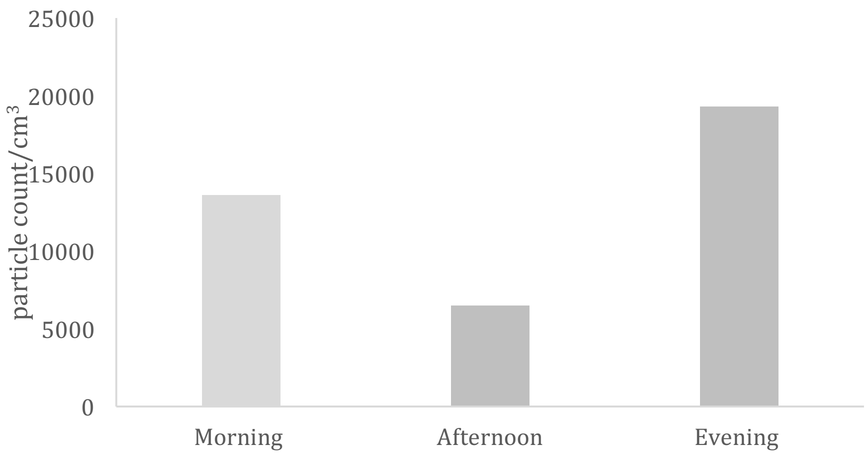

Figure 6. Median particle concentration (particles/cm^3) for Morning (7am-9am), Afternoon (11am-1pm), and Evening (7pm-9pm) times across all streets. Data collected during October and November 2019 by Dalhousie University undergraduate students.

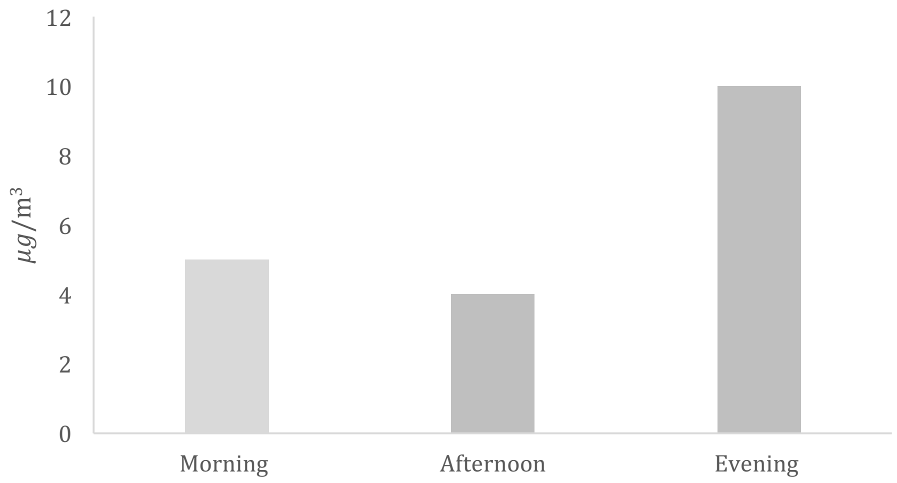

Figure 7. Median $PM_{2.5}$ ($\mu g/m^3$) for Morning (7am-9am), Afternoon (11am-1pm) and Evening (7pm-9pm). Data collected during October and November 2019 by Dalhousie University undergraduate students.

Data from only SGR was used to compare time periods as data from all time segments and sites along SGR was collected. The results of this analysis revealed that the afternoon (11am-1pm) period had the highest median particle concentration (18330 particle count/cm^3). Comparatively, the evening (15172 particle count/cm^3) and the morning (13604 particle count/cm^3) (Figure 8). $PM_{2.5}$ saw a similar trend of afternoon having the highest median values (9 $\mu g/m^3$), compared to evening (8 $\mu g/m^3$) and morning (5 $\mu g/m^3$) (Figure 9). Results from the Kruskil-Wallis test found significant differences with both particle concentration ($H=971$, $p<0.000$, $df=2$) and $PM_{2.5}$ ($H=5099$, $p<0.000$, $df=2$). Therefore, the null hypothesis of no significance between time periods on SGR is rejected.

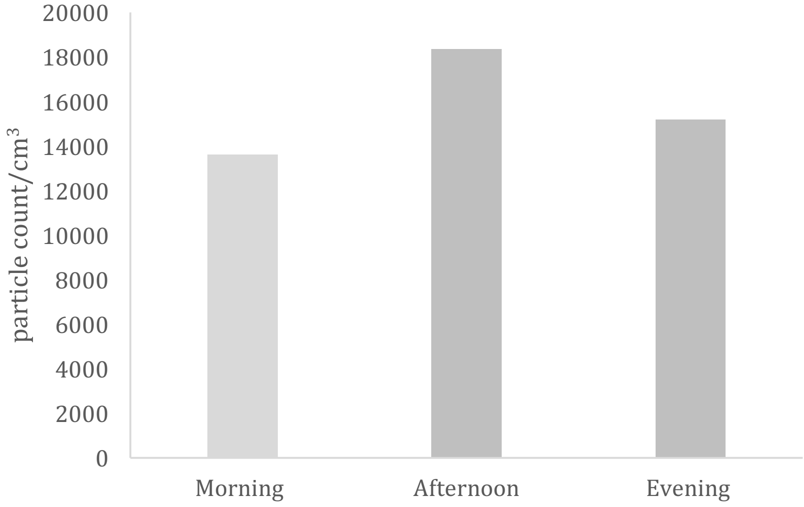

Figure 8. Median particle concentration (particle count/cm^3) for Morning (7am-9am), Afternoon (11am-1pm), and Evening (7pm-9pm) time periods for Spring Garden Road in Halifax. Data collected during October and November 2019 by Dalhousie University undergraduate students.

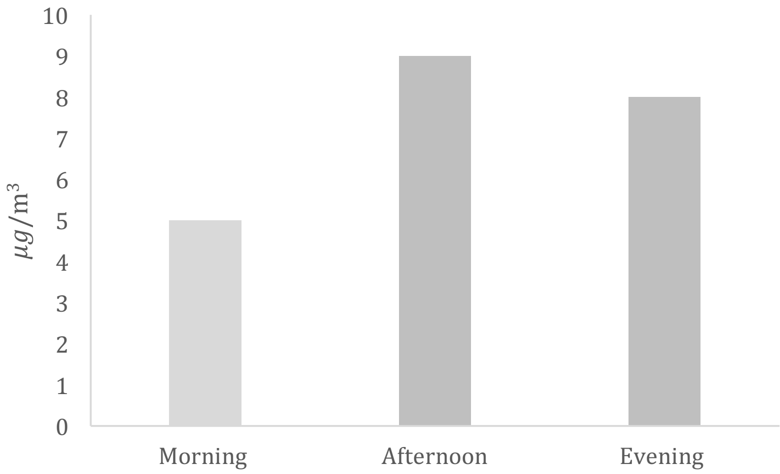

Figure 9. Median $PM_{2.5}$ ($\mu g/m^3$) for Morning (7am-9am), Afternoon (11am-1pm), and Evening (7pm-9pm) for Spring Garden Road in Halifax. Data collected during October and November 2019 by Dalhousie University undergraduate students.

4.4 Comparison of $PM_{2.5}$ data to Nova Scotia Environment collected data

Hourly mean $PM_{2.5}$ data collected during this study on SGR were compared to data previously collected by NSE for the same months and time periods over the past five years, 2014-2018 (Figure 10). As a caveat, due to differences in the locations of the NSE sampling site and SGR, the comparison is for reference only. The results illustrate that for the evening periods (7pm and 8pm) are higher for the year 2019 than in the previous years recorded (Figure 10). The morning periods (7am and 8am) show a general increase in $PM_{2.5}$ concentrations over the years with 8am for the year 2016 having higher concentrations thank the other documented years (Figure 10). A boxplot of the data was also computed to show the trend in $PM_{2.5}$ between the years of 2014-2019 (Figure 11). The results show a general increase of $PM_{2.5}$ concentrations from 2014-2019.

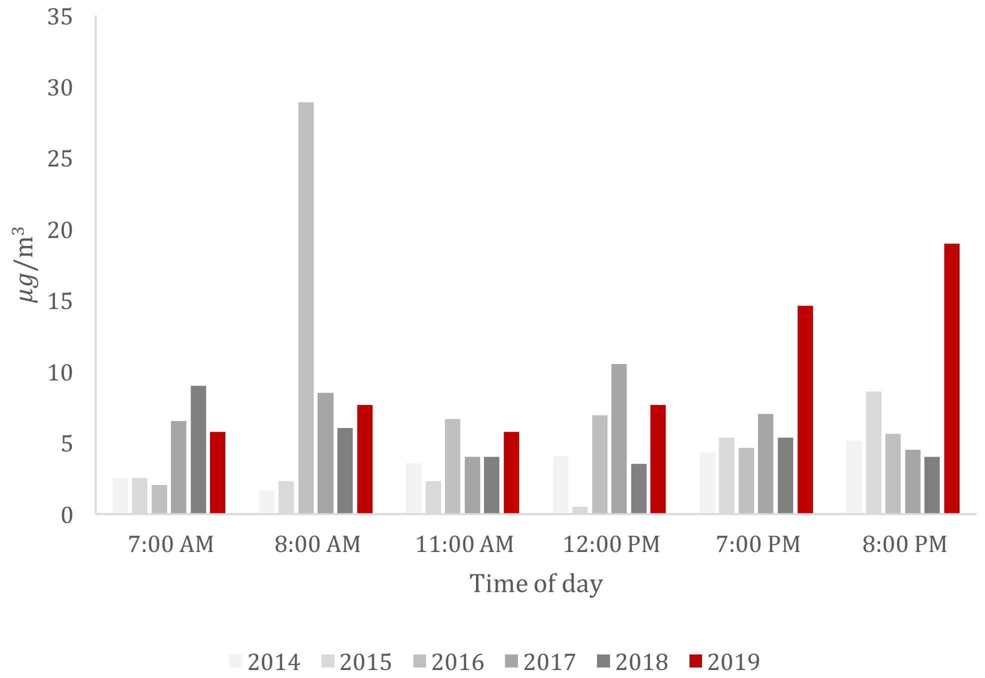

Figure 10. Hourly averages for $PM_{2.5}$ in 2014. 2015, 2016, 2017, 2018 and 2019 for downtown Halifax for time periods 7am, 8am, 11am, 12pm, 7pm, and 8pm. 2014-2018 data from obtained from Nova Scotia Environment Granville Street, Halifax, data station during the months of October and November for each year (grey scale bars). 2019 data collected on Spring Garden Road, Halifax by Dalhousie University undergraduate students in October and November 2019 (red bars).

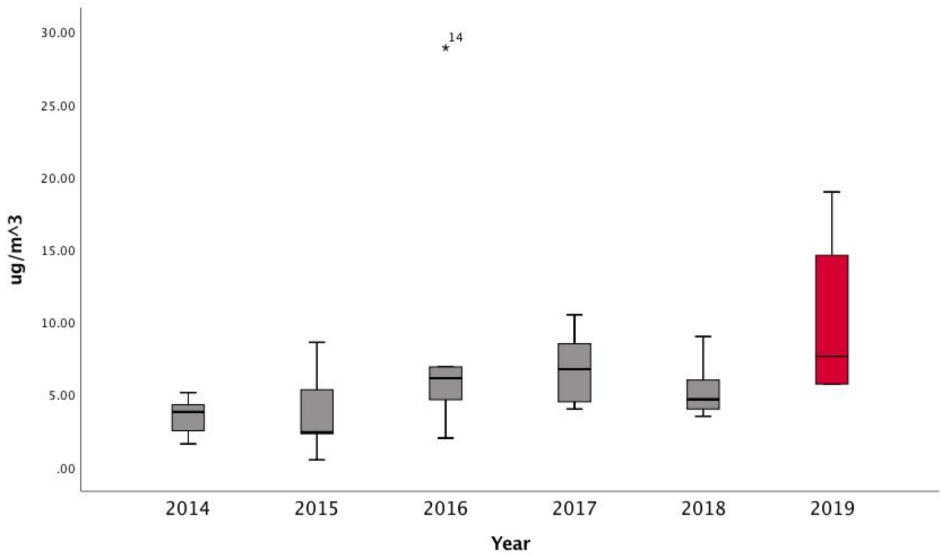

Figure 11. Box plot of $PM_{2.5}$ (μg/m^3) data for 2014 to 2019 in downtown Halifax between the hours of 7am-9pm. 2014 to 2018 data collected by Nova Scotia Environment on Granville Street, Halifax, during October and November each year (grey boxes). 2019 data collected by Dalhousie University undergraduate students on Spring Garden Road during October and November 2019 (red box).

5.0 Discussion

This study acted as a baseline for determining air pollution concentrations for specific locations in the downtown Halifax area that are likely to be affected by the SGREP. All four objectives for this thesis were met. Data collection commenced on Sackville Street, Spring Garden Road and Morris Street. The three streets were compared to see the difference in particle concentration and $PM_{2.5}$ levels. However, because data were not collected from each sampling site for each time period, the entire dataset could not exclusively be used to compare the data. Therefore, the evening time period was used to compare the streets, as all three sites for the 7-9pm have collected measurements. From this analysis, Morris Street had the highest median levels of particle concentration and $PM_{2.5}$. This was unexpected, as it was assumed that SGR would have the higher levels being indicated as the busiest street in the study. Pollution concentrations were found to be statistically different between the three streets, which demonstrated that particulate matter could vary amongst location within a close geographical region. This variance could be due to external influences such as construction sites. Morris Street also had some active construction sites during the time of the study. This could have influenced the data collected if particles from the construction site were captured by the equipment. Wind speed and direction could have also brought external particles to the study area, and depending on the direction of the wind could influence certain sites over the others. Studies have shown that wind speed and direction has had a great influence on particulate matter levels observed in the atmosphere (Du et al., 2013).

The second analysis compared particulate matter concentrations between the different time periods. When analysis was completed on the entire data set, results revealed that the evening time period (7-9pm) had the highest median values for both $PM_{2.5}$ and particle concentration. These particular results could be influenced by the planetary boundary layer height (PBLH) being low in the 20:00-24:00 hour periods of the day (Du et al., 2013). Studies have shown that there is a negative relationship between PBLH and particulate matter in the atmosphere, therefore the lower the height of the layer, the higher the PM concentration (Du et al., 2013). Overall, the PBLH is lower in the autumn and winter months because of factors such as temperature, heat fluxes, cloud cover, wind speed and wind direction (Du et al., 2013).

Consequently, not all sampling locations had equal amounts of data. It was therefore determined that SGR was going to be used for further analysis of differences in time periods as it had data from all sites and time periods. The results from this analysis showed the afternoon having higher median levels of both $PM_{2.5}$ and particle concentration. Other studies have shown that production of $PM_{2.5}$ from precursor gasses more frequently occurs at warmers temperatures (Liu & Cui, 2014; Tai et al., 2012). Warmer temperatures could explain why $PM_{2.5}$ levels were greater in the afternoon period on SGR than at the other time periods, since the temperature is more likely to be higher in the afternoon when thermal radiation is present as opposed to the mornings and evenings when it is lower. Moreover, studies also show that photochemical reactions in the atmosphere enhance the formation of secondary particles such as particulate matter (Hu et al., 2019). During daylight hours, there are more photochemical reactions occurring resulting in higher particulate matter concentrations (Hu et al., 2019). This is also consistent with the findings in our study, as the time periods with daylight show higher median values than evening time periods where there is no sunlight available for photochemical reactions. More research comparing the meteorological data to the air pollution data collected would be needed to support this hypothesis. The statistical analysis did show that there was a significant difference between time periods for all analysis done on time period comparisons. It is indicated that it is possible that time of day could impact the levels of pollutant concentrations in Halifax. This is consistent with the literature, as one study found that morning rush hour and evening rush hour time periods had higher pollutant levels than in the middle of the day (Patton et al., 2014). This is similar to the results this study found when the entire data set was analyzed (Figure 6; Figure 7).

Overall, it is important to note that there are various external factors that can impact PM levels in the atmosphere besides only vehicle emissions. In addition to external factors, the data collection process and analysis could have impacted the results shown. Since not every location or time period was sampled equally, the results could be skewed. The data from different dates and times were aggregated into the same dataset for analysis. Therefore, inaccuracies in the comparisons could have occurred as a result of combining different sets of data. However, these results remain important as this information could provide insight into policy that could put restrictions on traffic to allow for less air pollution.

The $PM_{2.5}$ data collected for this study were compared to data collected by NSE between the years of 2014-2018 (Figure 10; Figure 11). Multiple years of NSE data were used to analyse potential trends from previous years to current data. Moreover, these data and trends could be used for comparison for post SGREP data collection and analysis. Figure 10 shows that the years 2016 (8am), 2017 (12pm), 2019 (7pm & 8pm) have higher mean values than the 10 $\mu g/m^3$ CAAQ standard for annual $PM_{2.5}$ levels (Canadian Council of Ministers of the Environment, 2012). Despite the fact that the majority of the time periods have values lower than the CAAQS, this particular analysis demonstrates that Halifax can have values outside of $PM_{2.5}$ suggested levels. Figure 11 illustrates more comprehensive descriptive statistics of the data by including the minimum, maximum, upper and lower quartiles and median for the NSE $PM_{2.5}$ data from 2014-2018 and data collected for this thesis. The overall trend shows a possible increase of $PM_{2.5}$ over the years (Figure 11). This increase is significant because the upward trend could result in $PM_{2.5}$ levels surpassing CAAQS in future.

The 2019 $PM_{2.5}$ shows significantly higher PM levels than the previous year's (Figure 11). However, direct comparisons between the NSE data and the $PM_{2.5}$ data for this thesis cannot be made, thus no analytic statistics were computed between the data. Direct comparisons cannot be made because the NSE data were collected at a different location, different height and through using different equipment than the 2019 data. These differences could impact the results and thus a direct comparison would be invalid. In 2012, Halifax showed to have a three-year average of approximately 16 $\mu g/m^3$ of $PM_{2.5}$ Canadian Council of Ministers of the Environment, 2012). The sampling scheme aimed to collect data from three sites across the three streets for time periods 7am-9am, 11am-1pm, 7pm-9pm, however; data collection did not occur for all time periods and sites (Table 1; Table 2). The limited data collection was primarily due to volunteer availability. When volunteers were limited, SGR was prioritized as the area to collect data as this is the street that is going to be reconstructed during the SGRE project. Moreover, every site was sampled for the evening time period (7-9pm) as this was the time period that most volunteers were available for data collection. The unequal amount of data collected between streets, sites and time periods could impose biases and inaccuracies within the data analysis. Other limitations included only being able to take accurate samples when there was a lack of precipitation, due to the equipment not being waterproof. This could also impact results, as precipitation reduces $PM_{2.5}$ in the atmosphere compared to when there is no precipitation (Jacob & Winner, 2009). Therefore, the data that were collected is not a full representation of $PM_{2.5}$ in all atmospheric conditions, and therefore could represent higher data values due to the lack of rain present which would have dispersed the particulate matter. The study also has temporal limitations as data collections were only conducted during October and November in 2019. This time duration only represents one out of four seasons during the year, and results cannot accurately be extrapolated to yearly trends. For example, literature indicates that summer seasons show higher values for $PM_{2.5}$ as warmer temperatures help the production of $PM_{2.5}$ from precursor chemicals, while other seasons have lower values (Jacob & Winner, 2009; Tai et al., 2012). Therefore, the data collection that occurred in this study could represent data values that are lower and not representative of every season. Future studies could look further into the relationship of the data collected and the meteorological effects that occurred during the sampling periods.

Despite the limitations to the data collection, this study is important as it acts as a baseline for air pollution levels at the streets that were sampled. The methods set in this study can be repeated in future seasons to add to the baseline data pool. Most importantly, this study should be repeated after the construction of the SGRE project to understand the effects of streetscaping on air pollution in Halifax.

6.0 Conclusions

This thesis aimed to answer the question: What are the current air quality levels of areas likely to be impacted by the Spring Garden Project Enhancement? $PM_{2.5}$ and ultrafine particle concentration measurements were taken along Sackville Street, SGR and Morris Street to assess the current air quality levels. Data were collected on these three streets during the months of October and November 2019. Non-parametric data analysis was employed to compare median concentrations of air pollution among streets and sampling periods. Although some time periods and streets had values above the recommended 10 $\mu g/m^3$ guideline, overall the pollution concentrations in the SGR area were lower. This thesis contributed new information to HRM by providing a baseline of air pollution levels for the SGR area. It is recommended that the baseline data collection phase continue into the Summer and Autumn of 2020 to get a more comprehensive sampling of data for the baseline. To fully understand the effects of streetscaping projects on air quality levels, this study should be repeated after the construction of the SGRE project to test for significant differences in air quality levels. The results can be used to make policy decisions about pollution levels and to guide future streetscaping initiatives in Halifax.

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