AIR QUALITY AT BUS STOP MICROENVIRONMENTS IN A METRO VANCOUVER URBAN AND SUBURBAN AREA

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ABSTRACT

BACKGROUND
Those commuters waiting in small-scale transportation microenvironments, such as bus stops, can be exposed to levels of pollution higher than what is registered by ambient air quality monitoring stations. In addition, historically, those commuting in urban areas experience greater exposure to air pollutants than those commuting in suburban or rural areas, due to the nature of the environment. Little quantitative research has been conducted in the Metro Vancouver area regarding air quality in small scale transportation microenvironments.

OBJECTIVES
The aim of this study was to assess the differences in commuter exposure during AM Peak and PM Peak periods between an urban (Vancouver) and suburban (Ladner) bus stop. Furthermore, results were to be compared to the Metro Vancouver 24 hour rolling average objective as well as nearby Lower Fraser Valley (LFV) Ambient Air Quality Monitoring Network stations.

METHODS
The author measured particulate matter (PM) 2.5 (particulate matter ≤ 2.5 µm in aerodynamic diameter), using the DustTrak™ Aerosol Monitor 8520 between January 6, 2014 and January 21, 2014 on 12 weekdays, from 6:30am to 7:00am and 5:00pm to 5:30pm, at Stop #55165 Northbound Harvest Dr at Ladner Trunk Rd in Ladner, BC and from Stop #50043 Burrard Stn Bay1 in Vancouver, BC. In addition, meteorological conditions, traffic density, bus volume, and other observations were taken during sampling periods.

RESULTS
The author found that average $PM_{2.5}$ exposures were highest during the morning in Ladner (μ=34.38667µg/m^3) and lowest during the morning in Vancouver (μ=13.44 µg/m^3). In addition, there was a statistically significant difference ($p<0.05$) between Vancouver AM and the other groups (Ladner AM, Ladner PM [μ=28.07778 µg/m^3], and Vancouver PM [μ=30.16667 µg/m^3]), but the other groups were not significantly different from each other. Furthermore, the author found that the Vancouver AM average (μ=13.44 µg/m^3) was below the Metro Vancouver 24 hour rolling average (25µg/m^3) while all other groups (Ladner AM, Ladner PM, and Vancouver PM) exceeded this average. Lastly, when comparing all groups to the AM and PM hourly averages of their respective LFV Air Quality Monitoring Network stations (Ladner AM and PM vs. Tsawwassen AM and PM and Vancouver AM and PM vs. Kitsalano AM and PM), the author found that all groups averages exceeded the hourly averages of their respective stations.

CONCLUSION
Commuters' peak hour exposures were significantly influenced by different microenvironments and were found to be higher than the ambient $PM_{2.5}$ levels registered by the respective LFV Air Quality Monitoring Network stations. In order to address this, Metro Vancouver should implement personal exposure assessments, especially near roadways, to obtain actual levels of exposure to pollutants, such as $PM_{2.5}$, by their residents. In this way, acute and chronic health outcome risks to air pollution can be better understood.

Keywords: air pollution, $PM_{2.5}$, bus stop, commuting, microenvironment, personal exposure, ambient air, urban, suburban, Metro Vancouver

INTRODUCTION

Air is of vital importance to human beings from their first gasp to their last breath. Clean air is vital to human survival and well-being, but in today's urbanized world, clean air is something that is increasingly hard to find. Despite major improvements, such as the introduction of cleaner fuels, more stringent emissions limits for newer vehicles, and road management, increasing traffic volume in urban areas is undermining the benefits of major improvements (World Health Organization, 2005).

Hertel & Goodsite (2009) state that "air pollution is estimated to cause about 2 million premature deaths worldwide annually." The highest concentration of air pollution is in urban environments and is associated with a greater amount of negative health impacts compared to suburban or rural environments. Almost half of the world's population resides in cities and this number is increasing (Hertel & Goodsite, 2009).

Of the ambient air pollutants, particulate matter is considered to be the most hazardous (Hertel & Goodsite). In Metro Vancouver, the Lower Fraser Valley Air Quality Monitoring Network monitors for air pollutants such as particulate matter. PM2.5, along with ozone, is considered a priority pollutant by Metro Vancouver (2012a) because "PM2.5 particles are small enough to be breathed deeply into the lungs, resulting in impacts to both respiratory and cardiovascular systems." Also, Metro Vancouver (2012a) highlighted PM2.5 emitted from diesel fuel combustion engines to be of particular concern.

Exposure to PM2.5 is of particular concern to those commuters waiting at bus shelters due to their close proximity to roadways and diesel buses. However, these small-scale transportation microenvironments are often overlooked when using large scale monitoring networks such the Lower Fraser Valley Air Quality Monitoring network. Kaur, Nieuwenhuijsen, & Colvile (2007) have stated "fixed monitoring sites have been repeatedly shown to be poor surrogates of personal exposure, particularly in the transport microenvironment." In addition, little research has been conducted in Metro Vancouver regarding air quality in these small-scale transportation microenvironments.

Due to the aforementioned reasons, the author took particular interest in this topic and decided to focus her research on small-scale transportation microenvironments in the Metro Vancouver suburban town of Ladner and urban city of Vancouver. Moreover, being a student who regularly commutes by bus and lives in Ladner, the topic was well suited and had a personal element.

This study is of particular importance because the public is increasingly encouraged to switch from private to public modes of transportation for environmental reasons (Hess, Ray, Stinson, & Park, 2010). Currently, 239 million transit trips occur each year and the number of persons using transit services will continue to grow (TransLink, 2012). Knowledge of the varying amount of pollution commuters will be exposed to in their specific small-scale transportation microenvironments could be beneficial in helping to protect them from this very pollution.

Therefore, the objective of the proposed research project will be to evaluate bus stop microenvironments for PM2.5 at a bus stop in Vancouver's downtown core compared to a bus stop in the suburban community of Ladner. This will help gain a better understanding of the personal pollution exposure in small-scale transportation microenvironments within Metro Vancouver.

LITERATURE REVIEW

PARTICULATE MATTER

Health Canada (2007) states that particulate matter (PM) "refers to all airborne solid and liquid particles, except pure water, that are microscopic in size." PM can be composed of a broad range of chemical species, but compared to other atmospheric constituents, particulate matter is unique in that it is not categorized based on its chemical composition (Health Canada, 2007). The composition of PM can include, but is not limited to, the following chemical species: elemental and organic carbon compounds; oxides of silicon, aluminum and iron; trace metals; sulphates; nitrates and ammonia (Health Canada, 2007).

When describing the behaviour of PM in the atmosphere, the aerodynamic diameter of PM is the most important parameter to consider (Health Canada, 2007). PM in ambient air is generally broken down into the following three distinct class sizes: ultrafine (diameter: 0.01-0.1μm), fine (diameter: 0.1-2.5μm), and coarse (diameter: >2.5μm) (Hertel & Goodsite, 2009). PM10, the concentration, by mass, of particles less than 10μm in diameter, encompasses all these distinct class sizes whereas PM2.5, the concentration, by mass of particles less than 2.5μm in diameter, encompasses the fine fraction. Both PM10 and PM2.5 are regularly monitored throughout the Lower Fraser Valley (LFV) Air Quality Monitoring Network (Metro Vancouver, 2012a).

PM10 is known as the inhalable fraction of airborne particles and reflects the proportion of suspended particles that can be inhaled into the respiratory tract (Brauer, 2002). The coarse fraction of PM10 (2.5-10μm) mainly originates from "soil material, such as re-suspended road dust and windblown dust and from materials handling, crushing, and grinding operations" (Brauer, 2002).

On the other hand, PM2.5 is known as the respirable fraction of airborne particles and encompasses the particles capable of entering the alveolar region of the lung (Brauer, 2002). PM2.5 consists mainly of particles produced due to fuel combustion (motor vehicles, industry, power plants etc.), fireplaces, and wood stoves, and via atmospheric reaction of gases (Brauer, 2002). In regards to this study, PM2.5 is of particular concern due to the fact that commuters waiting at bus stops can easily be exposed to particulates produced by fuel combustion in motor vehicles (e.g. cars, trucks, motorcycles, heavy duty vehicles, and buses).

PARTICULATE MATTER LEGISLATION AND AIR QUALITY OBJECTIVES

The presence of particulate matter in the atmosphere is from a contribution of both natural (e.g. volcanoes, forest fires, erosion) and anthropogenic sources (e.g. motor vehicles, home heating, industry). Background concentrations (ambient PM) in North America, based on an annual or long term basis, for PM10 range from 4 to 11 μg/m3 while PM2.5 ranges from 1 to 5 μg/m3 (Health Canada, 2007).

Currently in British Columbia (BC) and Metro Vancouver, there is legislation put in place to limit the amount of PM that contributes to public exposure over the background concentration. The Motor Vehicle Act, the Environmental Management Act (EMA), and various municipal and regional bylaws are provincial pieces of legislation that govern air quality and the controlling of air contaminants and fuel emissions. Additionally, the EMA provides the Minister of Environment with the power to develop guidelines that provide objectives for the management of air quality in BC (BC Air Quality, 2013). Air quality objectives are non-statutory objectives that guide air quality management decisions in BC.

Metro Vancouver has established their own air quality objectives that apply within the Metro Vancouver area. These objectives are based on a suite of ambient air quality criteria that has been developed both provincially and nationally (BC Air Quality, 2013a). Metro Vancouver PM10 objectives for a maximum 24 hour rolling average and annual average are 50 μg/m3 and 20 μg/m3, respectively, while PM2.5 objectives for maximum 24 hour rolling average and annual average are 25 μg/m3 and 8 μg/m3, respectively (Metro Vancouver, 2012a).

Data is collected by the LFV Air Quality Monitoring Network and PM10 and PM2.5 concentrations are usually below the objectives, but when exceedances do occur, it is usually attributed to distinct episodes relating to smoke and forest fires (Metro Vancouver, 2012a).

Despite the fact objectives are being met, research has indicated that adverse health impacts can still result from the pollutant concentrations in the LFV (Metro Vancouver, 2012a). In addition, these are objectives for ambient air quality and do not accurately pertain to small-scale transportation microenvironments experienced by individual people. Persons in small-scale transportation microenvironments can easily experience high quantities of PM2.5 pollution that can be hazardous to health, which will never register on the LFV Air Quality Monitoring Network. This study seeks to determine what persons in these small-scale transportation microenvironments are really being exposed to while they are commuting. In addition, these are only objectives or positive goals to aim for, not strict legislative standards that protect air quality.

HEALTH IMPACTS OF PARTICULATE MATTER

In general, PM is considered to be the most hazardous of the ambient air pollutants (Hertel & Goodsite, 2009). However, Li et al. (2013) found that most studies state that PM2.5 is more strongly associated with respiratory-related death than PM10. In addition, a study conducted by Cesaroni et al. (2013) discovered that long term exposures to PM2.5 were associated with an increase in non-accidental mortality especially due to cardiovascular causes. Given the small size of these particles, they can penetrate deeper in the lungs into an area that is more vulnerable to disease (i.e. PM is harder to remove, there is a presence of delicate structures, and there is easier access to circulatory and lymphatic systems).

Metro Vancouver (2012a) has also labelled PM2.5 as a priority pollutant to be monitored by the LFV Air Quality Monitoring Network due to its chronic and acute human health impacts, its ability to aggravate pulmonary and cardiovascular disease, and its capacity to increase symptoms in asthmatics that increase mortality.

Furthermore, Metro Vancouver (2012a) states that "of particular concern is PM2.5 emitted from diesel fuel combustion in [bus,] car, truck, marine, rail and non-road engines." These particles, also known as diesel particulate matter, are thought to contribute significantly to the health effects mentioned above. There is an extensive amount of studies that relate diesel particulate matter to adverse health effects (Buzzard, Clark, & Guffey, 2009). Additionally, diesel particulate matter is thought to be responsible for "[67%] of the lifetime cancer risk from air pollution in Metro Vancouver" (Ministry of Transportation and Infrastructure, 2011).

Since PM2.5 is linked to many adverse health outcomes, is considered to be a high priority pollutant by the LFV Air Quality monitoring network, is associated with diesel fuel combustion (i.e. buses), and there is a strong correlation between diesel particulate matter and increased cancer risk in Metro Vancouver, PM2.5 is the focus pollutant of this study.

EXPOSURE TO PARTICULATE MATTER IN URBAN ENVIRONMENTS

Hertel & Goodsite (2009) state that "urban air pollution arises from the competition between emission processes which increase pollutant concentrations, and dispersion advection and deposition processes that reduce and remove them." In general, when the ability of the urban environment to disperse PM vertically and horizontally increases, the PM concentration in that environment decreases (Salmond & McKendry, 2009).

Due to the usually complex built form of urban environments and the human activities associated with these urban environments, there is a great impact on the dispersion of pollutants compared to surrounding rural areas (Salmond & McKendry, 2009). The World Health Organization (2005) found that "urban and urban background levels have been shown to be consistently higher than levels in suburban and rural locations." Moreover, a study conducted by Kaur, Nieuwenhuijsen, & Colvile (2007) found that "[average] exposure to particulates has been found to be nearly double at intersections surrounded by buildings than those surrounded by open space."

In urban areas, trafficked streets are considered to be air pollution hot spots (Hertel & Goodsite, 2009).

The largest contributors to air pollution emissions are mobile sources, which include any combustion-powered vehicle, aircraft, and marine transport (Brauer, 2002). Buzzard, Clark, & Guffey (2009) have estimated that 35% of ambient PM2.5 is contributed by mobile sources. Also, the low release heights associated with vehicular transport contributes significantly to the concentrations of PM2.5 at ground level (Hertel & Goodsite, 2009). This is due to the fact that low release height emissions aren't diluted as well as those released from tall release heights; therefore resulting in a more concentrated exposure to PM2.5 for persons at ground level.

Key mobile sources of air pollution in urban areas are usually attributed to gasoline-engine vehicles, but diesel engines have been shown to emit higher levels of PM2.5 contributing significantly to fine particle accumulation (Hess, Ray, Stinson, & Park, 2010). A study conducted by Buzzard, Clark, & Guffey (2009) found that "due to the nature of many vehicles exhaust systems, pedestrians in close proximity to a vehicle's tailpipe may experience events where diesel particulate matter concentrations are high enough to cause acute health effects for brief periods of time." Also, Hertel & Goodsite (2009) found studies where PM concentrations in urban streets are significantly reduced if the sulfur content in diesel is decreased.

PARTICULATE MATTER EXPOSURE AT BUS STOPS

Moore (2012) has found that diesel transit buses in particular have been singled out as substantial mobile PM sources in urban environments. Those persons waiting at bus stops and who routinely use public transit will have acute and chronic exposure to diesel particulate matter. As mentioned previously, Buzzard, Clark, & Guffey (2009) found that diesel particulate matter exposure during drive by incidents can easily exceed the low concentrations that can cause acute health effects. In addition, the United States Environmental Protection Agency (2002) states that chronic exposure to diesel particulate matter is "likely to pose a lung cancer hazard as well as damage the lung in other ways…."

TransLink (2012), the Metro Vancouver areas public transit provider, estimates that 239 million transit trips occur each year and the number of persons using transit services will continue to grow. With improvements in the availability of transit and the push to take a more environmentally friendly way to commute, more and more Vancouverites will begin to use transit. In the Vancouver area, the average commuting time using public transit is 48 minutes and 32% of those living in central municipalities use public transit services (Turcotte, 2011). Since the majority of travelling “occurs during rush hours, commuting contributes significantly to total exposure to transport-related air pollution” (Zuurbier et al., 2010).

TransLink’s Bus Technology & Alternative Fuel Demonstration Project is an ongoing project that “is designed to allow TransLink to gain experience and knowledge of bus and alternative fuel technologies that can reduce exhaust emissions from its bus fleet” (M.J. Bradley & Associates, 2006). In 2010, for standard 40 foot buses, trolley and hybrid buses consisted of 35% of TransLink’s fleet with the other 65% consisting of Diesel/Compressed Natural Gas buses (TransLink, 2013). Even though TransLink has sought to replace their older buses with new technologies to reduce diesel emissions, these new technologies comprise only a modest portion of their fleet; meaning commuters will still be exposed to a diesel particulate matter while waiting at bus stops.

In addition to being exposed to diesel particulate matter from buses, public transit patrons wait at bus shelters that are located close to roadways; therefore being exposed to even higher levels of particulate matter. The construction of bus shelters are not designed to protect the public from PM exposure, but are more concerned with the transit system performance. Transit BC’s BC Transit Municipal Systems Program (2011) has designed guidelines for bus stop shelters called the “Design Guidelines for Accessible Bus Stops.” These guidelines state requirements for accessibility, comfort, safety, and security and don’t mention protection from pollution. In addition, for those waiting at bus stops in highly trafficked urban areas where pollution dilution rates are low, they will be exposed to higher amounts of PM than less trafficked and open suburban or rural areas (Buzzard, Clark, & Guffey, 2009).

A study conducted by Hess, Ray, Stinson, & Park (2010) in Buffalo, New York researched commuter exposure for passengers waiting at bus stops over 840 minutes of simultaneous exposure levels. In addition, the study determined factors that contribute to PM inside and outside bus shelters. It was found that “[four] determinants have a statistically significant effect on particulate matter: time of day, passengers' waiting location, land use near the bus shelter, and the presence of cigarette smoking at the bus shelter” (Hess, Ray, Stinson, & Park, 2010). Also, it was determined that the mean value of PM2.5 inside bus shelters was 17.24 µg/m3 while the mean value of PM2.5 outside bus shelters was 14.72 µg/m3 (Hess, Ray, Stinson, & Park, 2010). This study shows the magnitude of air pollution commuters can be exposed to at bus stops.

ROLE OF THE EHO

In regards to ambient air quality (outdoor air quality) the Environmental Health Officer (EHO) plays a secondary role. Ambient air quality is a sector monitored primarily by the "provincial government, Metro Vancouver, and industry (where required with a permit) in cooperation with Environment Canada and regional districts " (BC Air Quality, 2013b). However, the EHO may get involved in ambient air quality by playing the following roles:

- Educating the public on the sources of ambient air pollutants, their impact on health, and how to avoid exposure.
- Informing the public on how they can make changes in their lives to reduce ambient air pollution.
- Answering any questions the public may have about ambient air quality.
- Encouraging, supporting, and becoming involved with policy changes that reduce ambient air pollution and improve health.
- Responding to complaints about ambient air pollution and attempting to resolve the problems associated with these complaints.
- Assisting to inform the public about air quality advisories and what actions they should take.

The ultimate goal of the EHO is to promote and protect the health of the public. Even though they play a secondary role when it comes to ambient air quality, they can still make an impact on the health of the public and the well-being of the planet through the roles mentioned above.

OBJECTIVE OF THE RESEARCH PROJECT

As was mentioned previously, the study mentioned above by Hess, Ray, Stinson, & Park (2010) shows the magnitude of exposure to PM2.5 commuters waiting bus stops can experience. In addition, as the author mentioned earlier in the literature review, those persons waiting in small-scale transportation microenvironments can experience episodes of pollution higher than those ever registered by the LFV Air Quality Monitoring Network.

Human beings are dynamic receptors that spend different proportions of their time in different microenvironments, such as bus stops (Vardoulakis, 2009). Those traveling within transport microenvironments (i.e. those waiting for buses) will be exposed to higher levels of PM2.5 and other pollution due to the nature of the environment.

Metro Vancouver's LFV Air Quality Monitoring Network may provide valuable information for PM2.5 concentration over a broad area, but it is not adequate to measure small-scale transportation microenvironments. Consequently, public transit commuter exposure can be underestimated. Kaur, Nieuwenhuijsen, & Colvile (2007) further support this statement by saying that trends extrapolated from ambient studies and applied to population exposures have "been repeatedly shown to be poor surrogates of personal exposure, particularly in the transport microenvironment."

As well, there have been limited studies conducted about commuter exposure at bus stops in the Metro Vancouver area. There are many examples from studies around the world, but it would be interesting to determine the PM2.5 exposure experienced in the small-scale transportation microenvironments of Metro Vancouver. Furthermore, Metro Vancouver is composed of many different municipalities that are urban, suburban and rural in nature. Comparing the PM2.5 concentration of a small-scale transportation microenvironment in a busy urban area to one in a less busy suburban or rural area would be valuable in order to show the impact of urbanization on air quality.

Therefore, the objective of this research project will be to evaluate bus stop microenvironments for PM2.5 at a bus stop in Vancouver's downtown core compared to a bus stop in the suburban community of Ladner. In addition, peak AM (6:30am to 7:00am) and peak PM (5:00pm to 5:30pm) hours will be compared at both locations. Lastly, all groups will be compared to a standard, the Metro Vancouver 24 hour rolling average objective of 25μg/m3, and to nearby LFV Air Quality Monitoring Network stations, Tsawwassen and Kitsalano for Ladner and Vancouver, respectively.

NULL AND ALTERNATE HYPOTHESESE

The null hypotheses (Ho) for these objectives will be the following:

1. There is no difference between PM2.5 measurements between Ladner and Vancouver.
2. There is no difference between peak AM and peak PM hours.
3. There is no difference between PM2.5 measurements and the Metro Vancouver 24 hour rolling average.
4. There is no difference between PM2.5 measurements and the respective LFV Air Quality Monitoring Network station.

The alternate hypotheses (Ha) for these objectives will be the following:

1. There is a difference between PM2.5 measurements between Ladner and Vancouver.
2. There is a difference between peak AM and peak PM hours.
3. There is a difference between PM2.5 measurements and the Metro Vancouver 24 hour rolling average.
4. There is a difference between PM2.5 measurements and the respective LFV Air Quality Monitoring Network station.

METHODS

The author measured PM 2.5 using the DustTrak™ Aerosol Monitor 8520. The DustTrak™ Aerosol Monitor 8520 was set to log 1 minute averages of data points.

Samples were taken at Stop #55165 Northbound Harvest Dr at Ladner Trunk Rd in Ladner, BC and from Stop #50043 Burrard Stn Bay1 in Vancouver, BC from 6:30am to 7:00am and 5:00pm to 5:30pm. Each location received equal sampling time over a period of 12 weekdays between the dates of January6, 2014 to January 21, 2014. In order to ensure the sample was taken from the breathing zone area, the inlet of the DustTrak™ Aerosol Monitor 8520 was set at five feet from ground level. Samples were taken regardless of meteorological conditions.

In addition, meteorological conditions, traffic density, bus volume, and other observations were taken during sampling periods to account for other parameters that could affect PM2.5 readings.

DATA ANALYSIS

The author used NCSS 9 (Hintze, 2013) and Excel (Microsoft, 2010) to perform statistical analysis of descriptive and inferential statistics. Data was broken up into the following four groups: Ladner AM, Ladner PM, Vancouver AM, and Vancouver PM.

Descriptive statistics analyzed were the mean, median, and range of PM2.5 readings, meteorological data, traffic density, bus volume during sampling period, and smoking.

Inferential statistics for this study involved the use of a 1-way ANOVA and multiple One-Sample T-Tests to analyze the gathered PM2.5 data. The level of significance was defined at $p<0.05$.

Analysis of the 1-way ANOVA used the non-parametric Kruskal-Wallis One-Way ANOVA on Ranks test. Post-hoc analysis was conducted using the Tukey-Kramer Multiple Comparison test.

For the one-sample t-tests, the Wilcoxon Signed-Rank Test was used to test differences between the mean PM2.5 levels of the different groups and the Metro Vancouver 24 hour rolling average objective or respective LFV Air Quality Monitoring Network Stations.

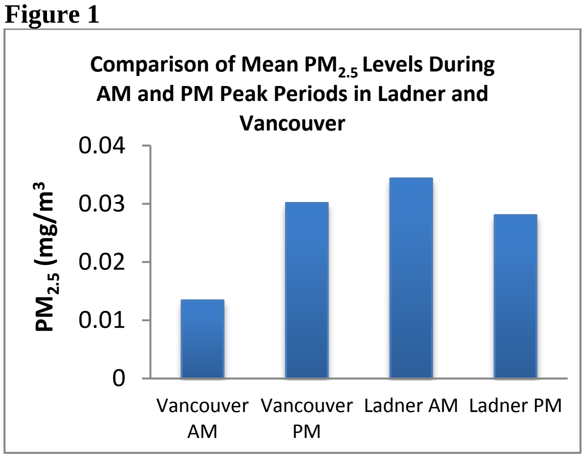
RESULTS

DESCRIPTIVE STATISTICS

<u>Mean</u>

Ladner AM mean $PM_{2.5}$ levels are the highest amongst the groups while Vancouver AM mean Peak $PM_{2.5}$ levels are the lowest amongst all the groups. See Figure 1 below.

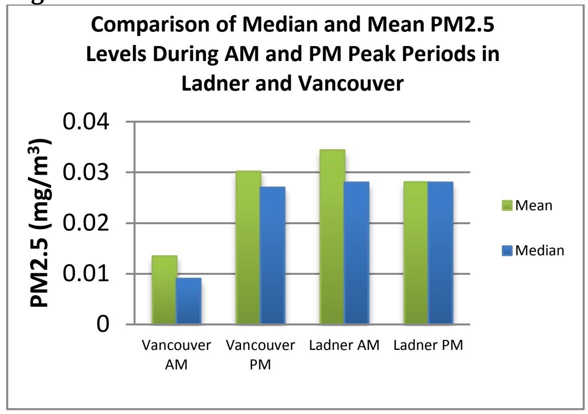
Figure 1



<u>Median</u>

Since most of the group's data is close around their respective means, it is expected that the median would be close to the mean. The data shows this to be true. See Figure 2 below.

Figure 2



<u>Range</u>

Ranges between locations and times are different which indicates the variability of the data being collected. See Table 1 below.

Table 1: Range Data for all Groups with their Respective Minimums and Maximums

Group	Range	Minimum	Maximum
Ladner AM	0.487mg/m^3	0.01mg/m^3	0.497mg/m^3
Ladner PM	0.047mg/m^3	0.016mg/m^3	0.063mg/m^3
Vancouver AM	0.052mg/m^3	0.004mg/m^3	0.056mg/m^3
Vancouver PM	0.072mg/m^3	0mg/m^3	0.72mg/m^3

<u>Meteorological Data</u>

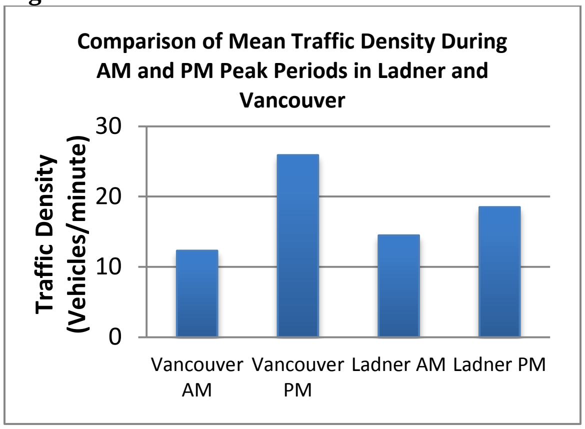
Ladner and Vancouver locations are relatively similar amongst all meteorological data except for wind speed and direction (wind speed is faster in Vancouver and has an eastwardly, as opposed to westward direction). Also, for all locations, temperature increases from AM to PM hours. See Table 2 below.

Table 2: One Hour Average Meteorological Data for Ladner and Vancouver

Location	Time	Tempe-rature	Relative Humidity	Wind Speed	Dominant Wind Direction
Ladner	6:00 am	3.4˚C	92.8%	6 km/hr	Westward-Northwestwardly
	5:00 pm	6.5˚C	88.5%	5.75 km/hr	Westward-Northwestwardly
Vancou-ver	6:00 am	5˚C	90.3%	7.33 km/hr	Eastwardly
	5:00 pm	5˚C	90%	10.67 km/hr	Eastwardly

Traffic Density
Ladner had a higher density of vehicle traffic compared to Vancouver during the AM Peak hours while Vancouver had a higher density of vehicle traffic compared to Ladner during the PM Peak hours. Also, Traffic density was higher in the PM Peak hours over the AM Peak hours in both locations. See Figure 3 below.

Figure 3



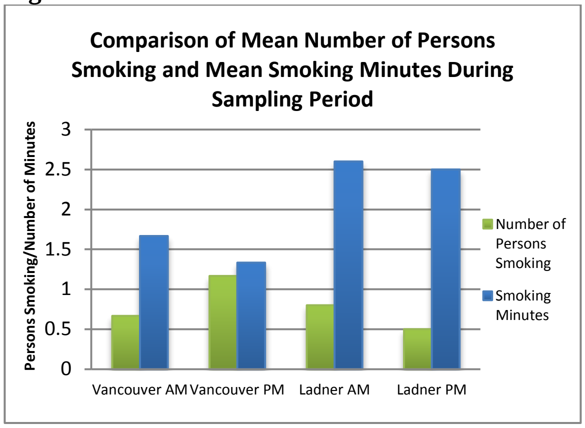
Number of Buses Arriving/Departing During 30 Minute Sampling Period
Vancouver had a higher volume of buses during both the AM Peak and PM Peak hours compared to Ladner (13 buses/30 minutes and 21.3 buses/30 minutes respectively vs. 10.8 buses/minute and 11.25 buses per minute respectively). Furthermore, bus volume was higher in the PM Peak hours over the AM Peak hours in both locations. See Table 2 below.

Table 2: Bus Volume Data for all Groups

Time	Group	Bus Volume
AM Peak	Ladner	10.8 buses/30 minutes
	Vancouver	13 buses/30 minutes
PM Peak	Ladner	11.25 buses/30 minutes
	Vancouver	21.3 buses/30 minutes

Smoking
Vancouver during the PM Peak had the highest mean number of smokers while Ladner during the PM Peak had the lowest mean number of smokers. On the other hand, Ladner had a higher amount of mean smoking minutes during both the AM Peak and PM Peak hours compared to Vancouver. See Figure 4 below.

Figure 4



INFERENTIAL STATISTICS

1-way ANOVA
The null hypotheses (Ho) for the 1-way ANOVA were the following:

1. There is no difference between PM2.5 measurements between Ladner and Vancouver.
2. There is no difference between peak AM and peak PM hours.

The alternate hypotheses (Ha) for the 1-way ANOVA were the following:

1. There is a difference between PM2.5 measurements between Ladner and Vancouver.
2. There is a difference between peak AM and peak PM hours.

The data was not normally distributed according to the tests of assumption.

$p=0.000000$ ($p<0.05$), therefore, one can reject Ho and conclude there was a statistically significant difference in mean PM2.5 values between the different groups.

Post hoc analysis, according to the Tukey-Kramer Multiple Comparison Test, found that there was a statistically significant difference between Vancouver AM (μ=0.01344 mg/m3=13.44 μg/m3) and the other groups (Ladner AM [μ=0.03438667 mg/m3=34.38667 μg/m3], Ladner PM [μ=0.02807778mg/m3=28.07778 μg/m3], and Vancouver PM [μ=0.03016667 mg/m3=30.16667 μg/m3]), but there was no significant difference between the other groups and each other.

POTENTIAL ALPHA AND BETA ERRORS

Since p=0.000000 ($p<0.05$), it was very statistically significant at $\alpha=0.05$ and indicates a large difference between Vancouver AM and the other groups. Also, since the difference was so large, the difference was unlikely due to chance and the chance of an alpha error was extremely low.

Also, since power was high at 0.999852 (power>0.80), there was a strong likelihood that the Ho was being correctly rejected when it was in fact false.

One-Sample T-Tests\

The null hypotheses (Ho) for the one-sample t-tests will be the following:

1. There is no difference between PM2.5 measurements and the Metro Vancouver 24 hour rolling average.
2. There is no difference between PM2.5 measurements and the respective LFV Air Quality Monitoring Network station.

The alternate hypotheses (Ha) for the one-sample t-tests will be the following:

1. There is a difference between PM2.5 measurements and the Metro Vancouver 24 hour rolling average.
2. There is a difference between PM2.5 measurements and the respective LFV Air Quality Monitoring Network station.

Ladner AM vs. Metro Vancouver 24 hour rolling average

The data was not normally distributed according to the tests of assumption.

There was a statistically significant difference between PM2.5 levels during Ladner AM (μ=34.38667μg/m3) and the Metro Vancouver 24 hour rolling average (0.025 mg /m3=25 μg/m3) with p=0.001100 ($p<0.05$). Therefore, we could reject the Ho and could not reject the Ha ($\mu>25$).

Ladner PM vs. Metro Vancouver 24 hour rolling average

The data was not normally distributed according to the tests of assumption.

There was a statistically significant difference between PM2.5 levels during Ladner PM (μ=28.07778μg/m3) and the Metro Vancouver 24 hour rolling average (25 μg/m3) with p=0.001065 ($p<0.05$). Therefore, we could reject the Ho and could not reject the Ha ($\mu>25$).

Vancouver AM vs. Metro Vancouver 24 hour rolling average

The data was not normally distributed according to the tests of assumption.

There was a statistically significant difference between PM2.5 levels during Vancouver AM (μ=13.44μg/m3) and the Metro Vancouver 24 hour rolling average (25 μg/m3) with p=0.00000 ($p<0.05$). Therefore, we could reject the Ho and could not reject the Ha ($\mu<25$).

Vancouver PM vs. Metro Vancouver 24 hour rolling average

The data was not normally distributed according to the tests of assumption.

There was not a statistically significant difference between PM2.5 levels during Vancouver PM (μ=30.16667μg/m3) and the Metro Vancouver 24 hour rolling average (25 μg/m3) with p=0.059809 ($p<0.05$). Therefore, we could not reject the Ho and we rejected the Ha ($\mu>25$).

Ladner AM vs. Tsawwassen AM

The data was not normally distributed according to the tests of assumption.

There was a statistically significant difference between PM2.5 levels during Ladner AM (μ=34.38667μg/m3) and the average Tsawwassen AM PM2.5 hourly average (0.00566mg /m3=5.66 μg/m3) with p=0.000000 ($p<0.05$). Therefore, we could reject the Ho and could not reject the Ha ($\mu>5.66$).

Ladner PM vs. Tsawwassen PM

The data was not normally distributed according to the tests of assumption.

There was a statistically significant difference between PM2.5 levels during Ladner PM (μ=28.07778μg/m3) and the average Tsawwassen PM PM2.5 hourly average (0.00592mg /m3=5.92 μg/m3) with p=0.000000 ($p<0.05$). Therefore, we could reject the Ho and could not reject the Ha ($\mu>5.92$).

Vancouver AM vs. Kitsalano AM

The data was not normally distributed according to the tests of assumption.

There was a statistically significant difference between PM2.5 levels during Vancouver AM (μ=13.44μg/m3) and the average Kitsalano AM

PM2.5 hourly average (0.00462mg /m3=4.62 µg/m3) with p=0.000000 (p<0.05). Therefore, we could reject the Ho and could not reject the Ha (µ<4.62) (refer to Appendix XII).

Vancouver PM vs. Kitsalano PM
The data was not normally distributed according to the tests of assumption.

There was a statistically significant difference between PM2.5 levels during Vancouver PM (µ=30.16667µg/m3) and the average Kitsalano PM PM2.5 hourly average (0.0077mg /m3=7.7µg/m3) with p=0.000000 (p<0.05). Therefore, we rejected the Ho and we could not reject the Ha (µ>7.7).

POTENTIAL ALPHA AND BETA ERRORS

Ladner PM and Vancouver AM vs. Metro Vancouver 24 hour rolling average
For each of the above, since p=0.001065 (p<0.05) and p=0.00000 (p<0.05) respectively, they were both statistically significant at α=0.05, which indicated a difference between the groups PM2.5 levels and the Metro Vancouver 24 hour rolling average (25 µg/m3). Also, since the difference was so large, the difference was unlikely due to chance and the chance of an alpha error was extremely low.

Also, the results stated that power was high at 0.97373 (power>0.80) and 1.00000 (p>0.80). Therefore, there was a strong likelihood that the Ho was being correctly rejected when it was in fact false.

Ladner AM vs. Metro Vancouver 24 hour rolling average
Since p=0.001100 (p<0.05), it was statistically significant at α=0.05, which indicated a difference between the groups PM2.5 level and the Metro Vancouver 24 hour rolling average (25 µg/m3).

Since power=0.71942 (power<0.8), there was a possibility the Ho was being incorrectly rejected. In order to confirm or refute findings, one should increase sample size.

Vancouver PM vs. Metro Vancouver 24 hour rolling average
Since p=0.059809 (p>0.05), it was not statistically significant at α=0.05 and the Ho could not be rejected. Consequently, if there really was no difference between the groups, there was a chance that an alpha error was committed. Alpha error is minimized by decreasing the acceptable alpha.

Also, the results stated that power was high at 0.82206 (power>0.8). Therefore, there was a strong likelihood that the Ho was being correctly rejected when it was in fact false.

Ladner AM and PM vs. Tsawwassen AM and PM and Vancouver AM and PM vs. Kitsalano AM and PM
For each of the above, since p=0.000000 (p<0.05), they were all statistically significant at α=0.05, which indicated a difference between the groups PM2.5 levels and their respective stations. Also, since the difference was so large, the difference was unlikely due to chance and the chance of an alpha error was extremely low.

Also, the results stated that power was high at 1.00000 (power>0.80). Therefore, there was a strong likelihood that the Ho was being correctly rejected when it was in fact false.

DISCUSSION

As stated previously, the aim of this study was to assess the differences in commuter exposure to PM2.5 during AM Peak and PM Peak periods between an urban (Vancouver) and suburban (Ladner) bus stop. In addition, the study sought to compare the data obtained at these urban and suburban locations to the Metro Vancouver 24 hour rolling average objective of 25µg/m3 and nearby LFV Air Quality Monitoring Network stations.

Historically, those commuting in urban environments are exposed to higher levels of pollution than those commuting in suburban or rural environments (Salmond & McKendry, 2009; World Health Organization, 2005; Buzzard, Clark, & Guffey, 2009). Salmond & McKendry (2009) describe that dispersion of pollutants in urban areas is more difficult than surrounding rural areas due to the complex built form of urban environments. In addition, given that intersections in urban areas are often surrounded by buildings, while rural and suburban intersections may provide more open space, Kaur, Nieuwenhuijsen, & Colvile (2007) found that intersections surrounded by buildings can double exposures to particulates compared to intersections provided with open space.

However, the results of this study showed different from this commonly held theory. There was found to be a statistically significant difference between the Vancouver AM Peak (13.44 µg/m3) and the other observed groups (Ladner AM [µ =34.38667 µg/m3], Ladner PM [µ=28.07778 µg/m3], and Vancouver PM [µ=30.16667 µg/m3]). Based on these results, PM2.5 levels at the suburban location were found to be higher or at par with the urban location.

These unexpected findings could be the result of the nature of PM emissions as well as the nature of the bus stop locations. PM is often subject to high pollution periods that can be episodic and infrequent and are very dependent on meteorological factors. For example, Ladner was subject to fog, while Vancouver often experienced rain during sampling; both of these factors could affect particulate dispersion. Moreover, the Vancouver stop was close to the Vancouver Harbour, which brought in a breeze that could easily disperse particulate matter. On the other hand, there was no significant body of water close enough to the Ladner location to have a significant impact on PM2.5 dispersion.

Additionally, the Ladner bus stop was located right by the roadway, while the Vancouver bus stop had a bus lane and bike lane separating the stop from regular traffic. Given the low release heights associated with vehicular transport, there can be significant accumulation of PM2.5 at ground level (Hertel & Goodsite, 2009). As a result, Vancouver's bus lane and bike lane could have acted as a barrier and diluting factor reducing PM2.5 exposure in this location compared to Ladner who did not have these lanes in place.

Also, at the Ladner stop, there was a McDonalds across the way, traffic often got backed up in front of the stop due to a nearby traffic light, and there was a higher amount of mean smoking minutes. Trafficked streets are air pollution hot spots (Hertel & Goodsite, 2009). Even though the Ladner location was a suburban area, the nature of the location contributed to traffic build up and thus elevated PM2.5 readings. Also, the presence of persons smoking has a significant impact on PM2.5 readings. In the aforementioned study conducted by Hess, Ray, Stinson, & Park (2010), which looked at commuter exposure at bus stops in Buffalo, New York, it was found that cigarette smoking was one of the four determinants that had a statistically significant effect on particulate matter.

Lastly, the fleet of TransLink buses utilized in Ladner appeared to be of an older stock and were mainly diesel fueled buses. Conversely, the fleet of TransLink buses utilized in Vancouver appeared to be of a newer stock and were a mixture of both diesel fueled buses and electric trolley buses. Diesel transit buses are considered to be a substantial mobile source of PM (Moore, 2012). Given that the buses were older in Ladner (thus less efficient) and diesel fueled, this could also contribute to the higher PM2.5 readings which were observed.

Likewise, it was found that Ladner was statistically significantly higher than the Metro Vancouver 24 hour rolling average objective of 25µg/m3. Conversely, Vancouver PM Peak was found to be higher than this 24 hour rolling average objective, but it was not found to be statistically significant, and Vancouver AM Peak was statistically significantly below this 24 hour rolling average objective. This further goes against the commonly held theory that urban commuters are exposed to higher levels of pollution than their suburban counterparts. Moreover, this demonstrates that the 24 hour rolling average objective can often be exceeded.

On the other hand, research that has suggested that ambient air studies are not representative of personal exposure (Kaur, Nieuwenhuijsen, & Colvile, 2007; Environment Canada as cited in Woolsey, 2013) has been demonstrated by this study. When comparing Ladner and Vancouver results to their corresponding LFV Ambient Air Quality Monitoring stations, Tsawwassen and Kitsalano, PM2.5 levels were found to be statistically significantly higher at the bus stop locations. Those commuting in small-scale transportation microenvironments can often be exposed to high episodic concentrations of PM2.5 (Hertel & Goodsite, 2009; Buzzard, Clark, & Guffey) that will never register in ambient air studies, such as the LFV Air Quality Monitoring Network.

The results above all demonstrate the importance of considering small-scale transportation microenvironments when assessing PM2.5 exposure. Commuters are exposed to varying levels of PM2.5 due to the nature of the pollutant and different exposure experiences in unique microenvironments that often do not follow the norm (i.e. higher exposures in urban vs. suburban environments is not always the case). Furthermore, commuters waiting at bus stops can be exposed to levels of PM2.5 that are higher than desired objectives or what is being registered by ambient air studies, which could result in an underestimation of the impact of PM2.5 on health of Metro Vancouver residents.

LIMITATIONS

Being an individual, student conducted study, many limitations were experienced. The limitations experienced by the author can be seen below:

- Author was inexperienced in research, which was extremely limiting to the study.

- Equipment was unpredictable and would often fail during sampling providing results that could not be used (equipment could have been taking inaccurate readings resulting in potential error and, due to decreased sample size, there was an increased chance for beta error).
- Equipment only measured mass concentration and size fraction and was unable to determine composition (PM2.5, although associated with combustion and diesel vehicles, could have been from other non-anthropogenic sources).
- Samples were taken on different dates for both Ladner and Vancouver locations, which could impact results (weather pattern variances could have impacted differences in PM2.5 levels between locations).
- Samples were taken regardless of weather conditions (weather, especially rain, has a great influence on PM2.5 levels and could have impacted results).
- Author could only speculate on the impact of weather and bus stop locations on PM2.5 levels due to a lack of experience (she could be wrong in her speculations).
- Standard method for personal sampling was not used due to money and time constraints (magnitude of commuter exposure could have been under or overestimated as a result).
- Sampling was only conducted at two bus stops, over a 3-5 day period at each stop, and during peak hours due to time constraints (only provides a small snapshot of PM2.5 levels in different bus stop microenvironments and results may not be a completely accurate comparison to the Metro Vancouver 24 hour rolling average objective).
- Sampling was only conducted for half hour periods (results may not be a completely accurate comparison to the hourly averages of LFV Ambient Air Quality Monitoring Network stations).
- Sampling was only taken in the winter, which does not account for differences in PM2.5 levels seen between seasons.

The study could have easily been improved with more and experienced man power, up to date and accurate equipment, and more time and areas to sample. All of these factors could have helped to reduce potential for error or bias, as well as strengthen the study's results.

CONCLUSIONS AND RECOMMENDATIONS

In regards to public health, the results of this study suggest that Metro Vancouver conduct smaller scale air quality monitoring operations in order to assess personal exposure to pollutants, such as PM2.5, in small-scale transportation microenvironments. Ambient air quality studies often are not accurate representations of near source risks, such as roadways near bus stops, which require more refined exposure assessments (Lioy, Watkins, & Allen, 2009). For example, mean midweek concentrations of PM2.5 can be seen to be 23% higher than Sunday means, but when considering close proximity to the roadway, the difference can increase to 60% (Environment Canada as cited in Woolsey, 2013). This demonstrates the importance of taking into account transportation related emission sources, such as buses, especially since taking public transit and other active forms of transportation are increasingly encouraged.

Lioy, Watkins, & Allen (2009) state that "issues surrounding relationships between ambient air quality monitoring and actual human exposures have been elevated and brought to the attention of the scientific community." More accurate personal exposure studies need to be conducted in order to assess how human behaviour, activity patterns, and different microenvironments can lead to higher risks of exposure to pollutants, such as PM2.5, and higher risks of either acute or chronic health outcomes due to these exposures.

When considering PM by itself, Hertel & Goodsite (2009) consider it to be one of the most hazardous air pollutants. Yet, PM2.5 has been associated with more severe health impacts than the coarse fraction of PM (Li et al., 2013; Cessaroni et al., 2013). In addition, as discussed previously, the Ministry of Transportation and Infrastructure (2011) blame PM2.5 from diesel fuel combustion for "67% of the lifetime cancer risk from air pollution in Metro Vancouver."

Due to its capacity to cause chronic and acute human health impacts, its ability to aggravate pulmonary and cardiovascular disease, and its capacity to increase symptoms in asthmatics that increase mortality (Metro Vancouver, 2012a), PM2.5 is a pollutant not to be ignored. Metro Vancouver has recognized this and implemented strategies to address the issue. For example, PM2.5 has been included as one of the priority air pollutants monitored by the LFV Air Quality Monitoring Network and Metro

Vancouver has also set strict ambient air quality objectives for this pollutant.

Along these lines, Metro Vancouver has been very proactive in their effort to improve air quality of the region and often meets their strict ambient air quality objectives. However, as mentioned previously during the literature review, despite meeting their objectives, Metro Vancouver (2012a) has stated that health impacts can still result from the pollutant concentrations in the LFV. In order to make greater strides towards cleaner air in Metro Vancouver, one first needs to understand personal exposure to air pollutants since ambient air quality exposures are not necessarily accurate correlations. In this way, Metro Vancouver can implement policies and legislation that can reduce their residents' exposures to hazardous air pollutants, such as PM2.5.

FUTURE RESEARCH

Below are some suggestions the author has for further research by other students:

1. Assessing post-secondary student exposure to PM2.5 amongst different institutions (i.e. Simon Fraser University, University of British Columbia, British Columbia Institute of Technology etc.).
2. Assessing PM2.5 concentration at different distances from the roadway.
3. Assessing PM2.5 exposure at bus stops close to LFV Air Quality Monitoring Network stations and compare hourly averages.
4. Assessing PM2.5 exposure on different bus models (e.g. trolley, diesel, hybrid etc.).
5. Assessing exposure to PM2.5 at undercover bus loops versus unsheltered bus loops.
6. Assessing PM2.5 concentrations at a bus stop during the week compared to the weekend.

The authors declare they have no competing interests beyond the scope of this course.

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