Environmental Study of Mission Industrial Area and South St. Boniface Neighborhood, Winnipeg, Canada.

by

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A Thesis submitted to the Faculty of Graduate Studies of

The University of Manitoba

in partial fulfilment of the requirements of the degree of

MASTER OF NATURAL RESOURCES MANAGEMENT

Natural Resources Institute

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Winnipeg, Manitoba

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Abstract

A seven months analysis of pollution levels for particulate matter ($PM_{2.5}$) in air, toxic metals in snow, as well as noise was undertaken and mapped in the Mission Industrial Area (MIA) and South St. Boniface (SSB) neighbourhood in Winnipeg, Manitoba. Daytime respirable fine particulate matter ($PM_{2.5}$) was monitored by Dylos DC 1700 PM air quality monitor and A-weighted noise level measurements was taken by Reed Digital Sound Level Meter. Evaluation of toxic metals (lead, chromium, arsenic, nickel, mercury and zinc) in snow were measured and compared to different pollution indices, including: contamination factor (*cf*), degree of contamination (*cd*) and pollution load index (PLI) for heavy metals.

The $PM_{2.5}$ Canadian Ambient Air Quality Standard of 28 $\mu g/m^3$ was sporadically exceeded downwind of the property line of the scrap metal shredder, with 5 out of 35 days averaging between 28.9 $\mu g/m^3$ to 38.1 $\mu g/m^3$. During the wildfire in August, the levels were high in the residential area at 21.9 and 25.6 $\mu g/m^3$ although other monitoring days ambient levels averaged 0.59 $\mu g/m^3$ to 9.81 $\mu g/m^3$, indicating satisfactory $PM_{2.5}$ levels. However, the *cf* indices were high for lead, zinc, nickel and mercury compared to background levels in MIA and SSB. One-way ANOVA and Spearman rank correlation analysis revealed statistically significant higher levels for $PM_{2.5}$ and heavy metals concentration in snow MIA and SSB. Mapping showed the highest pollution of $PM_{2.5}$, contaminant factors (cf), noise were downwind of IM and radiating out, but reducing and remaining significantly above background levels. Also, the noise levels regularly exceeded the city by-law level in the MIA, on the properties adjacent to the scrap metal shredder, with 90% of the sampling time over 200 hours (number of days= 35). The 55 dBA by-law guideline was also exceeded in the residential areas on 4 days out of the 33 monitored. This research shows high particulate matter, toxic heavy metals and noise levels adjacent to the scrap metal shredding operation in IM, which suggests the need for regulatory action to enclose the shredder for pollution control.

Acknowledgements

My deepest appreciation goes to my Advisor, Dr. Shirley Thompson, for her support, encouragement and patience throughout this project. Her guidance when I faced various difficulties with the field data collection were especially helpful in seeing the research progress. Her feedback, comments and advice are invaluable, as were her financial supports through nominations for scholarships, awards and stipends. I am forever grateful.

I would also like to express gratitude to my research committee members: Dr. Francis Zvomuya, Dr. David Herbert and Dr. Greg Selinger. Their involvement and immense input made this thesis a success. I wish you even greater heights in your respective endeavors.

I also extend my appreciation to Mr. Bo Pan of the Department of Soil Science, University of Manitoba, for helping with the provision of a Watchdog Weather Station and setting up of the instrument to enhance data collection.

Also, my warmest gratitude to every member of the South St. Boniface Resident Association, Winnipeg Manitoba. I acknowledge their financial support through the funds raised door-to-door for the acquisition of the research instruments and for their support and warm welcome during data collection. I appreciate Mr. Gary Tessier and Mrs. Madeleine Vrignon for accepting me into their home. Setting up my research instruments for a rigorous seven hours' of snow sample collections were made possible by their hospitality and support. I am forever grateful to every member of this association.

My special thanks to the faculty members and staff of the Natural Resources Institute, University of Manitoba, for their educational advice and support provided during the years of my study at the institute.

Last, a special appreciation to my parents, Mr. Kifuli and Mrs. Aderonke Solademi. Mrs. Aderonke Solademi has been a caring and sacrificing mother throughout my academic pursuits; the path she created for me has enabled me to meet diverse beautiful people in my life journey. A big thank you to my siblings, Mrs. Abiodun Obisesan and Omobolaji Solademi, as well as my friends, for their endless support and encouragement throughout my study.

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Glossary of Terms

Acronym	Meaning
$PM_{2.5}$	Particulate Matter of aerodynamic size below 2.5micrograms (μm)
TSP	Total Suspended Particulate Matter
ASR	Auto Shredder Residue
IARC	International Agency for Research on Cancer
ATSDR	Agency for Toxic Substances and Disease Registry
WHO	World Health Organization
GIS	Geographic Information System
A-weighting	noise frequency level response to the human ear
dBA	decibels in A-weighting
LAeq	A-weighted continuous equivalent continuous sound level in decibels measured over a stated period of time
LAePeak	Daily peak noise level from continuous sound level
CAAQS	Canadian Ambient Air Quality Standards
CCME	Canadian Council Ministers of Environment
Pb	Lead
As	Arsenic
Cd	Cadmium
Cr	Chromium
Mn	Manganese
Hg	Mercury
Zn	Zinc
Ni	Nickel
FRM	Federal Reference Monitors
FEM	Federal Equivalent Monitors
Cd	Degree of Contamination
Cf	Contamination Factor
PLI	Pollution Load Index
AQM	Air Quality Monitor
OSHA	Occupational Health and Safety Administration
COPD	Cardiovascular Obstructive Pulmonary Disease
$\mu g/m^3$	Microgram Per Cubic Meter

CHAPTER ONE:

1.0 Introduction

Since the late nineteenth century, industrialization and urbanization have contributed significantly to modern-day economic growth but have also caused health and environmental impacts (Behera & Reddy, 2002). Many processing and manufacturing industries, including oil and gas drilling/refining, iron and metal smelting, waste recycling, power plants and steel mills, emit pollutants (Chen et al., 2012; Liu et al., 2012; Olawoyin et al., 2014). Specifically, scrap metal recycling facilities are secondary metal processing facilities that process end of life wastes, called scrap metal, from automobiles, production, business and residences. While providing an environmental benefit by recycling scrap metals, these recycling facilities emit dust particles, noise and smoke (Loren et al., 2016). Scrap metal pollution poses human health risks and adversely impacts ecosystems (Olawoyin et al., 2018; Bunzl et al., 1999).

This thesis focuses on analyzing the levels and sources of pollution in the South St. Boniface neighbourhood, where homes are near a scrap metal shredder and an industrial area. Air pollutants and heavy metals are emitted into the environment during the scrap metal recycling processes (Tai et al., 2010; Owoade et al., 2013; Owoade et al., 2015; Peter et al., 2015). Harmful air pollutants from scrap metal shredders include particulate matter, lead, zinc, mercury, chromium and other trace metals (OSHA, 2008). Air emissions of particulate matter and metals in scrap metal recycling facilities in Nigeria and the USA showed measurements that exceeded the levels in background samples and the World Health Organization's guidelines (Owoade et al., 2015; Loren et al., 2016).

Short or long-term exposure to particulate matter impacts human health and can damage the lungs and respiratory airways, which exacerbates asthma symptoms, causes breathing difficulties and irritates the throat (Gyriparis et al., 2004; D'Amato et al., 2015; Eun-Jung et al., 2017). At greatest risk are workers exposed to these pollutants and residents living near these facilities. To protect the environment and human health from scrap metal recycling and processing industries hazards, it is crucial to assess air pollution and noise emissions from such facilities and compare results to policies and regulations. This study focuses on the potential environmental and health impacts of the Industrial Metals Inc. scrap metal recycling plant in the Mission Industrial Area, located in the South St. Boniface neighborhood in Winnipeg, Manitoba. This plant has received numerous pollution complaints from the residents and business owners on Dufresne Avenue in South St. Boniface over the last three years (King et al., 2012) and has been the source of fires and explosions (CBC, 2017).

Regulatory measures to reduce the source emission of these pollutants are needed. In June 2000, the Canadian Council of Ministers of the Environment (CCME) established a Canada-wide standard for particulate matter and ozone. This standard was targeted towards long-term air quality management to reduce human health and environmental risks associated with these pollutants (CCME, 2012). The impact of this regulation was profound. The levels dropped from 30% particulate matter and 50% ozone in 2001-2003 overall as averages in Canadian communities, to 2% and 28%, respectively, in 2010-2012 (CCME, 2012). In 2012, the ministers agreed to a new air quality management system (AQMS). This AQMS led to the formulation of Canadian Ambient Air Quality Standards (CAAQS) for inhalable Particulate Matter ($PM_{2.5}$) and Ozone (O_3). In exception of Quebec, other provinces and territories in Canada agreed to the implementation of the CAAQS. This national comprehensive and collective approach is designed to better protect both the health of Canadians and the environment by reducing air emissions and ambient concentration of these pollutants across Canada (CCME, 2012). Despite this progress in environmental regulation, poor air quality persists, especially among Canadians residing in densely populated industrial areas. In the industrial hub of Chemical Valley in Sarnia, Ontario, air pollution is of high risk to those living nearby, according to the World Health Organization (2011).

1.1 Study Area

This study took place in Winnipeg's Mission Industrial area (MIA) of the St. Boniface neighborhood. St. Boniface is a community of 57,724 residents (Statistics Canada, 2016) living in an area of mixed land-use. The north and east side areas are longstanding industrial areas called the Mission Industrial area and St. Boniface Industrial Park[1] (see Fig. 3.2). Residential areas cover some of the south-east section of the city, central St. Boniface, south St. Boniface and Southdale. The Mission Industrial Area (MIA) includes many diverse industries within a 24.5 km^2 area at the junction of the Red and Seine Rivers. Within this area resides Industrial Metals Inc. (IM), a scrap metal recycling plant with a metal shredder, located less than one kilometer from the closest residential street in the South St. Boniface neighborhood. This thesis focuses on:

1. Industrial Metals Inc. because of the installed metal shredder on the facility, with shredders emitting smoke, fumes, metal dust and noise beyond their property lines according to many studies (Loren et al., 2015;Owoade et al., 2015; Ogundele et al., 2017).

2. South St. Boniface area because of pollution concerns of that population.

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[1] [1] Saint Boniface Winnipeg. https://en.wikipedia.org/wiki/Saint_Boniface,_Winnipeg

Map 1.0: Map of St. Boniface, Winnipeg, showing the locations of residential neighborhoods and the industrial parks (Source: revised from Google Map Data, 2019).

1.2 Objectives of the Study

The overall objective of the study is to analyze the levels and sources of pollution in a) the South St. Boniface neighborhood, where homes are adjacent to an industrial area that includes a scrap metal shredder, and b) the Mission Industrial area in Winnipeg, Manitoba.

Specific Objectives:

The study focused on determining, analyzing and comparing pollution levels to regulatory standards or guidelines for environmental samples near Industrial Metals Inc. and other points in the South St. Boniface neighborhood for:

1. Fine respirable particulate matter emissions, which is below 2.5 µm ($PM_{2.5}$) in size.

2. Concentration of metals in snow samples, including lead, arsenic, zinc, nickel, cadmium, chromium and total mercury, calculating contamination factor (cf) and pollution load indices.

3. Noise pollution levels.

The above specific objectives are to answer the following research questions:

1. How do the levels of emissions of particulate matter in South St. Boniface compare to the Canadian Ambient Air Quality Standard (CAAQS) guidelines and to background levels?

2. Do scrap metal recycling emissions contribute to the deposition of heavy metals in snow cover in South St. Boniface?

3. How do the noise levels in industrial and residential areas of South St. Boniface compare to the Winnipeg bylaw community noise standard?

1.3 Statement of the Problem

In Winnipeg, Manitoba, the Mission Industrial Area which includes IM, is located less than one kilometer from the residential South St. Boniface neighbourhood, contributing unquantified risks from fine particulate matter ($PM_{2.5}$), metal toxicity and noise. $PM_{2.5}$ has an aerodynamic particle size of less than 2.5 micrometers. At this minute size, particulates are able to penetrate deeply into respiratory airways, the thoracic region, lungs and bloodstream (WHO, 2013). Detailed environmental and health risks associated with $PM_{2.5}$ are discussed in the next chapter.

1.4 Rationale

My study was in response to South St. Boniface residents' complaints about air pollution and noise from the Mission Industrial area. Air and noise pollution are major environmental, health and social issues faced by residents living nearby industrial operation (Fung et al., 2007; Guaita et al., 2011; Basner et al., 2014). Investigation and quantification of pollution levels are needed to provide a basis for the environmental and health risks posed by pollution and to institute regulatory actions for pollution control (Ana et al., 2009; Ogundele etal., 2017, Drew et al., 2017). Thus, air and noise pollution measurements were undertaken to identify the sources and to quantify levels of emission from scrap metal recycling operations in Mission Industrial Area and the levels in South St. Boniface.

In the Ogundele et al. (2017) study, particulate matter pollution was monitored using air samplers and elemental analysis of toxic heavy metals in air particles using an energy-dispersive x-ray fluorescence system (EDXRF). Similarly, my study measured particulate matter using a low-cost air sampler and toxic heavy metals present in air particles and subsequent deposition in snow as demonstrated in Sakai et al. (1988) and Suidek et al. (2015) studies. Noise measurements in this study was conducted as demonstrated by Anna et al. (2009) and Drew et al. (2017) using a digital Type II sound level meter. The monitoring results of this study provide information to the community and government about air and noise pollution concerns and their sources.

1.5 Significance of the Study

To inform regulations regarding scrap recycling facilities, more scientific data is required. The findings here will provide an in-depth assessment of environmental pollutants in the Mission Industrial Area in South St. Boniface, Winnipeg.

1.6 Organization of Thesis

Chapter 1 introduces the issues and objectives of the study. Chapter 2 encompasses a literature review of the scrap metal recycling industry and documents the environmental and health risks posed by facility operations and equipment. The risks of particulate matter are reviewed, as are regulatory approaches to reduce the impact of pollution. The chapter closes with a discussion of health/social risks associated with noise pollution and the regulatory measures/guidelines set in place to mitigate such pollution.

Chapter 3 discusses data collection and analysis. Chapter 4 of this study presents the study's findings regarding the deposition of heavy metals in snow cover samples taken in the air monitoring zones of the study area and background (control). Chapter 5 reports the findings regarding particulate matter emissions compared to regulatory guidelines. Chapter 6 provides the findings of noise monitoring and their conformity with regulatory guidelines. Chapters 7, 8 and 9 offer maps and analysis with GIS of the environmental monitoring data – namely, air particulate, metal snow samples and noise, respectively. The conclusion reviews the objectives and answers the research questions posed.

CHAPTER TWO: Literature Review

2.0 Overview

The literature review begins with a brief discussion of scrap metal recycling operations and the associated environmental and health risks posed by resultant air pollutants. Existing measurement or monitoring techniques of the existing regulatory guidelines for particulate matter pollution and some of the legal requirements of scrap metal recycling operations are also highlighted.

The elemental composition of the air pollutants ($PM_{2.5}$) monitored during the field data collection is a second aspect of the chapter. These elements include arsenic, cadmium, chromium, lead and nickel, classified by IARC as being a Group 1 carcinogenic to humans (IARC, 2017; Richmond-Bryant et al., 2014; Sun et al., 2016). The epidemiological studies and human health risks of these metals, how these metals are measured and analyzed in $PM_{2.5}$ and their evidence as an indicator of anthropogenic pollution are discussed. Last, the review explores anthropogenic noise emissions, the health impacts of noise, noise pollution legislation and regulatory guidelines.

2.1 Scrap Metals Recycling

Metals, including toxic metals, have many desirable chemical and physical properties, such as hardness, excellent electrical and heat conduction and catalysts for chemical reactions (Graedel et al., 2011). For these reasons, metals are widely applied in different industrial and consumer products: machinery, automobiles and transportation, electrical and electronic appliances, building and construction, catalytic converters and lead-acid batteries (Wernick and Themelis, 1998; Graedel et al., 2011). Metals in industrial and consumer products, when discarded, become scrap metals.

Scrap metals can be recycled repeatedly due to metals having “no end of life”. Thus, metals serve as a secondary source of metal production in offering a sustainable alternative to an intensive economic extraction of metal ores on the Earth's crust (Muller et al., 2006; Graedel et al., 2011). Scrap metal recycling (SMR) continues to grow globally due to increasing awareness of resource conservation and economic benefits (Spoel, 1990; Reuter, 1998; Anderson et al., 2017). Metals are indefinitely recyclable, retaining their full properties (Wernick and Themelis 1998; Graedel et al., 2011). In fact, iron and steel, as a result of their highly recyclable nature, ranked among the top 18 metals with a 50% global average recycling rate (Graedel et al. 2011). According to the Canadian Appliance Manufacturers Association and the Canadian Steel Producers Association (2007a), 92% of appliances and 98% of automobiles, respectively, can be recycled. In fact, steel, the world's most highly recycled metal, can be recycled more than five times without reducing the quality of the end product (Alberta Recycling, 2007; Canadian Steel Producers Association, 2007a). Recycled steel, copper and brass can be used to produce new cars and other appliances (Norgate et al., 2007).

Scrap metal recycling (SMR) can be traced back to when humans started using an iron to make tools. The first use of scrap was in an iron furnace in 1967, in Massachusetts. (Jordan and Crawford, 1993; Ayres, 2017). The SMR industry is critical for the global management of end-of-life waste from automobile use and production, businesses and residential environments (Sakai et al., 2014). The industry continues to grow because the operations are less resource-intensive and economical than mining and processing virgin ore, which damage the landscape and pollute the ecosystem (Muller et al., 2006; Ayres, 2017).

Currently, over 2,800 metal recycling facilities in Canada employ approximately 34,000 workers directly and create an additional 85,000 jobs indirectly (Natural Resources Canada, 2007; Canadian Association of Recycling Industries, 2018). In 2010, 5.9 million tonnes of recycled metals, valued at $3.6 billion (CAD), was exported from Canada. In 2014, approximately 135 million metric tonnes of scrap metals were recycled in the USA (Reconmetal, 2018). Nearly 10 million tonnes of ferrous and non-ferrous scrap metals are recycled annually in Canada. Ferrous metals are metals containing iron and has high carbon content which makes them prone to rust when exposed to moisture. Non-ferrous metals does not contain iron and can withstand moisture exposure without getting rust, making them more useful. Examples of ferrous metals include cast iron and wrought iron, while non-ferrous metals include lead, aluminium, and copper (Morecambe Metals, 2017).

2.1.1 Scrap Metal Recycling Operations and Processing

The scrap metal recycling process typically involves four stages, although some facilities only consider the first two stages, such as IM, before being shipped elsewhere for separation and :

1. Collection and Sorting - The first step involves collecting scrap metal products from different sources and delivering them to the metal recycling facility or scrapyard. The most commonly recycled scrap metals include radiators, steel or alloy wheels, white goods, bicycles, roller shutters and batteries (Local Recycling Centre and Scrap Metal Yard Adelaide, 2017). After collection, the mixed stream of scrap metals is then sorted into rubbish skips for further transportation to the processing centers (Local Recycling Centre and Scrap Metal Yard Adelaide, 2017).
2. Crushing and Shredding - The sorted scrap metals are crushed by hydraulic rams (bailing presses) for more compact handling and fed through conveyor belts that transport the crushed scrap metals to a shredder. The compacted metals are sheared into slices using a hydraulic guillotine before being shred into smaller pieces, relative to the size of an adult human hand, by the use of hammer mills (Yellishetty et al., 2011).

3. Separation – Nonferrous and ferrous metals are separated from the shredded metals through magnetic drums (Yellishetty et al., 2011; Local Recycling Centre and Scrap Metal Yard Adelaide, 2017).

4. Melting and Purification - Melting of the scrap metal is done in a large furnace to appropriate degrees capable of melting the particular metal. Hot air (550◦C) is blown on the shredded metals to remove non-metallic materials, such as plastics and paints, using a vacuum process that sucks up impurities (Local Recycling Centre and Scrap Metal Yard Adelaide, 2017).

2.2 Emissions from Scrap Metal Recycling Facilities

Loren et al. (2013) studied emissions near scrap metal recycling facilities in Houston, USA. They investigated the metal particulate matter and carcinogenic risk assessment to rank the severity of human health threats. This investigation collected airborne metal particulate matter, or Total Suspended Particulate (TSP) samples, downwind of five selected metal facilities for eight hours daily. The sampling was repeated upwind for the ten selected background locations for six to 13 different sampling periods. Also, TSP and PM_{10} for hexavalent chromium (CrVi) speciation were sampled.

The study discovered iron (4.3 – 18.21 µg/m^3), manganese (0.096 – 0.24 µg/m^3), copper (4.3 – 18.21 µg/m^3), chromium (0.11 – 0.471 µg/m^3), nickel (0.064 – 0.766 µg/m^3), lead (0.096 – 0.93 µg/m^3), cobalt, cadmium and mercury downwind of the metal recyclers. Chromium, nickel, lead, cobalt, cadmium and mercury were not detected in any TSP samples in the background locations. Also, iron (1.731 µg/m^3), manganese (0.0344 µg/m^3) and copper (0.0341 µg/m^3) concentrations in the background air samples were lower than the concentrations in the metal recycling facilities' samples.

A similar study, by Owoade et al. (2015), investigated the chemical composition and source identification of particulate matter ($PM_{2.5}$ and $PM_{>2.5-10}$) emissions from a scrap iron and steel smelting facility. The authors detected $PM_{2.5}$ at 300, 223 and 243 $\mu g/m^3$ for the three sampling points around the scrap iron and steel smelting facility respectively, which were 20, 15 and 16 times higher than the 15 $\mu g/m^3$ annual United State National Ambient Air Quality Standard (US NAAQS). Coarse particles $PM_{>2.5-10}$ measured 681, 606 and 320 $\mu g/m^3$ respectively, which were 11, 10 and 5 times higher than the 60 $\mu g/m^3$ annual US NAAQS. Also, $PM_{2.5}$ and PM_{10} levels exceeded the US NAAQS 24 hour standard of 35 and 150 $\mu g/m^3$ during some sampling days.

Owoade and others also discovered that elemental properties of $PM_{2.5}$, Mn, Ni, As, Cd and Pb exceeded the World Health Organization (WHO) guidelines. Studies by Loren et al. (2013) and Owoade et al. (2015) showed a significant presence of particulate matter and heavy metals in the ambient air around scrap metal recycling industries. Human exposure to particulate matter, mostly concerning fine particles $PM_{2.5}$, has been reported to cause numerous adverse health effects, such as asthma, lung cancer and cardiovascular diseases (Sanchez et al., 2009). Also, the atmospheric dispersion of heavy metal particles is known to cause injury to the lungs and other vital organs (Caricio et al., 2008; Leili et al., 2008).

The findings of the previous studies on scrap metal recycling and smelting industries are supported by the investigation by Kevin Li et al. (2015) of exposure to atmospheric heavy metals in the industrial city of Baotou China. Out of the four monitoring areas - City Area, Residential Area, Mining Area and Smelting Area - the regulatory standard limits of particulate matter and heavy metals level were exceeded only in the smelting area.

According to Li (2016), particulate matter in heavily industrialized areas contains carcinogens. The authors evaluated the lifetime cancer risks for residents at each monitoring area using the mean concentration of each carcinogenic metal in the $PM_{2.5}$. In the four selected sampling sites in Baotou, the lifetime lung cancer risk was in excess of 1 in a million (>1 x 10-6) as posed by the total of five carcinogenic metals (Pb, Cr, Co, Ni and Cd), indicating some carcinogenic risk. Among the sites, the smelting area posed the highest risk, followed by the Mining Area, the Residential Area and City Area; this indicates SA residents face a higher level of the cancer risk posed by heavy metals in $PM_{2.5}$.

2.3 Effect of Scrap Metal Recycling on Sound Emissions.

Machinery used in industrial operations creates noise (Stansfeld and Matheson, 2003), characterized as having continuous, impulsive, and intermittent sound pressure levels from the movement and functional parts of industrial machinery (Baeglund et al., 1999). For example, scrap metal shredders can generate sound pressure levels up to 82 dBA at distances of 60 meters further from proximate residential property (Saxelby, 2012). Exposure to industrial noise poses both auditory and non-auditory effects (Sharp, 2010; Basner et al., 2014). According to the World Health Organization community noise guideline (1999) and Basner et al. (2014), A-weighted noise levels ranging from 70 to 85 dBA is known to cause hearing impairment and noise-induced hearing loss from long term exposure in industrial settings.

2.4 Effect of Emissions from Scrap Metals Recycling on Soils, Plants and Humans

Industrial pollutants are not limited to the local area but can be spread through wind dispersion, runoff or wet and dry deposition (Liu et al., 2013). Impacts can be acute and/or chronic with exposure to pollutants in areas with highly concentrated industrial parks or activities; for example, Sarnia's Chemical Valley in Ontario (Kulizhskiy et al., 2014; Olawoyin et al., 2018). Similarly, the proximity of scrap metal facilities to residential areas/public spaces increases the potential human exposure to inherent environmental and health risks associated with recycling technologies, especially when coupled with lax environmental management procedures and regulations (Wernick and Themelis, 1998; Gößling-Reisemann and Gleich A.von, 2007).

Surface soil and plants are natural sinks for suspended particles and metals in the air through atmospheric wet and dry deposition (Shi et al., 2008; Luo et al., 2011). For example, the study by Owoade et al. (2014) found heavy metals' content in the soil for the dry season ranged between 0.84–3.12 mg/kg for Pb, 0.26–0.46 mg/kg for Cd, 9.19–24.70 mg/kg for Zn and 1.46–1.97 mg/kg for Cu. Across the seasons, the dry season heavy metal content in the soil was higher for most metals, except for lead, than those in the wet season, which ranged between 0.62–0.69 mg/kg for Pb, 0.67–0.78 mg/kg for Cd, 0.84–1.00 mg/kg for Zn and 1.26–1.45 mg/kg for Cu. In contrast, plant heavy metal content showed slightly elevated values in the wet season (Pb 0.53 mg/kg, Cd 0.59 mg/kg, Cu 0.88 mg/kg) compared with the dry season values (Pb 0.50 mg/kg, Cd 0.57 mg/kg, Cu 0.83 mg/kg). In the wet season, the contamination was entering plants and, thus, was reduced in soil. The concentrations of the trace metals in the plant tissues typically had the highest uptake or bioconcentration of lead and lowest for copper with the increasing order of Cu> Zn>Cd>Pb in both dry and wet seasons.

A similar study, by Miguel and Hector (2016), reported that the lead concentration in the soil near a metal recycling facility in Mexico averaged 4940 µg/g, with individual samples ranging from 73 to 84,238 µg/g. The mean value exceeded, by far, the maximum permissible Pb concentration of 375 µg/g in soils for agricultural purposes (OECD 1993). Miguel and Hector further report in this study that the Pb levels for medicinal plants, notably Mexican Arnica and

Epazote Inc. (C. graveolens), were between 16-530 µg/g, respectively, with all samples exceeding the WHO (2005) maximum permissible limits of 10 µg/g. The presence of heavy metals in a concentration above the allowable limits indicates the bioaccumulation of this metal in the plant. Consumption of these medicinal or edible plants from the contaminated site may lead to exposures above toxicological threshold levels (Zheng et al., 2007; Xu et al., 2013).

2.5 Toxic Wastes from Scrap Metal Recycling Industries

Most end-of-life vehicles (ELVs), electronics and electrical appliances wind up in scrap metal recycling industries for dismantling, sorting and shredding for recovery of reusable metals (Saki et al., 2014; Cossu and Lai, 2015). These phases of recycling generate waste after the removal of recyclable shredded metal components, known as automobile shredder residue (ASR). Automobile or auto shredder residues make up 25% of ELV waste.

Heavy metals' content in ASR is a potential source of environmental pollution through leaching of untreated ASR not correctly stored in a scrap metal recycling facility or disposed of in a landfill facility. Thus, the potential ecological risk of ASR requires proper management through treatment before disposal in a controlled landfill facility. A study, conducted by Singh and Lee, (2016) reported a high concentration of heavy metals in fine particles of ASR samples from a shredder plant in Korea. The authors further tested for heavy metals recovery in fine particles of ASR using 2% hydrogen peroxide and nitric oxide to recover heavy metals in the fine fraction of ASR, which reflect high risk/medium risk. After treatment, the heavy metals would be categorized as a low risk/no risk. Singh and Lee (2016) concluded that hydrogen peroxide combined with nitric acid is a promising treatment for the recovery and reduction of the eco-toxicity risk of heavy metals in ASR.

2.6 Legal Requirements for Scrap Metal Recycling

Scrap metal recycling processes are environmentally regulated under the provisions of the Environmental Act License 2011 No. 2856 RRR, dated January 23, 2012. The sections of the license as applicable to this study for Industrial Metals Inc. are listed below:

(1) “The license shall not cause or permit a noise nuisance to be created as a result of the construction, operation or alteration of the Development and shall take such steps as the Director may require to eliminate or mitigate a noise nuisance (Section 29)”.

(2) “The license shall reduce the production and dissemination of waste by initiating and maintaining waste reduction and waste recycling programs (Section 2)”.

(3) “The license shall prevent the seepage or surface flow of any liquid waste emanating from the said operation from entering any land or body of water off the site of the said operation (Section 7)”.

(4) “The license shall only store materials in a manner that prevents pollution to the groundwater, surface water and soil (Section 13)”.

(5) “The license shall not cause or permit odor nuisance to be created as a result of construction, operation, alteration of the development and shall take steps to as the Director may be required to eliminate or mitigate an odor nuisance (Section 14)”.

(6) “The license shall collect ASR from the shredder in a covered bin to minimize dust emissions (Section 23)”.

(7) “The license shall not emit from the development particulate matter in any air emissions that exceed 0.23 grams per day standard cubic meter calculated at 25 degrees Celsius and 760

millimeters of mercury, corrected to 12 percent carbon dioxide from any point source of the Development (Section 40 Ai)".

(8) "The license shall comply with Manitoba Regulation 113/2003 respecting special waste (Shredder Residue) whenever ASR generated at the Development is disposed of at a waste disposal ground (Section 27)".

(9) "The license shall not allow any combustible materials collected from the shredding process to be burned at the development (Section 12)".

(10) "The licensee shall, before processing scrap metal assemblies and components, remove all radioactive material, dangerous goods and hazardous waste, and dispose of these materials by applicable legislation (Section 8c) (Adapted from Industrial Metal's Environmental Act License 2011 No. 2856 RRR)".

2.7 Particulate Matter

Particulate matter (PM) refers to any tiny solid, semi-solid and liquid particles or a mixture thereof that can be suspended in the air and remain for an extended period (Pfeiffer, 2005). Particulate matter is categorized into different inhalable sizes based on their aerodynamic particle size: PM (<0.1 to 0.1 µm) ultrafine particles, PM (>0.1 to 2.5 µm) fine particles, known as $PM_{2.5}$, and PM (>2.5 to 10 µm) coarse particles, known as PM10 (Olawoyin et al., 2018). These aerodynamic sizes of PM are composed of inorganic ions (nitrates, sulphates, sodium, potassium, ammonium and calcium), metals (nickel, zinc, lead, cadmium, copper, nickel and vanadium), polycyclic aromatic hydrocarbon (PAHs), organic and elemental carbon (Cheung et al., 2011; Kim et al., 2015; Qie et al., 2018).

2.7.1 Sources of Particulate Matter

Globally, PM pollution is caused by both natural and anthropogenic activities. Episodic and seasonal occurrences of volcanic ash, windblown dust, dispersion and transboundary movement of wildfire smoke contribute to the emission of PM into the atmosphere (Claiborn, 2000; Navratil et al., 2013; Sapkota et al., 2005). Similarly, human activities cause significant PM pollution in the atmosphere with risks for public health and environmental hazards (Rai., 2016; WHO, 2018). Such activities include mining, coal-fired power plants, combustion of fossil fuel, metal recycling, industrial processing, vehicular emissions and agricultural operations (Monaci et al., 2000; Sun et al., 2004; Pfeiffer, 2005; Adeyeye et al., 2017). The contribution of natural sources to global emissions of PM is far less compared to those from human activities (Navratil 2010; Hladil, 2010).

During the past two decades, numerous studies worldwide have identified rapid urbanization and industrialization as the primary cause of PM pollution (Triantafyllou et al., 2002; Adeyeye et al., 2017; Wang et al., 2018). These emissions are often concentrated in industrialized cities with high population densities. For example, rapid urbanization and industrialization in China and India have contributed to severe levels of air pollution; $PM_{2.5}$ levels, in particular, are high above the recommended guidelines of the World Health Organization (Zhang et al., 2015; Greenpeace and AirVisual, 2019). In addition, PM is also formed from various human activities as a secondary pollutant when previously emitted gaseous pollutants, such as sulphur dioxide, nitrogen dioxide and volatile organic compounds, react with sunlight and water vapour (Atkinson et al., 2010).

2.7.2 Environmental and Health Impacts of PM

Scientific studies have documented PM pollution as a global environmental and health risk, especially $PM_{2.5}$, which are 30 times smaller than the width of a human hair (USEPA, 2018). $PM_{2.5}$ is regarded as the deadliest form of air pollution, due to the ability of these fine particles to penetrate deeper into the thoracic region, lungs and bloodstream in an unfiltered form (WHO, 2013).

Recent epidemiological studies link adverse human health effects and exposure to $PM_{2.5}$ or smaller. According to Guaita et al., (2011), inhalation of $PM_{2.5}$ contributes to coughing and wheezing, shortness of breath (dyspnea), and chest discomfort and pain. Older adults and young children or people with respiratory and cardiovascular diseases are more prone to the health risks associated with exposure to particulate matter. According to Brauer et al. (2012), exposing children to $PM_{2.5}$ affects their lung development, resulting in deficits in short- and long-term lung function and reduced lung growth. Children's exposure to a $PM_{2.5}$ concentration of 65 $\mu g/m^3$ for 24 hours increases the risk of respiratory symptoms and, in turn, increased use of asthma medications (Gold et al., 2000). Cadelis et al. (2014) also reported an increased risk of visiting health emergency departments in children with asthma in the Guadeloupe region of France, due to exposure to pollutants contained in PM_{10} and $PM_{2.5}$ of the Saharan dust.

Similarly, PM bound metals, such as Pb, Ni, Zn, Hg, Fe, Mn, Ag, As, Cd, Cr VI and Ni, are classified as Group 1-3 carcinogenic substances (IARC, 2013). Although metal concentration in PM is minute due to the size of the particulates, accumulation in the air may pose significant human health risks, especially with sustained exposure. The release of heavy metals in $PM_{2.5}$ is risk factors for the development of cardiovascular and respiratory diseases (Loomis et al., 2013; Bai and Sun, 2016), due to the oxidative stress in these organs. For example, a study by Sorensen et al. (2017) suggests that vanadium and chromium in outdoor $PM_{2.5}$ induce oxidative stress and DNA damage, which could trigger or contribute to the health risks and disease development linked with $PM_{2.5}$. Also, exposure to particulate matter was declared by the International Agency for Research on Cancer (IARC) as a human carcinogen (IARC, 2013).

The persistence of these toxic heavy metals in the environment as airborne particles, transported by wind and subsequent wet and dry deposition on soil, plant and runoff into water bodies, pose subsequent biomagnification in the food chain (Olawoyin et al., 2012). The primary routes of human exposure to these substances are through: 1) the ingestion of contaminated foods and water, 2) inhalation of airborne particles, and 3) absorption through the skin (Olawoyin et al., 2012). Toxic heavy metals are persistent chemicals and so are therefore impossible to metabolize by the biological systems. Some metals have forms that are fat soluble making these heavy metals bioaccumulate in humans posing acute toxicity from high dose or chronic effect at low concentration (Jaishankar et al., 2014).

In the past three decades, millions of diseases and deaths as a result of exposure to air pollution have been reported globally. For example, in 2010, approximately 3.22 million deaths were caused by exposure to air pollution, which was roughly a 10% increase from 1990, when 2.91 million air pollution-related deaths were reported (Lim et al., 2012). As such, to reduce the environmental and adverse human health effects of air pollution, air monitoring data is crucial to evaluate the air quality of an area and measure levels of particulate matter from different sources. Such information is used to determine the level of particulate matter that poses significant deleterious ecological and adverse human health effects in ambient air. Also, air monitoring is conducted to identify the potential source of anthropogenic emissions into the ambient air and instituting pollution control strategy (Loren et al., 2015).

2.8 Heavy Metals and Particulate Matter

Toxic heavy metals, especially those in $PM_{2.5}$, can stay longer in the air; subsequent wind transportation beyond their source of emission increases human exposure through inhalation deep into the lungs (Wiseman and Zereini, 2009; Urman et al., 2016). The resultant induced oxidative stress may lead to inflammation of respiratory organs, increased potential etiological factors to lung cancer and PM-induced cardiovascular disease (Brook et al., 2010; Shu et al., 2016; Lawal, 2017). According to Lipmann et al. (2006), Fe, Cr and Ni in $PM_{2.5}$ have acute effects on mice by increasing their heart rate and reducing heart rate variability.

2.8.1 Arsenic

Arsenic (As) and its compounds are well known as ubiquitous metalloids that occur naturally as an environmental contaminant, which humans are frequently exposed to in drinking water, air, food and soil (Hughes et al., 2011). Naturally occurring in the earth's crust, arsenic is notably present in all environmental media - air, soil and water - resulting from wind-blown crustal dust, leachate from rock weathering and volcanic ash (Witham, 2005; Atarodi et al., 2018). Conversely, anthropogenic emissions of inorganic arsenic from agricultural use in pesticides, electronics and semiconductors, metals mining and processing have contributed to the presence of this contaminant in the environment (USEPA, 1998; WHO, 2003). Arsenic‘s long life in the ecosystem classifies as a toxic environmental contaminant and a group one carcinogen by national and international environmental and health regulatory agencies (IARC, 2013; ATSDR, 2014).

Consequently, in recent years, arsenic has gained global attention owing to high concentrations present in the air, soil, and drinking water forming major pathways into the food chains and human exposure posing significant health risks (Niazi and Burton, 2016; Mandal, 2017;

Shahid et al., 2018). Consumption of inorganic arsenic through contaminated drinking water and foods can cause cancer, skin lesions, cardiovascular diseases, and diabetes from acute and chronic toxicity in humans (WHO, 2018).

Arsenic is also an airborne pollutant attached to the surface area of particulate matter emission from industrial processes and fuel combustion (Chung et al., 2014). Airborne arsenic occurs in two oxidation states in the atmospheric particulate matter; namely, trivalent and pentavalent arsenic (Hughes et al., 2011; Tirez et al., 2015). Although the concentration of arsenic in particulate matter is typically low in both rural and urban areas, high concentrations have been reported in hotspot areas near industrial operations (Tirez et al., 2015). Human inhalation of airborne arsenic occurs in people living near copper smelting factories as an outcome of occupational exposure. According to Owoade et al. (2013), high levels of arsenic in $PM_{2.5}$ air samples was over 300 times (0.20-0.47 $\mu g/m^3$) above the WHO guidelines of 0.00066 $\mu g/m^3$ for a carcinogenic risk of 1:1,000,000 from inhalation. Also, Tirez et al.'s (2015) study of arsenic speciation in PM_{10} and $PM_{2.5}$ air monitoring shows trivalent arsenic as the most toxic arsenic to humans and the dominant species in $PM_{2.5}$.

Human exposure to arsenic and the associated health risks is more common in contaminated food, water and soil, while exposure through inhalation is usually at a low concentration of about 1% (Chung et al., 2014). Wet and dry deposition of airborne As into the soil and subsequent accumulation may increase children's exposure to arsenic and subsequent poisoning from frequent contact with contaminated soil. Therefore, all pathways to arsenic must be considered during the monitoring and control of environmental factors/media to reduce human exposure.

2.8.2 Lead

Lead (Pb) occurs naturally in the environment; however, human activities have contributed to a significant increase in lead concentration in the ecosystem. For example, Pb is used as an additive in metals production and subsequently emitted from scrap metals recycling providing a potential source of pollution in soil and plants. Previous research on the environmental impact in the soil around a metal recycling facility in Mexico detected lead concentrations above the maximum at 375 µg/g (OECD, 1993) lead concentration in soils for agricultural purposes (Miguel and Hector, 2016). Human exposure to lead through inhalation of polluted air or dust and/or ingestion of contaminated food and drinking water causes adverse human health effects, especially in children (Baldwin et al., 1999; NSC, 2009; Morgan et al., 2013).

Anthropogenic activities, such as fossil fuel combustion, metal extraction, processing, and recycling and industrial use of lead, constitute a significant source of lead pollutants entering the environment (UNEP, 2010). Although the use of lead as a fuel additive was banned in the past, lead has been used globally for the production of lead-acid batteries (Chen et al., 2012). Despite the ban, lead continues to be produced on a smaller scale but has a higher recycling rate when used as a single commodity for the production of lead-acid batteries (Ahmed, 1996).

2.8.3 Cadmium

Cadmium (Cd), a rare soft and silver-white metal found on the earth's crust, is a cancer-causing element ranked as a group 1 carcinogenic hazardous substance by IARC (ATSDR, 2012). The major means of dispersal, through atmospheric emissions, is during mining and smelting, metals processing and other human usages, such as in phosphate fertilizers, Ni-Cd batteries and industrial discharges (NCM, 2003; ATSDR, 2008). Being water-soluble, cadmium can accumulate in the kidneys and liver (Hogan, 2010; Rani et al., 2014). Cadmium is toxic to biological functioning and metabolism in humans.

Cadmium is one of the organic constituents of particulate matter. The concentration of cadmium in fine particles is lower when compared to other PM-bound metals such as lead and manganese (Hrsak et al., 2000; Arshad et al., 2015). According to Yaaqub et al. (1991), 33-72% of cadmium in the environment is produced locally by air and the remainder comes from subsequent large-scale atmospheric transportation (Komarnicki, 2005). Despite the low concentration, fine particles bound cadmium still poses a significant health risk from inhalation leading to acute toxic effects, such as increased blood pressure (Cakmak et al., 2014). Human exposure to cadmium raises health concerns for the population living in proximity to air emissions from cadmium-emitting processing industries (ATSDR, 2012).

2.8.4 Nickel

The diverse chemical properties of nickel (Ni), namely, malleability, hardness, ductility and a fair conductor of heat/electricity, make nickel, when combined with other elements, suitable for the production of alloys (IARC, 2012). Nickel is used for the production of Ni-Cd and nickel-metal-hydride batteries. Due to its usefulness, nickel is an abundant and widely distributed heavy metal in the environment (Kim et al., 2014).

2.8.4.1 Sources of Nickel in the Environment

Generally, the distribution of nickel into the environment is similar to those of the previously discussed heavy metals. Thus, nickel is released into the atmosphere as metal particles from natural and anthropogenic activities (Cempel et al., 2006). The natural release occurs through wind-blown soil dust, volcanic emissions and forest fires (Nriagu, 1979). According to the Agency for Toxic Substances and Diseases Registry (2005), natural emissions of nickel into the atmosphere range between 8 million kg/year and was as high as 30 million kg/year between the 1980s and early 1990s.

Anthropogenic atmospheric emissions, notable, nickel mining, processing and smelting, fossil fuel combustion are the leading source of nickel in the ambient air (Chan & Luis, 1986; Bennett, 1994; Xu et al., 2016). Other human causes of nickel in the atmosphere include vehicular exhaust emissions, environmental tobacco smoke (ETS), and indoor smoke from domestic activities, such as home-heating, stainless steel appliances and cooking fuels (Kim et al., 2014). Airborne and PM-bound nickel in the air poses environmental and health risks in industrial/urban hotspots for processing and production of nickel and resultant wastes, and recycling of wastes comprising nickel (Denkhaus and Salnikow, 2002; Cempel et al., 2006; Das et al., 2015). According to WHO (2007), the atmospheric emission of nickel in urban areas, ranging from 5-35 ng/m^3, is significantly higher than the concentration of 1-3 ng/m^3 found in rural areas.

2.8.4.2 Exposure to Nickel and Associated Health Risks

The primary routes of human exposure to nickel are through food, potable water and dermal absorption; exposure through inhalation is of a lesser degree compared to the primary routes (NTP 2000; ATSDR, 2005). The accumulation of nickel in the environment and subsequent exposure can be toxic to various organisms in the ecosystem (Denkhaus and Salnikow, 2002). Ni toxicity depends on factors such as the route of exposure, level of concentration and speciation (Xu et al., 2016). For example, inhalation of an increased concentration of nickel in ambient air has been linked to an elevated prevalence of nickel sensitization and urinary nickel concentration in humans (Mann et al., 2010). Chronic exposure to nickel compounds and $PM_{2.5}$-bound Ni has been found to cause an increased incidence of daily mortality, lung cancer, fibrosis, nasal cancer and cardiovascular and kidney diseases (Laden et al., 2000; NCI, 2019).

In recent years, enforcement/implementation of regulatory and technological actions to lessen air pollution and associated human health risks has led to a significant reduction in airborne nickel in cities and industrialized areas (Kim et al., 2014). Nevertheless, nickel, notably, soluble nickel compounds, still rank among the top hazardous substances by various national and international organizations/agencies as a toxic and human carcinogen (IARC, 1990; WHO, 2000; NCI, 2019). As such, monitoring PM-bound nickel in different environmental media during pollution studies remains a top priority to check for non-compliance with regulatory standards/guidelines and to identify potential associated human health and environmental risks.

2.8.5 Chromium

Chromium (Cr) covers about 0.037 percent of the earth's crust and ranks 21st in terms of its natural abundance to other metals (USEPA, 1984). Chromium occurs naturally in the oxidation state of -2 to +6; the most environmentally significant is the +6 natural state (hexavalent) chromium. Anthropogenic activities, especially industrialization and urbanization, have contributed to the increased level of (+6) hexavalent Cr^{VI} in the air, water and soil (Kampa & Castanas, 2008; Cheng et al., 2014; Huang et al., 2014).

2.8.5.1 Sources and Effects of Hexavalent Chromium in the Environment

Hexavalent chromium Cr^{VI} and its compounds are emitted into the atmosphere as a by-product of industrial processes, fossil fuel combustion, coating operations and waste incineration (Cong 2011; Tian 2012). For example, Cr^{VI} was reported to account for nearly one-third of the 2700-2900 tons of chromium emissions in the US (ATSDR, 2008). Similarly, in metropolitan Toronto, Canada, 17 kg/year of total hexavalent chromium was released into the air in 2013 from coating operations (Toronto Public Health, 2015). Enrichment of hexavalent chromium in $PM_{2.5}$

has been reported by numerous studies as a human carcinogen and hazardous air pollutant (Huang et al., 2014; Yu et al., 2014). Bell & Hipfner's (1997) study of airborne hexavalent chromium in Windsor Ontario, Canada, suggested that inhalable particle fraction has the highest concentration of Cr^{VI} in the city's ambient air samples, ranging from 0.1 to 1.6 ng/m^3. Human exposure to Cr^{VI} in ambient $PM_{2.5}$, through inhalation, has been linked to pulmonary diseases as well as lung and nasal cancer (Kitsa et al., 1992; Hazelwood et al., 2004).

The wide industrial use and processing of chromium (Cheng et al., 2014), escalates the emission of Cr^{VI} into the ambient air and subsequent deposition into the soil. Wind transportation of ambient particulate matter, wet and dry atmospheric deposition, accumulation of sediment from industrial wastewater and leachate from chromium slag may serve as the pathway of ambient hexavalent chromium into the soil (Kitsa et al., 1992; Kimborough et al., 1999; Werner et al., 2007).

Airborne hexavalent chromium pollution has received global attention due to its inherent human cancer-causing risk and accumulation in the ecosystem. Consequently, environmental monitoring of chromium and its speciation has enhanced regulatory measures towards the dwindling of airborne CrVI pollution from the atmosphere and the environment. For example, in Canada, atmospheric hexavalent chromium has successively declined from approximately 3.3 tonnes in 2005 to approximately 0.8 tonnes in 2011 (Environment Canada, 2013).

2.9 Regulation of Particulate Matter in the Ambient Air

Particulate matter has been designated as criteria and hazardous air pollutants, posing threats to public health and the environment. Over the last two decades, national and international regulatory agencies, as well as population groups that are more vulnerable to the health risks of exposure to PM, have increased measures to improve air quality standards to protect public health, (WHO, 2005; USEPA, 2012; CCME, 2012). Specifically, $PM_{2.5}$, when deeply inhaled, can cause a wide range of short- and long-term health effects. This $PM_{2.5}$ is a foremost contributor to the global burden of disease and premature deaths (WHO, 2012; Cohen et al., 2017).

The World Health Organization established guidelines aimed at reducing the ambient levels of $PM_{2.5}$. The guideline values of the ambient concentration of $PM_{2.5}$ were set at 25 $\mu g/m^3$ for a 24-hour mean concentration and 10 $\mu g/m^3$ for the annual mean concentration (WHO, 2006). Similar to the WHO guideline values, at national levels, standards were set to reduce the ambient concentration of $PM_{2.5}$. The guidelines set by the Canadian Ambient Air Quality Standard (CAAQS, 2012) and the United States Environmental Protection Agency standards are designed to improve ambient air quality (USEPA, 2012; CCME, 2012). The guidelines were established to aide public health policymakers and regulatory/compliance enforcement agencies to understand air pollution issues and implement the best technological practices to minimize its impact.

Canada's ambient air quality standards provide the mechanism for an air quality management system through the Canadian Council of Ministers of Environment. These standards were enacted following the objective of Sections 54 and 55 of the Canadian Environmental Protection Act of 1999[i]. In 2015, the Canadian-wide standard value for $PM_{2.5}$ was replaced by the more ambitious Canadian Ambient Air Quality Standard (CAAQS). Various stakeholders, such as industries, non-governmental organizations and indigenous groups, participated in the development and review (CCME, 2014) of standards designed to protect Canadians, especially those who live in industrialized and urbanized locations, who may be exposed to outdoor $PM_{2.5}$ higher than the national average (Environment and Climate Change Canada, 2013). The $PM_{2.5}$ standards for air management threshold values and respective actions for each to prevent deterioration of air quality are summarized in Table 2.0.

Table 2.0: CAAQS Air Management Threshold Values and Actions

Canadian Ambient Air Quality Standards (CAAQS)					
	PM$_{2.5}$ annual (ug/m3)		PM$_{2.5}$ 24-hour (ug/m3)		
	2015	2020	2015	2020	Management Level & Action
Threshold Values	10	8.8	28	27	Action needed for achieving CAAQS Air Zone
	6.4		19		Action for Preventing CAAQS Exceedance
	4		10		Action Preventing Deterioration of Air Quality
	<4		<10		Actions for Maintaining and Keeping Clean Air Zones

Source: adapted from Canadian Council Ministers of Environment (CCME, 2014).

Table 2.1 Studies on Impacts of Scrap Metal Recycling Industries

Author (Year)	**Method**	**Study Setting**	**Pollutants**	**Results**	**Impacts**
Gonzalez-Fernandez et al. (2008)	Evaluation of Total Metal Content using XRF and TCLP of ASR* samples	Two different metal shredders near Barcelona, Spain.	Heavy metals distribution in ASR	High presence of Lead (Pb) and Zinc (Zn) in fine fraction of ASR*	Landfill disposal of untreated ASR and risk of heavy metals leaching.
Ngo et al. (2012)	ICPMS for Cadmium analysis in food samples and Interview (Questionnaire) of local communities.	Two rural communities metal recycling and reference communities n1 = 132 and n2 = 130, Vietnam.	Cadmium release from metal recycling plants	3-5 times presence of Cd in staple foods of metal recycling village than reference village.	Agricultural soil, water and food chain contamination
Loren et al. (2013)	Air monitoring of TSP and PM_{10} using high volume samplers, HAZ-DUST EPAM-5000 samplers and Cancer Risk Assessment	Five metal recycler facilities and background location (residents), Houston, USA.	Particulate metals (Iron, Lead, Zinc, Hexavalent Chromium etc.)	Metals particulates (Iron, Lead, Zinc etc.) were detected in 100%; up to 2% in the metal recycler facilities.	Less carcinogenic effects on residents. However, some background locations had low metals concentration.
Owoade et al. (2014)	AAS for heavy metals concentration in soil and plant	Vicinity of metal recycling facility, Ile-Ife, South Western Nigeria.	Heavy metals from gaseous emission of metal recycler facilities	Elevated levels of heavy metals (Lead, Iron, Zinc,) concentration in soil and plant around the metal recycler facility	Inhalation of gaseous emission by workers and passerby, contamination of agricultural soil
Owoade et al. (2015)	Low volume GENT sampler for $PM_{2.5}$ and PM_{10}, XRF for heavy metals concentration in particulates matter	Three different points of scrap metal recycling and smelting facility, Ile-Ife, South Western Nigeria.	Fine particles and Coarse particles ($PM_{2.5}$ and PM_{10}) and heavy metals	Annual concentration of $PM_{2.5}$ and PM_{10} were 15 to 20 times and 5 to 11 times higher than annual US NAAQS 2014 for the three sampling points respectively. Concentration of Iron, Manganese, Lead, Cadmium, Nickel exceeded WHO air quality standard	Highly polluted ambient air around scrap metal recycling and smelting facility.
Miguel and Hector, (2016)	EDXRF for analysis of Lead concentration in soil and edible plants	Soil and plant sampling in agricultural area locatearound the metal-recycling plant in San Ignacio, North of Zacatecas city, Mexico	Lead (Pb) concentration in soil and edible plant	Mean concentration of Lead in agricultural soil exceeded OECD, 1993. Mean concentration of Lead in edible and Medicinal plants exceeded WHO (2004, 2005) and other regulatory standards	Geoaccumulation and bioaccumulation of Lead in soil, plant and humans. .

Author (Year)	**Method**	**Study Setting**[1]	**Pollutants**	**Results**	**Impacts**
Singh et al. (2016)	ICP-AES for heavy metals analysis Ecological Risk Assessment Heavy metals reduction in ASR using Hydrogen peroxide and Nitric oxide	ASR samples from metal shredder plants in Seoul, South Korea.	Determination of heavy metals concentration in ASR and toxicity	High concentration of heavy metals in fine fraction of untreated ASR Treatment of ASR with hydrogen peroxide reduced heavy metals toxicity from moderate or high risk to low risk.	Disposal of untreated ASR is a potential source of environmental pollution.
Kexin Li et al. (2016)	Mid-volume aerosol sampler for mass concentration of $PM_{2.5}$ and PM_{10} ICP-OES and ICP-MS for particulates heavy metals analysis Risk assessment (Exposure Dose)	Industrial city in Baotou, inner Mongolia, China. Smelting Area, City Centre Area, Mining Area and Residential Area.	Determination of mass concentration of PM (2.5 and 10) and particulates heavy metals concentration	Mass concentration of PM (2.5 and 10) exceeded China Air Quality Standard in Smelting Area. Lead and Nickel were above threshold limit for carcinogenic	Increased risk of respiratory problems to residents of smelting areas. Risk of lifetime cancer in smelting areas.
Jo, et al. (2017)	Extraction of daily admission data on respiratory diseases between 2007 and 2010 from National Health Insurance Corporation. Data of hourly monitoring of PM_{10} and $PM_{2.5}$ made available by Korea Ministry of Environment Meteorological observation data by Korea Meteorological Administration.	Busan city, South Korea. Population 3.5 million. Age stratification: 0-15, 16-64, and ≥65 years	Particulates Matter	Meteorological factor influences PM in causing respiratory diseases. Low relative humidity increases hospital admission rate for respiratory diseases.	Higher $PM_{2.5}$ mass concentration shows increase in respiratory diseases.

2.10 Noise Pollution

Noise is one of the most common forms of pollution. An increase in human population, transportation (air, road, and rail), industrial machinery, commercial activities and construction works are the cause of noise pollution in an urban and industrial environment (Oyedepo and Saadu, 2008; de Paiva Vianna et al., 2015; Wichers et al., 2018). Although noise pollution is often considered to have less of a health impact when compared to other forms of environmental pollution, such as air and water, (Mansouri et al., 2006; Sharp 2010), exposure to varying sound pressure levels plays a significant role in the impact of noise in humans. A Sound Pressure Level less than 30 to 40 dB(A) has a modest or no substantial human health effect. Human health risk increases from 40-55dB(A), adverse health effects from 55dB(A) and 130 dB(A) and above may cause acute pain to the auditory system (Sharp, 2010). Consequently, noise pollution continues to receive attention from the public and scientists due to its potential health and environmental risks (Oyedepo and Saadu, 2008).

2.10.1 Sources of Noise Pollution

Numerous studies have identified noise pollution as causing two types of health concerns. First, machines create sound pressure levels that can cause hearing impairment and permanent hearing loss (Yankaskas, 2013; Lie et al., 2015). The second source is environmental noise, emanating from various urban audible sounds, such as transportation engines (aircraft, vehicles, trains), industrial plants and construction activities, among others (Muzet, 2007). Urban populations residing near these sources of environmental noises are susceptible to the adverse impact of noise pollution; namely, impacts on sleep through an increase in stress arousal levels, annoyance, interference with communication, cognitive impairment at work and in school and increased risk factors for cardiovascular diseases (Cecilia et al., 2005; Haralabidis et al. 2008; Basner et al., 2011).

Noise, usually a by-product of some accepted operations in a community (i.e. railways and traffic), receives the most complaints as an environmental stressor in large urban areas (Hunashal and Patil, 2012; Metcalfe, 2013; Kume, 2010). Thus, addressing noise nuisance requires striking a sustainable balance between the noise source and the population most adversely impacted by such noise. Measuring and evaluating noise levels in A-weighted decibels (dBA) is required to assess the loudness and the threshold of the human ear to lower and very high-frequency sounds (Ana et al., 2009).

Monitoring the level, frequency and intensity of noise, assessing the potential environmental and health risk, and devising mitigating measures are crucial to the protection of public health and the ecosystem. Therefore, this section of the literature review summarizes research and scientific knowledge on the third objective of this paper: the health and environmental effects of noise pollution.

2.10.2 Environmental Impact of Noise Pollution

Compared to other forms of environmental pollution, noise pollution leaves no residue or contaminants on any environmental media (air, soil and water) (Oyati and Stephen, 2017). Unwanted sounds, however, propagate through prevailing wind directions, posing significant adverse effects on exposed human and non-human species (Basner et al., 2014; Sordello et al., 2019). Noise emission and propagation through the air are not limited to human auditory systems but may also have an impact on sound communication in fauna species (Lengagne, 2008). Humans may habituate anthropogenic noise emissions for subjective reasons; however, anthropogenic noise can mask and inhibit sound communication in non-human species.

In animal behaviour, sound is used for communication, identification of partners and to signal the presence of predator and prey (Sordello et al., 2019). Increasing anthropogenic noise emissions on the landscape may mask and inhibit the ability of species to use, emit, hear and communicate with sound effectively (Suns and Narins, 2005). In the last two decades, several ecological studies have reported that anthropogenic noise emissions - primarily industrial and traffic noise - may be life-threatening to species and biodiversity in an urban landscape (Stuart et al., 2004; Warren et al., 2006; Sordello et al., 2019).

2.10.3 Health Impacts of Noise Pollution

Noise pollution has both auditory and non-auditory effects on human health (Walinder et al., 2007; Basner et al., 2014; Tabriaz et al., 2015). The severity of the impact depends on the duration or frequency of exposure to noise, the type of noise (continuous, impulsive or intermittent) and the source of the propagating noise (Postnote, 2009). Thus, noise pollution must be reduced to minimize risks posed from cumulative or immediate health and economic effects and to uphold the aesthetic quality of an urban environment (Yilmaz and Ozer, 2005; Rishi and Khuntia, 2012).

2.10.4 Auditory Impact of Noise

The human auditory system is genetically designed to listen and process sound to its advantage/preservation (Hughes and Jones, 2003). However, short- or long-term exposure to unwanted sounds above the background level can be detrimental to the human auditory system causing temporary/permanent hearing impairment or loss (WHO, 2004; Ana et al., 2009).

2.10.4.1 Noise-Induced Hearing Loss

Noise-induced hearing loss (NIHL) is a severe effect of exposure to two types of loud noise: continuous and intermittent (Seidman and Standring, 2010). Continuous noise is steady exposure to sound pressure levels above 75 to 85 dBA over a long period, as found, for example, in an industrial area (Basner et al., 2014). Intermittent noise is usually an intense impulse sound exceeding 140 dB under a short duration (Clark and Bohne, 1999). Either form of exposure levels stretches delicate inner ear tissues, specifically the cochlea, past their elastic limits and rips the tissue apart (Clark & Borhne, 1999; Le et al., 2017). Damage caused to the ear tissue may result in permanent hearing loss because cell regeneration in mammals is impossible (Basner. et al., 2014). Noise prevention and control are crucial to reduce the impact of noise on the human auditory system.

Noise pollution and the associated NIHL are global public health issues. According to the World Health Organization, an estimated 10% of the world’s population are exposed to high sound pressure levels, half of which may be vulnerable to potential hearing impairment (Daniel, 2007; Lancet, 2014). Similarly, according to Le et al. (2017), over 600 million people globally are at risk of noise-induced hearing loss. Hearing loss associated with noise has been a major environmental concern classified as one of the top 21 areas of research in the 21st century (Choi & Kim, 2014).

2.10.5 Non-Auditory Impact of Noise

The non-auditory impact of noise can lead to physiological and psychological responses (Passchier-Vermeer et al., 2000; Seidman & Standring, 2010). In fact, the World Health Organization has reported seven types of adverse social and health impacts of noise pollution: namely, cognitive and hearing impairment, interference with communication, cardiovascular illnesses, sleep disturbance and annoyance (Goines et al., 2007). Annoyance and perceived disturbance, cognitive impairment (mostly in children), and cardiovascular health issues are the most investigated non-auditory impacts of noise exposure (Basner et al., 2014).

2.10.5.1 Cognitive Impairment and Noise Pollution

Cognitive impairment is the inability or difficulty of a person to learn or remember new things, focus and make decisions that affect their daily life and well-being (Centre for Disease Control, 2009). Numerous noise pollution studies have shown the negative impact of noise exposure in school children in learning outcomes and cognitive performance (Evans and Hyggee, 2007; Stansfeld and Clark, 2015). National testing has shown that children exposed to chronic traffic, rail and aircraft noise performed poorly in areas of reading comprehension compared to children not exposed to such noise (Hygge et al., 2002; Lercher et al., 2003; Clark et al., 2012; Basner et al., 2014).

The connection between chronic noise exposure and school children's cognition has been identified by different studies, which include noise annoyance, increased arousal, enhanced frustration between teachers and pupils and impaired attention (Evans et al., 2007; Clark et al., 2012). The severity of these impacts depends on various factors. The summary of a literature review by Szalma and Hancock, (2011) suggests that the magnitude of noise exposure and associated detrimental health and social effects depends on noise intensity, sound pressure level, noise duration and task performance.

Aircraft noise impact studies by Lercher et al. (2003) and Clark et al. (2005) assessed the level of chronic aircraft noise exposure and cognitive impairment in school children. The authors reported a linear relationship between the exposure and the children's recognition memory/reading comprehension in schools near airports in the Netherlands and Spain. A 5 dB increase in A-weighted equivalent background sound level from aircraft noise exposure was linked to a 2-month delay in the reading age of children in the United Kingdom and a 1-month delay in the Netherlands (Basner et al., 2014). To reduce the adverse impacts of environmental noise on school children, the community guideline for noise by WHO recommends that background sound pressure level should not exceed 35 dB(A) during teaching hours in a school environment (Mackenzie and Galburn, 2007).

2.10.5.2 Sleep Disturbance

The most detrimental adverse impact of the non-auditory effect of exposure to environmental noise is sleep disturbance (Muzet, 2007; Fritschi et al., 2011), which may interfere with the quality of life, daytime mental alertness and optimal performance of daytime tasks (Basner et al., 2014; Terre, 2014). As the auditory system can perceive, assess and react to sound pressure levels during sleep (Dang-Vu et al., 2010) exposure to maximum A-weighted sound levels of 33 dB during sleep can cause physiological reactions such as motor and cortical arousals; namely, body movement, frequent awakening and increased tachycardia (Basner et al., 2006; Muzet, 2007).

Noise-induced arousals and sleep disturbances are more prevalent among susceptible population groups - seniors, shift-workers, school children and people with a pre-existing sleeping disorder (Dang-Vu et al., 2010). Frequent noise-induced arousals alter sleep structure, which includes prolonged sleeping onset, increased awakening, deteriorated deep sleep and rapid eye movement during sleep (Basner et al., 2010; Basner et al., 2011). Other notable short-term effects of noise-induced arousal and sleep disturbance include impaired mood, increased daytime sleepiness and cognitive impairment (Basner, 2008; Elmenhorst et al., 2010). These disruptions in the sleeping pattern may degenerate to other health problems, such as perturbation of the endocrine and metabolic functions that have been linked to cardiometabolic, psychiatric and negative social outcomes in children and adults (Halperin, 2014).

2.10.5.3 Cardiovascular Health Problems from Noise

In the previous section, the acute effects of exposure to environmental noise were discussed as interfering with communication, disrupting sleep and annoyance. Growing evidence also suggests that exposure to environmental noise pollution may cause negative health impacts. Short- and long-term exposure to outdoor environmental noise ≥55 to 73.6 dB(A) has been linked to cardiovascular issues and manifestation of other diseases, which lead to increased medical costs (Drew et al., 2017; Sharp, 2010; Basner et al., 2014; Munzel et al., 2014).

A notable relationship exists between chronic exposure to road traffic/railway noise and hypertension, ischemic heart disease, stroke, use of antihypertensive medication and myocardial infarction (Babisch, 2011). An increase in daytime noise level ≥55 dBA in the UK has significantly contributed to 788 new cases of stroke and 542 hypertension-related myocardial infractions at an estimated medical cost of £1.09 billion per annum (Harding et al., 2013).

According to Sorensen (2011), outdoor exposure to noise is believed to cause hypertensive conditions resulting from an increase in the release of cortisol, shifts in blood pressure levels and rapid heart rate. Exposure to road traffic noise was linked to increasing the arousal of the autonomous and endocrine system, risk factors that increase the mortality of ischemic heart disease (WHO, 2011). Furthermore, certain noise levels are linked to coronary heart disease, an increase in blood pressure and alteration in the heart’s blood vessels (World Health Organization, 2017).

Numerous epidemiological studies have reported an increase in the mortality rate of cardiovascular diseases resulting from exposure to elevated outdoor noises. In a study by Sorensen et al. (2011), a high incidence rate of 1.14 of stroke was found in exposures to a 10 dBA increase of noise from residential road traffic among people over 64.5 years old. A noise-induced CVD study by Recinoe et al. (2016) reported an increase in death risks from exposure to a 1 dB increase in nighttime noise levels ranging from 58.7 to 76.3dBA. The authors' findings revealed a 3.5% increase in myocardial infarction, a 2.9% increase in ischemic heart disease and a 2.4% increase in cerebrovascular disease. Similar results by Seidler et al. (2016) and Sorensen et al (2012) found an increased risk in the mortality rate of myocardial infarction and ischemic heart disease from exposures to 55-60 dBA of daytime noise and ≥50 dBA at night.

Last, auditory and non-auditory adverse impacts of noise are more prevalent in urban and industrialized landscapes characterized by sound pressure level emissions from sources such as road traffic, aircraft, industrial machinery and construction activities. In 2016, the Department of Toronto Public Health noise monitoring study reported a 24-hour average of 62.9 dBA noise level in the City of Toronto (Drew et al., 2016). Approximately 60 percent of the noise was attributed to traffic. The adverse impacts associated with noise exposure, established by two WHO reviews in 2009 and 2011, respectively, concluded that cardiovascular diseases, cognitive impairment, annoyance and sleep disturbance are likely to occur in a noisy urban environment.

2.10.6 Regulatory Guidelines/Standards for Noise Pollution

The adverse health and social impacts of exposure to noise pollution are widely documented and reveal a pandemic concern of its contribution to the global burden of disease (Fuster et al., 2014). Noise pollution is not only an environmental nuisance, but the acute and chronic impacts constitute a public health threat. Numerous scientific studies on the relationship between noise exposure level and the potential health impacts concluded with the need to develop and enforce quantitative noise exposure limits to protect public health (Berglund & Lindvall, 1995; Clark et al., 2006; Basner et al., 2014; Drew et al., 2017).

Guidelines to limit noise levels in the environment to threshold limits not detrimental to the public are statutorily enacted by national and international regulatory agencies. For example, WHO established noise guidelines to protect human health across different times of the day and different sources of noise: 55dBA threshold limit for daytime outdoor sound pressure level and 40 to 50 dBA for interim nighttime outdoor exposure (Berglund et al., 1999). Also, 35 dBA Leq during school hours was established as a background level in the school environment to prevent cognitive impairment (Berglund et al., 1999).

Threshold limits represent sound pressure levels established to protect populations that may be affected by cognitive impairment, noise-induced sleep disturbances and annoyance. In Canada, regulatory guidelines for noise threshold limits were established at federal, provincial and municipal levels. The Ontario Ministry of Environment and Climate established 55 dBA daytime and 50 dBA nighttime for outdoor noise threshold limit values at the midpoint of a window or door opening (Drew et al., 2017). Similarly, Part 5 of the Neighbourhood Livability By-law Winnipeg, Manitoba, established noise threshold limits in residential areas at 55 dBA for daytime (7:00 AM to 9:00 PM) and 50 dBA for nighttime (9:00 PM to 7:00 AM) (City of Winnipeg, 2008).

2.12 Summary

This chapter encompassed literature related to scrap metal hazards including particulate emissions. Data showed that scrap metal recycling operations present environmental and health risks. As a result, an environmental study of the Mission Industrial and South St. Boniface, Winnipeg, areas is worthwhile to assess and evaluate the pollution-related complaints.

CHAPTER THREE: Research Methods

3.0 Overview

This research methods chapter covers the methodology used to measure pollutants and noise to compare to regulatory standards, guidelines and background levels. Table 3.1 shows the connection between the study's research questions, objectives and methods.

3.1 Methodology

This study focused on sampling environmental pollution in Winnipeg's Mission Industrial Area (MIA) and the South St. Boniface neighborhood. An observation and measurement approach for the collection and analysis of quantitative data was used (Bergman, 2008). According to Given (2008), quantitative research is the orderly process of having a direct observation that measures observable phenomena and analyzes numerical data collected through the use of computational, statistical and mathematical techniques. The observation and techniques usually take two approaches: 1) a descriptive approach to establish the relationship between two variables; and, 2) an experimental approach to analyze causality (Babbie, 2010).

The quantitative approach was used for comparison with regulatory levels and pollution indices. Data collection tools and procedure were implemented using a community-based environmental monitoring design (CBEM) where local citizens were engaged in the study design, including: the monitoring instruments adopted, selection and siting of strategic monitoring points, installation of monitoring instruments and data collection (English et al., 2017).

3.2 Description of Study Site

The study sites were selected based on the urban monitoring network and distribution of monitoring points of pollutants[2]. Sites were established as industrial, commercial and neighborhood monitoring points[3], as shown in Figure 3.2. The wind directions were recorded daily after the installation of an anemometer (Watchdog 2000 series weather station) by the researchers and a community member in an open area west of the metal shredder. The environmental monitoring points were established up and downwind of the perimeter line (north, east, west, south and southwest) of the shredder.

The study site also covered selected neighbourhoods in proximity to industrial operations where outdoor activities may lead to potential exposure to outdoor pollution. The residential areas, notably Dufresne Avenue in South St. Boniface, are one and a half kilometres from the automobile shredder. Monitoring points, to record vehicular and transport-related air and noise pollution, were established on the adjacent businesses downwind of the scrap metal recycling plant and the two major roads around the neighbourhood.

3.2.1 Meteorological Parameters in the Study Site

After assessing the study site, a meteorological station was set up to locate a zone free from physical barriers, such as walls or trees, that could undermine the accuracy of the data recorded by the Watchdog. Four meteorological parameters that play significant roles in the dispersion and propagation of air and noise pollutants (Ayanlade & Oyegbade 2016) were measured: wind direction, wind speed, relative humidity and ambient temperature.

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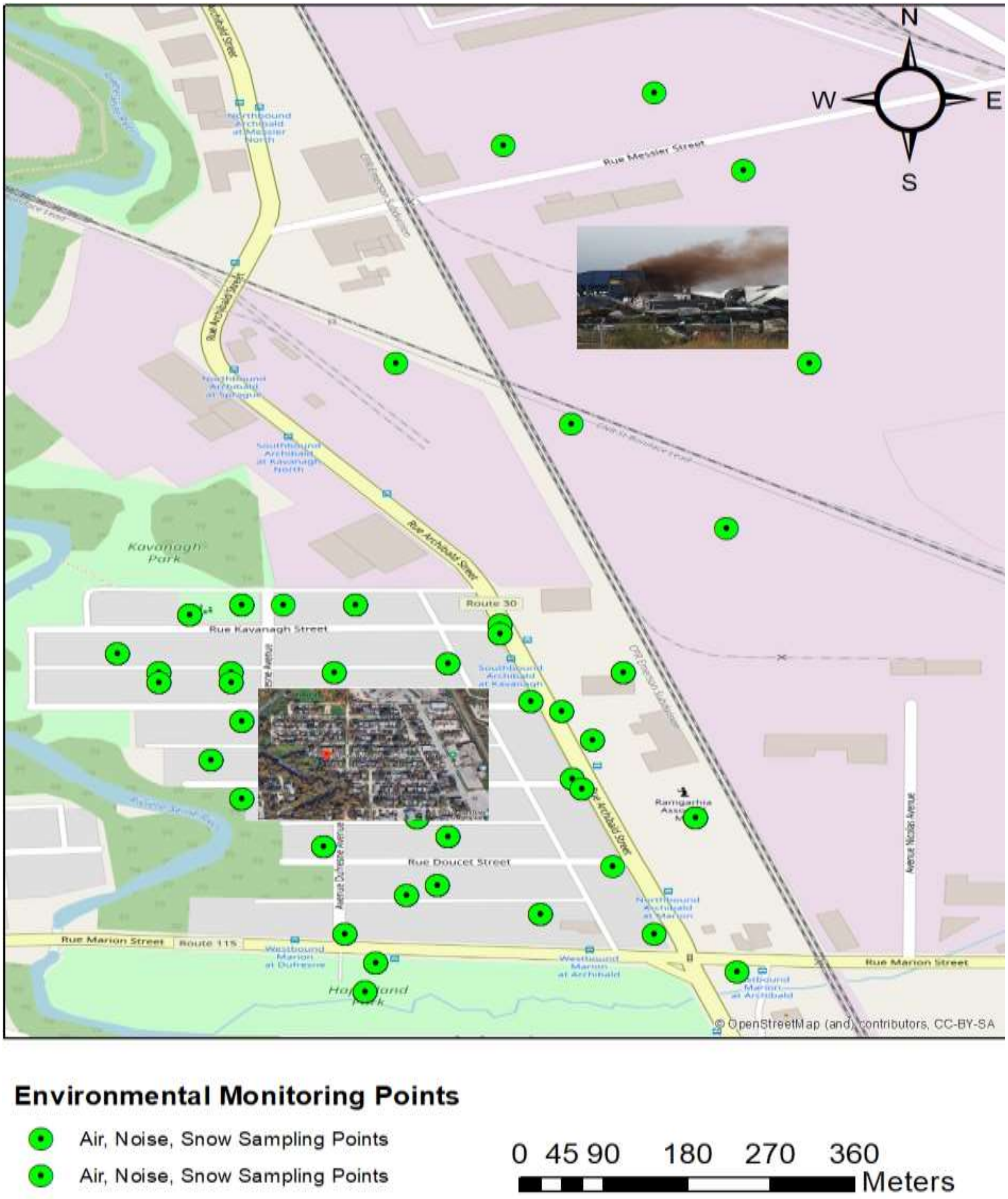
[2] Ambient Air Monitoring Protocol For $PM_{2.5}$ and Ozone: Canada-wide Standards for Particulate Matter and Ozone. (2011). Canadian Council of Ministers of the Environment. Retrieved from http://deslibris.ca/ID/229734

[3] Ambient Air Monitoring Protocol For PM2.5 and Ozone: Canada-wide Standards for Particulate Matter and Ozone. (2011). Canadian Council of Ministers of the Environment. Retrieved from http://deslibris.ca/ID/229734



Map 3.0: Map of the selected monitoring sites and the installed Watchdog showing the locations of residential neighborhoods and the industrial parks.

Environmental monitoring procedures used to collect data focused on the deleterious effects that human activities, such as industrial operations, pose on the environment and public health. Primary data from various environmental samples were compiled through three individual phases:

1. fine particulate matter ($PM_{2.5}$) sampling;

2. snow sampling and analysis of airborne metals; and

3. industrial and community noise monitoring survey.

3.3.1 Fine Particulate Matter Monitoring Approach and Instrument

Air quality management systems for air monitoring and environmental regulations are needed to determine the emissions of air pollutants (Forbes, 2015). Such systems are used in urban and rural areas of specific emission sources for community health investigation where residents can be affected by local pollution (Canadian-Wide Standard, 2011). The air monitoring design of this study measured industrial fugitive emissions of $PM_{2.5}$ from scrap metal recycling and shredding, as well as other environmental sources. Ambient air monitoring of particulate matter is done in neighbourhoods and areas of commercial activities where residents could be susceptible to $PM_{2.5}$ dispersed from an identified local emission source (Wong et al., 2016; Eom et al., 2018). When the source is known the preferred method to determine emissions is to test at the stack or point of release, which can then be compared to the regulation of the licensee. However, this was not possible with IM.

Air monitoring of $PM_{2.5}$ is the measurement of mass concentration (ug/m^3) of suspended particulate matter near an emission source or ambient concentration in the atmosphere (Loren et al., 2015; Owoade et al., 2015). Measuring the mass concentration of particulate matter requires the use of designated EPA Federal Reference Methods (FRM) and Federal Equivalent Methods (FEM) air monitors that use manual gravimetric pre-weighed filter paper and non-filter-based techniques (Noble et al., 2001; Ambient Air Monitoring Protocol, 2011). These air monitors are often deployed by government regulatory agencies to report city or regional air quality levels. These air monitors are expensive and require technical expertise for their operation. Community residents in areas with air pollution concerns have questioned the effectiveness of FRM and FEM regulatory air monitors, which may not adequately measure concentrations of local source emissions (Carvlin et al., 2017). As such, community groups have been adopting low-cost air monitors to measure local air emissions in their area. Data generated is used as an advocacy tool for establishing air monitoring networks and mitigating localized air pollution (Clements et al., 2017).

In recent years, commercially available low-cost particulate monitoring technologies have been developed to enhance air monitoring networks for temporal and spatial regional variations of PM concentrations (Northcross et al., 2013; Wang et al., 2015; Jiao et al., 2016). One such device is a battery-operated Dylos DC 1700-PM laser particle counter used to monitor both indoor and outdoor $PM_{2.5}$ concentrations (Dylos Corporation, 2019). For covering both industrial and residential areas, this low-cost laser particle counter Dylos DC 1700 was used to monitor air of respirable fine $PM_{2.5}$ (Steinle et al., 2015).

3.3.1.1 Validation and Use of Dylos Laser Particle Counter for $PM_{2.5}$ Measurement

The Dylos DC 1700-PM Battery Operated AQM (Dylos Corporation, California, USA) is a laser particle counter that uses light scattering to detect and count particles in two size ranges: large at greater than 2.5 ug to 10 ug (PM_{10}) and small at between 2.5 ug and 0.5 ug ($PM_{2.5}$) (Dylos Corporation, 2019). The large particulate that is greater than 2.5 up to 10 micrograms, is known as coarse particulate matter, which were not measured in this study. The small size is 2.5 ug down to 0.5 ug known as fine particulate matter ($PM_{2.5}$), which were measured in this study. The $PM_{2.5}$ is what Dylos measured from 2.5 ug to 0.5 ug size or respirable fine particulate matter. Particles less than 0.5 down to 0.1 are nanoparticles and are not measured by Dylos.

The Dylos is relatively low-cost compared to traditional gravimetric and continuous designated EPA particulate matter monitors (Han et al., 2017). The DC 1700 draws the airstream at 28.32l/minute with an inbuilt computer fan and monitors the particles in the measurement chamber with a laser beam operating at 650 nm wavelength (Northcross et al., 2013). The airstream particles pass through a laser light which cause scattering effects. The number of particles detected for each particle size discriminated by the scattering effect is logged on an inbuilt memory, which can store up to a week's worth of time-stamped data recorded every minute (about 10,000 samples).

Previous studies using the Dylos DC 1700 have monitored $PM_{2.5}$ in different settings in both indoor and outdoor environments (Semple et al., 2013; Northacross et al., 2013; Steinle et al., 2015). These studies validated data recorded by Dylos records through collocation with designated EPA FRM and FEM $PM_{2.5}$ air monitors in comparable environments (Steinle et al., 2015; Carvlin et al., 2017). According to Steinle et al. (2015), the validity of Dylos with a FEM national $PM_{2.5}$ air monitoring network showed $R^2 = 0.9$ and $R^2 = 0.7$ at urban and rural background sites (see Fig. 3.4).

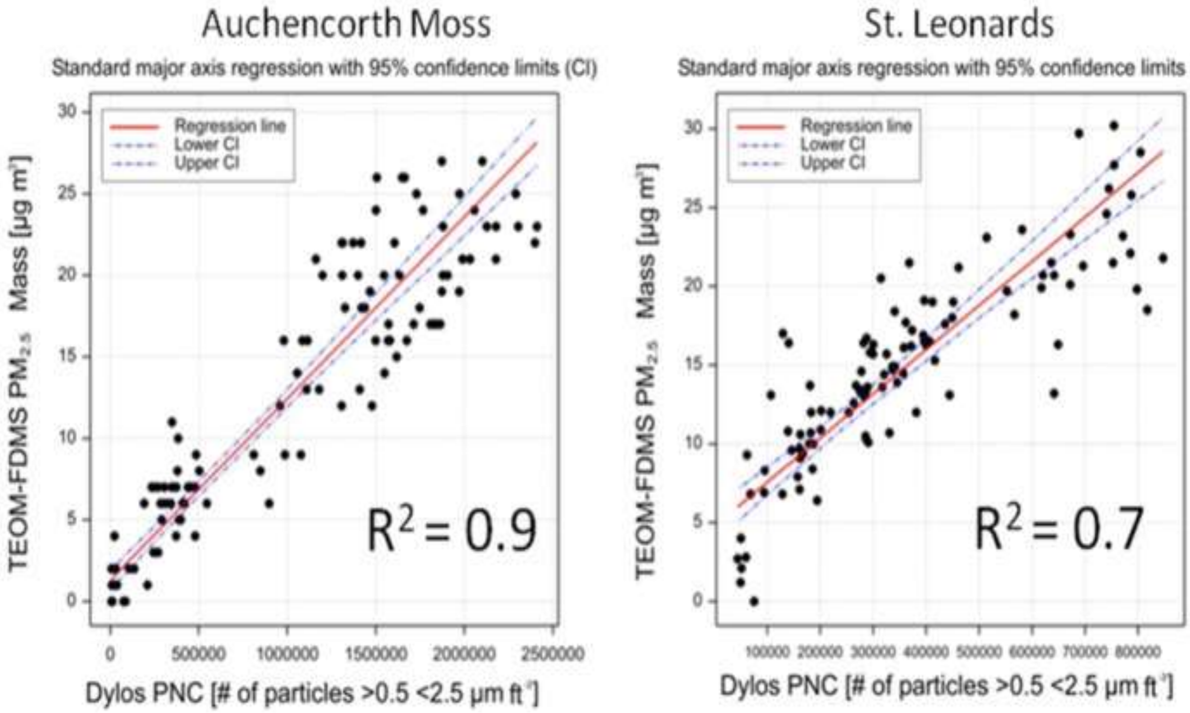


Fig. 3.0 Regression analysis of converted Dylos particles number for $PM_{2.5}$ with TEOM-FDMS federal equivalent $PM_{2.5}$ national monitors (Steinle et al., 2015).

Similarly, Northcross et al. (2013) conducted a field test of Dylos 1700 with a commercially available industrial air monitor (FEM), DustTrak and an E-bam beta attenuation monitor (Met-One™). A 24-hour ambient aerosol field test for woodsmoke between Dust Trak and Dylos (BAIRS term used by author) showed R^2 0.81 for January 27-29, 0.98 for February 10-11, and 0.99 for February 17-18 (see fig 3.5.1).

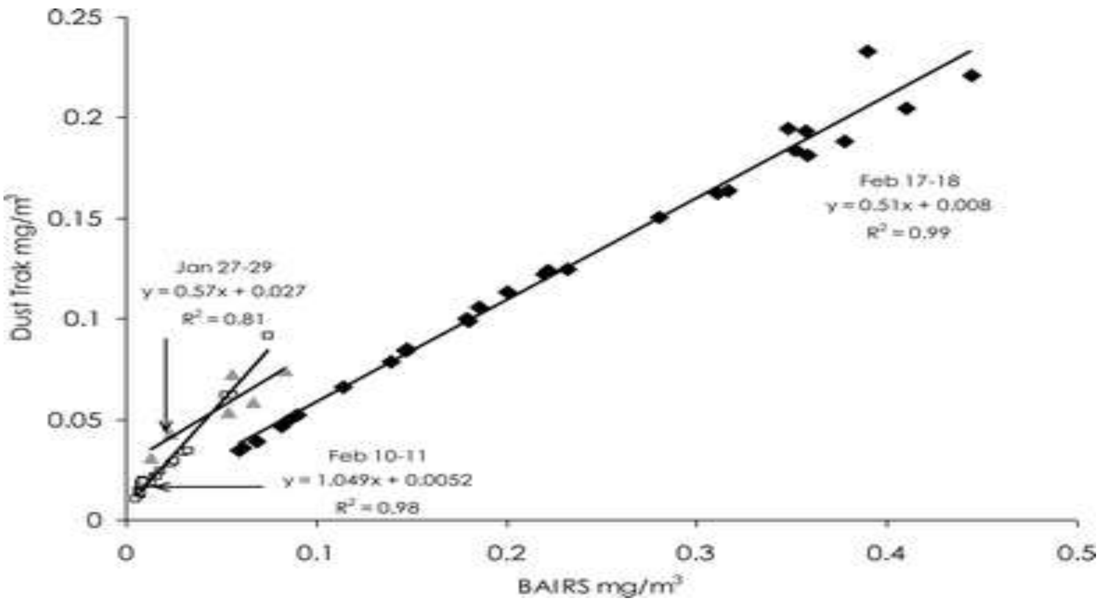


Fig. 3.1 Linear regression analysis for ambient $PM_{2.5}$ mass concentrations of woodsmoke monitored by two particulate monitors, Dylos (BAIRS) and TSI Dust Trak, in mg/m^3.

This study confirmed that the Dylos DC1700 is a viable and affordable $PM_{2.5}$ air quality monitoring instrument. The Dylos DC1700 effectively measured emissions adjacent from scrap metal recycling operations in MIA. Also this instrument was able to monitor ambient concentration of $PM_{2.5}$ at Dufresne Avenue and in the South St. Boniface neighborhood.

3.3.2 $PM_{2.5}$ Air Monitoring Procedure

Air monitoring was designed to measure the upwind and downwind fine respirable $PM_{2.5}$ emissions from the automobile shredder of the scrap metal recycling plant. The upwind $PM_{2.5}$ was measured twice daily: one-hour measurement in the early morning (7:30 AM to 8:30 AM) and late afternoon (4:15 PM to 5:30 PM). Results were used to measure background $PM_{2.5}$ in the industrial area and to quantify the influx of ambient $PM_{2.5}$ in the direction of the scrap metal recycling plant (Watson et al., 2011). Monitoring sites/points were selected on public property or other properties adjacent to the automobile shredder property based on the daily prevailing wind direction. These air monitoring sites were selected to record fine respirable particulate matter emission directly from the scrap metal shredding by directing the air inlet of the Dylos DC 1700 AQM facing the scrap metal shredder.

Fig. 3.2 Upwind measurement of ambient $PM_{2.5}$ in Mission Industrial Area, Winnipeg (June, 2018).

Downwind $PM_{2.5}$ monitoring of fugitive emissions adjacent to the automobile shredder property. Five monitoring points were established based on the prevailing wind direction from the installed meteorological real-time instrument: downwind of south, north, west, east and southwest prevailing daily and hourly wind directions. Measurements were recorded daily during the metal shredder's operating hours of 8:30 AM to 4:30 PM.

Fig. 3.3 Downwind measurement of $PM_{2.5}$ emissions during scrap metal shredding operations in Mission Industrial Area, Winnipeg (June, 2018).

For two to three weekdays (7:40 AM to 5:00 PM), I monitored the outdoor $PM_{2.5}$ mass concentration in the South St. Boniface residential areas. Residential monitoring was designed to measure the ambient $PM_{2.5}$ levels in order to give an indication of air quality levels in South St. Boniface. The air monitoring sites covered: roadsides, parklands, front lawns and mostly gardens of residents. Daily daytime monitoring started with roadside measurements, approximately two meters away from the road entering each street, to record traffic-related $PM_{2.5}$ between 7:40 AM to 8:40 PM. Subsequent residential daytime hourly measurements were taken at different households that signed up for air monitoring near their property (9:00 AM to 3:30 PM). Late afternoon air measurements were recorded for traffic-related emissions between 4:00 PM and 5:00 PM. Weekend

(Saturday) samples were also taken from the first weekend in August to the last weekend in October 2018. The $PM_{2.5}$ air monitoring measured over 550 hourly data for both source emission levels from the scrap metal recycling property lines and residential monitoring points in South St. Boniface. The hourly data and respective sampling points are presented in Appendix A.

Fig. 3.4 Roadside air and noise monitoring on Marion and Archibald Roads in South St. Boniface, Winnipeg, Manitoba (June, 2018).

For industrial and residential monitoring, the Dylos DC1700 was placed on a tripod and set at a height of 1.7 m above ground to measure particle emissions at human breathing level. The air sampler measured airborne particles at the upwind and downwind direction to compare the levels of respirable particulate matter in the upwind concentration with the downwind concentration of the scrap metal recycling plant (Watson et al., 2011; Owoade et al., 2013). Weekend air monitoring was conducted to determine and compare the ambient concentration of $PM_{2.5}$ with measurements taken during weekdays.

3.4 Noise Monitoring

Noise monitoring has often been used to quantify primary sources and distribution of noise, to institute corrective and mitigating action plans for disturbances or potential health risks related to the noise around workplaces, school environments and residential areas (Barron, 2001; Anna et al., 2009).

3.4.1 Noise Measurement Instruments and Approach

The noise levels in this study (see Fig. 3.5) were measured with an IEC61672-1 Class 2, ANSI S1.4 Type 2 battery-powered factory-calibrated REED R8080 Sound Level Meter/Data Logger (SLM), equipped with a ½ inch electret condenser microphone, and a measuring range of 30 to 130dB. The SLM time weighting was set at the slow response mode and A-weighting (A-weighted decibels (dBA)) to measure the relative loudness of sound in the air that humans can perceive. This noise measuring instrument was mounted and screwed on a Dynex lightweight camera tripod (see Fig. 3.5) about 1.60 meters above ground for daily use in the study area (EPA, 2016).

The SLM was strategically deployed daily depending on the prevailing real-time wind direction data recorded by the installed Watchdog 2000 Series Weather Station in the study area. Prevailing wind direction is an important meteorological factor that affects noise emission and propagation. Noise emissions and propagation are the most significant downwind of a noise source with a 6 to 7 dBA lower noise propagation loss at a distance over 1000 meters than the upwind direction of noise emissions (Evans & Cooper, 2012). Thus, the SLM, shielded with a windscreen, was installed downwind of the prevailing wind direction at each noise monitoring point in the study area (see Fig. 3.5).

3.4.2 Noise Monitoring Design and Procedure

The study's noise monitoring design included three monitoring points: the industrial area, road-side and residential area. The sampling duration for each site varied but was typically two to three days a week, as well as Saturdays, between 8:45 am to 4:30 pm, over a six month period from July to December 2018. Combined, sampling spanned a total of 89 days. The SLM was installed daily on a lightweight camera tripod, downwind of the prevailing wind direction and at least 1.5 meters away from any physical barriers, such as walls or trees, that could inhibit noise propagation. In addition, the noise instrument was set to record the minimum and maximum noise levels; data was logged at five-second intervals.

The industrial area noise measurement followed an 8-hours daytime fence-line noise data logging on the SLM during the operating hours of the MIA scrap metal recycling plant. This monitoring design was aimed to measure emission levels along the perimeter of the plant. Intermittent noise was recorded as a qualitative observation (see Fig. 3.5.2a) during the daytime monitoring of noise emissions.

Fig. 3.5 REED digital logging sound level meter installed for logging noise levels in dBA during scrap metal shredding in Mission Industrial Area, Winnipeg (July, 2018).

Daily residential noise measurement, also known as the community noise survey, was taken at five different points across each street: road-side noise traffic measurement at the entrance of each street at one hour measurements during early morning and late afternoon traffic rush hours 2-3 days/week (7:45 am to 8:45 am and 4:00 pm to 5:00 pm).

Residential noise monitoring measured outdoor noise levels at seven houses on each of the four streets in Dufresne Avenue of South St. Boniface. The SLM's location was changed every hour to a new house to monitor the measurement of spatial and temporal variation of noise levels. The noise levels recorded on the SLM for each of the monitoring sites were downloaded using the manufacturer's SE323 PC installed downloader interface with a USB cable to the PC and saved logged data saved, daily, as a Microsoft Excel file. Over 450 hourly noise data was recorded in all the noise monitoring sites both in the scrap metal recycling property lines and residential monitoring points in South St. Boniface. Hourly noise data for each monitoring sites were presented in Appendix B.

3.5 Sampling and Analysis of Airborne Heavy Metals in Snow

Snow cover provides a temporary medium for deposition of airborne toxic metals and other air pollutants removed or transported by wind from the atmosphere of industrial and urban environments (Elik, 2001; Baltrenaite et al., 2014). Toxic metals accumulate in the snow because pollutants slowly migrate into the ecosystem due to snow acting as an aerodynamic barrier to particles suspended in the air and condensation of heavy metals on fine particles (Krastinyte et al., 2013). These characteristics justify the need for investigating the presence and distribution of air pollutants in snow as an indicator of urban pollution. To gather information on the atmospheric deposition of air pollutants in snow, sampling and chemical analysis of monthly snowfall or accumulated snow cover are conducted for particulates, nitrates, sulphates and airborne heavy metals in industrial, urban and arctic areas (Sakai et al., 1988; Nawrot et al., 2016).

Hence, this study collected and analyzed undisturbed accumulated snow samples between late December 2018 and March 2019 in the Mission Industrial Area, South St. Boniface neighbourhood and roadsides (Loranger et al., 1996; Kuoppamaki et al., 2014; Pilecka et al., 2017). The snow sampling and collection, preparation and analytical procedures are discussed in the following sections in accordance with the community-based environmental monitoring design.

3.5.1 Snow Sampling Procedure

Five composite samples (automobile shredder 1, 2, 3, 4 and 5) were collected from the scrap metal recycling fence-line, downwind of the air monitoring points (south, north, west, east, and southwest) (see Fig. 3.6). The wind rose to detail the wind direction and wind speed during the dominant period of snowfall and snow cover exposition between November 2018 and March 2019 are shown below in Fig 3.6.

Ten composite samples were taken in the residential/parkland area: two composite samples on each of the four streets and two samples from the two parklands. Four composite snow samples on Archibald and Marion roads and another four composite samples in the commercial areas were also included (Table 3.0 for sampling site characteristics). The composite samples were collected across the sampling areas on 13 March 2019, between 9:30 am and 5:50 pm. Composite sampling was adopted to minimize analytical costs and for use as a preliminary descriptive method to determine the presence of heavy metals in accumulated snow cover (Lancaster & Keller-Mcnulty; Johnson and Patil, 2001).

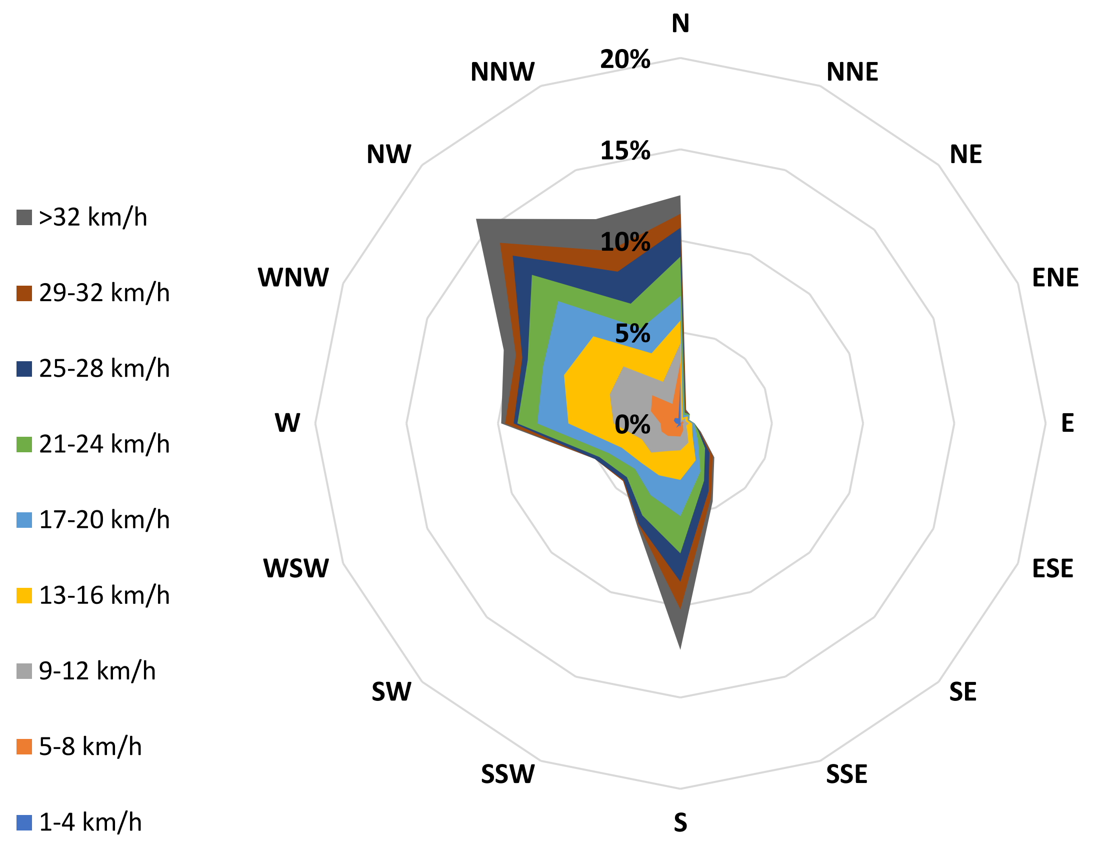


Fig. 3.6: Wind Rose for Wind Speed and Wind Direction Measurement from The Forks Weather Station, Winnipeg. (1st November 2018 to 13th March 2019)

Two background samples were collected at Silverstone, Fort Richmond, near the University of Manitoba, from two different houses in a neighbourhood judged to be free of local pollution sources (Tchepel et al., 2010). The background samples were collected in this neighbourhood due to the absence of local industrial operations and not having high vehicular traffic (Sakai et al., 1988). The samples served as the control to determine the natural concentration of heavy metals in the snow deposit and to compare with the concentration of heavy metals in study sites samples. Hence, a total of 25 composite snow samples were taken for total metals and total mercury analysis, including a) five at the fence-line of scrap metal shredding, b) four at commercial sites and c) 10 in the residential/parkland zone of South St. Boniface, with four being roadside. Two background composite snow samples were also collected.

Snow samples were collected with a clean, rust-free aluminium shovel at the depth of 10-43 cm of the accumulated snow deposit across the sampling points in the study sites (Wolf and Peel, 1988). The aluminium shovel was rinsed with distilled water at each of the sampling points to prevent sample contamination. Four random snow sampling points, at least 5 m away from one another, were selected in each of the industrial, residential, commercial, roadside and background areas to draw a composite sample. The accumulated snow cover for each of the sampling point was removed to the depth of 35 cm above the soil level to avoid crustal contact with the frozen ground. The removed snowpack from the four sampling points was divided into top, middle and bottom layers. Each layer was scooped into two pre-cleaned 500 ml HDPE bottles (BOD style) labelled for total metals and total mercury, respectively, and shaken vigorously to have a homogenous mixed composite sample. This sampling procedure was replicated to acquire different composite snow samples from the study area.

Table 3.0 Snow Sampling Site, GPS Coordinates and Site Characteristics

No.	Name of Sampling Point	X Coordinates	Y Coordinates	Site Characteristics
1	Industrial area east downwind	49.8881	-97.1016	Construction storage site and nearby rail track
2	Industrial area west downwind	49.8881	-97.0976	Fence-line of auto shredder
3	Industrial area southwest downwind	49.8881	-97.0976	Fence-line of scrap metal recycling plant
4	Industrial area north downwind	49.8864	-97.0984	Nearby rail track and industrial operations
5	Industrial area south downwind	49.8909	-97.0991	Construction storage site beside Messier road
6	Archibald road point 1	49.885204	-97.10035	Intensive traffic street and transit bus stop
7	Archibald road point 2	49.883436,	-97.099733	Intensive traffic street and transit bus stop
8	Marion road point 1	49.881663,	-97.097664	Intensive traffic and all types of vehicle routes
9	Eastbound Marion road point 2	49.881869,	-97.10171	Intensive traffic and all types of vehicle routes
10	Commercial area 1	49.8877	-97.1026	Roadside and scrap metal savage yard
11	Commercial area 2	49.884912,	-97.099592	Back of auto repair and nearby rail track
12	Commercial area 3	49.884540,	-97.099347	Beside kid city and nearby rail track
13	Commercial area 4	49.8834	-97.13863	Sikh temple open field and nearby rail track
14	Kavanagh Park (Residential/Parkland)	49.8855	-97.1034	Strictly residential area and light vehicular movement
15	Happyland Park (Residential/Parkland)	49.8815	-96.8963	Beside Marion Road with busy traffic
16	Cherrier Street 1(Residential/Parkland)	49.884	-97.1035	Backyard of a residential area
17	Cherrier Street 2 (Residential/Parkland)	49.883923,	-97.100766	Backyard of a residential area
18	Kavanagh Street 1(Residential/Parkland)	49.8855	-97.1034	Residential area NNE downwind of Mission Industrial Area
19	Kavanagh Street 2(Residential/Parkland)	49.885583,	-97.101981	Residential area NNE downwind of Mission Industrial Area
20	Giroux Street 1(Residential/Parkland)	49.8849	-97.1039	Residential area NNE downwind of Mission Industrial Area
21	Giroux Street 2(Residential/Parkland)	49.8849	-97.1032	Residential area NNE downwind of Mission Industrial Area
22	Doucet Street 1(Residential/Parkland)	49.882666,	-97.101576	Residential area NNE downwind of Mission Industrial Area
23	Doucet Street 2(Residential/Parkland)	49.883110,	-97.10233	Residential area NNE downwind of Mission Industrial Area
24	Background sample 1	49.798540,	-97.145837	Non-industrialized neighborhood
25	Background sample 2	49.798868,	-97.1465	Non-industrialized neighborhood

3.5.2 Samples Storage, Preparation and Analysis

Before the submission of the snow samples at an accredited laboratory for heavy metals analysis, the samples were allowed to melt 16 hours at room temperature until the 500 ml sample bottles became snow water. Melted snow samples for total metals analysis were transferred into 61 ml metals bottles and nitric acid ($HNO3$) was added as a preservative. The snow water samples for total mercury were transferred into 40 ml total mercury vials, with hydrochloric acid (HCl) used as the preservative. The acidified melted snow samples were preserved in an ice pack cooler before transportation to the laboratory within 24 hours post-collection.

The acidified melted snow samples were submitted to the ALS laboratory, in Winnipeg, for heavy metals analysis. ALS is an environmental testing laboratory, accredited by the Canadian Association of Laboratory Accreditation (CALA) and Standards Council of Canada (SCC) for International Standards Organization (ISO/IEC) 17025. The 23 composite snow samples from the study site and the two background samples were analyzed for the presence of heavy metal concentrations using inductively coupled plasma mass spectrometry (ICP-MS) techniques (see Appendix C). Results of the 23 composite snow samples were compared with the background snow samples. The laboratory analysis results of total metals and total mercury in snowpack samples were presented in Appendix C.

3.6 Method of Data Analysis

The statistical software SPSS version 24 and Microsoft Excel 2016 were used for statistical analysis of the data obtained from air monitoring, noise monitoring and snow cover samples data, respectively. Descriptive statistics showing mean, median, standard deviation and coefficient of variation were analyzed. Graphical representation and comparison of data with background samples and regulatory guidelines/standards was also conducted. The analysis of all data recorded and obtained from the environmental monitoring methods was conducted by using one-way analysis of variance (ANOVA) and the Spearman rank correlation coefficient (Farahmandkia et al., 2010; Zamani et al., 2012).

CHAPTER FOUR

4.0 Air-bound Heavy Metals Deposition in Accumulated Snowfall

4.1 Heavy Metal Concentrations in Snow Samples

This section presents the results and the deposition of heavy metals in snow cover in the study area. The descriptive statistics of Pb, As, Cd, Cr, Ni, Hg, Zn and Mn in the snow cover samples of MIA, SSB neighbourhood, and background concentration of heavy metals are presented in Table 4.0 below. The background concentrations of heavy metals in the snow were analyzed from snow samples collected in a non-industrialized neighbourhood. In MIA and SSB, concentrations of toxic metals in ug/l varied between 0.64 and 85.5 for Pb, 0.14 and 1.04 for As, 0.01 and 1.5 for Cd, 0.17 and 10.8 for Cr, 0.65 and 10.2 for Ni, 0.03 and 0.2 for Hg, 9.3 and 1660 for Zn, 4.6 and 67.8 µg/l for Mn. The observed mean concentrations for all heavy metals tested were higher than their background concentration values, with the concentrations of As, Cd, and Hg not being detected in the background samples. The observed higher mean concentrations of all these toxic metals indicates anthropogenic emissions from the Mission Industrial and South St. Boniface areas.

Coefficient of variability (CV) is used to show or describe the extent of variability in sample data (Yang et al., 2016). The CV values for Pb, As, Cr, Ni, Hg, and Zn are 104.3, 112.5, 98.11, 204.7, 134.5, and 119.5, respectively. These values show widespread variability of heavy metals, signifying that concentrations of Pb, As, Cr, Ni, Hg, and Zn in snow are likely affected by anthropogenic sources. Zn and Pb had much higher levels of concentrations in the industrial areas and Hg concentration was only observed in the industrial sampling point.

Table 4.0: Summary Statistics of Toxic Heavy Metals in Snowpack Samples

Heavy Metals (μg/l)	Detection Limits (DL)	Sample Sites	Mean	Min	Max	Median	SD	CV	Background Value
Pb	**0.05**	Industrial	30.1	10.0	85.8	18.5	31.4	104	0.20
		Roadside	5.55	0.69	13.2	4.15	5.37	96.7	
		Commercial	4.75	2.84	8.07	4.05	2.38	50.1	
		Residential	1.42	0.64	2.90	1.05	0.92	65.0	
As	**0.10**	Industrial	0.33	0.15	0.72	0.27	0.22	66.8	<DL
		Roadside	0.48	0.14	1.04	0.37	0.41	84.9	
		Commercial	0.30	0.22	0.41	0.28	0.09	30.1	
		Residential	0.09	<DL	0.21	0.07	0.10	113	
Cd	**0.01**	Industrial	0.62	0.20	1.50	0.40	0.51	82.6	<DL
		Roadside	0.08	0.01	0.18	0.07	0.07	81.8	
		Commercial	0.06	0.04	0.08	0.06	0.02	30.4	
		Residential	0.03	0.01	0.04	0.03	0.01	41.3	
Cr	**0.10**	Industrial	4.29	1.13	10.8	3.09	4.00	93.3	0.22
		Roadside	2.20	0.43	5.21	1.57	2.15	98.1	
		Commercial	0.99	0.74	1.31	0.95	0.27	27.0	
		Residential	0.30	0.17	0.44	0.29	0.10	33.7	
Ni	**0.50**	Industrial	3.71	1.00	10.2	2.52	3.72	100	0.74
		Roadside	1.82	<DL	4.37	1.45	1.86	102	
		Commercial	0.86	0.65	1.08	0.85	0.18	21.3	
		Residential	0.94	0.83	4.8	<DL	1.92	205	
Hg	**0.01**	Industrial	0.06	0.03	0.2	0.03	0.08	134	<DL
		Roadside	<DL	<DL	<DL	<DL	<DL	<DL	
		Commercial	<DL	<DL	<DL	<DL	<DL	<DL	
		Residential	<DL	<DL	<DL	<DL	<DL	<DL	
Zn	**3.00**	Industrial	545.0	39.0	1660.0	410.0	651.0	119.0	8.30
		Roadside	78.5	28.5	80.2	52.4	21.2	39.7	
		Commercial	53.4	166	18.6	64.7	63.1	80.3	
		Residential	18.6	9.30	27.7	16.8	6.70	36.0	

Mn	**0.10**	Industrial	30.0	11.7	72.2	25.4	25.4	84.7	3.63
		Roadside	30.9	9.52	67.8	23.1	25.8	83.5	
		Commercial	11.2	9.94	12.8	11.1	1.24	11.0	
		Residential	6.07	4.60	7.26	6.19	1.03	17.0	

Notes:

A. Sample Size:
    1. 5 Industrial composite samples;
    2. 10 Residential/Parkland composite samples;
    3. 4 Roadside composite samples;
    4. 4 Commercial area composite samples; and
    5. 2 Background composite samples.

B. Abbreviations:
    1. Min- Minimum concentration of heavy metals;
    2. Max- Maximum concentration of heavy metals;
    3. SD – Standard deviation; and
    4. CV – Coefficient of variation.

4.2 Site Comparison of Heavy Metals Concentration in Accumulated Snow Cover

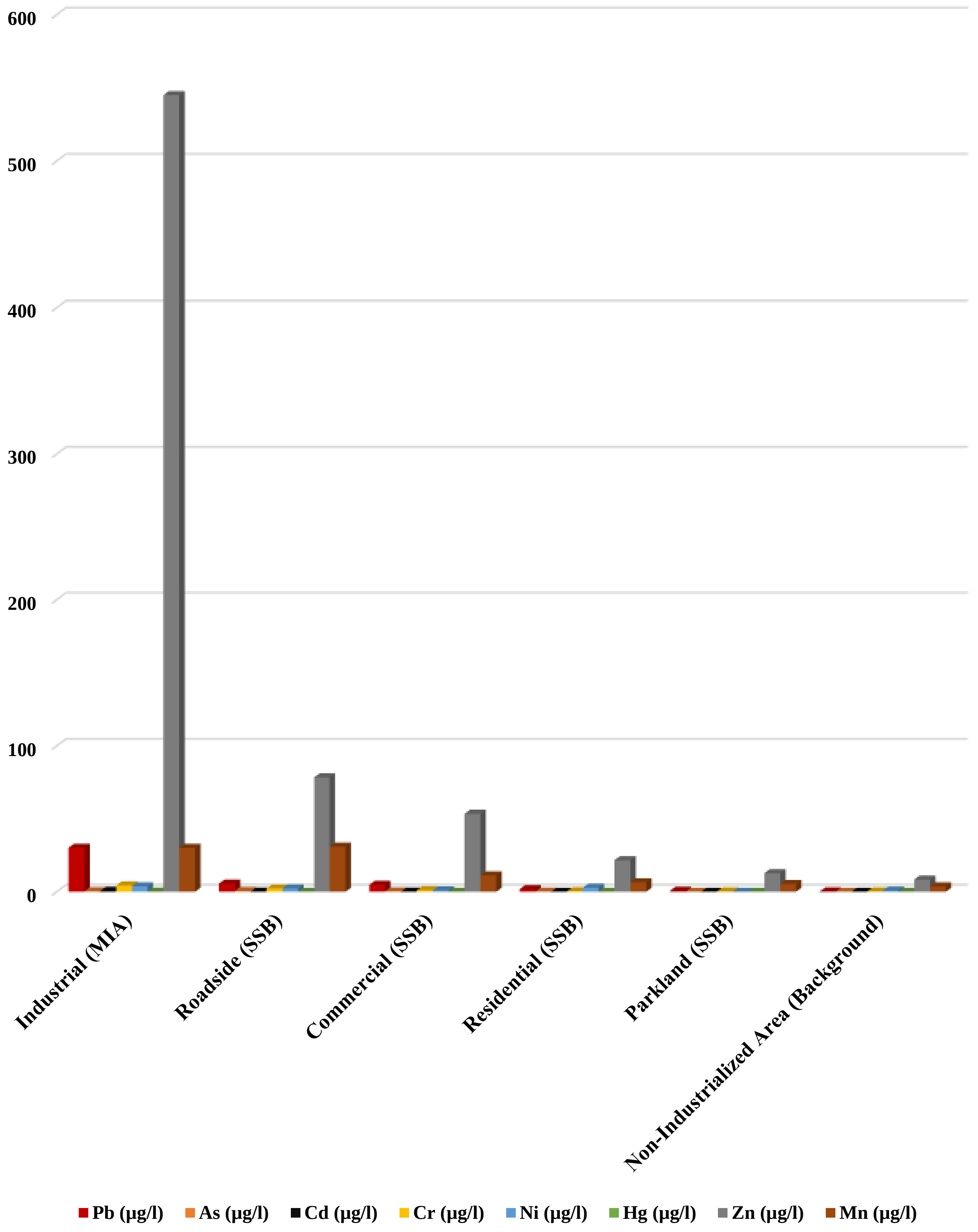
Numerous studies have reported toxic airborne heavy metals contamination in snowpack in various parts of the world with snowfalls. Various physical and environmental factors cause environmental contaminants to embed in snowpacks (Kuoppamaki et al., 2014). According to Engelhard (2007), adsorption and accumulation of organic and inorganic pollutants in the atmosphere to snow is influenced by the large surface area of snow and the slow pace of snowfall. Notably, small ice crystals and thin liquids in snowflakes provide the large surface area acting as the medium of adsorption, desorption and chemical reaction for environmental pollutants (Grannas, 2014; Nazarenko et al., 2016). Meteorological factors and wind velocity ranging from 0.1 to 1.1 m/s influence the local adsorption and accumulation of pollutants in snow surface area and subsequent deposition in snow cover (Siudek et al., 2015). Consequently, snowpack can serve as a temporary sink for airborne pollutants and a potential source of environmental contaminants during snowmelt in spring.

Based on the current study area land-use, the snow sample site was divided into four areas: 1) Mission Industrial Area, 2) roadside, 3) South St. Boniface (residential/parkland, and commercial area), and 4) background sample sites. The descriptive statistics of heavy metals concentration in snow samples collected from different sample sites are shown in Table 4.3. The mean and median concentrations of Zn and Pb were the highest of all heavy metals analyzed, with the industrial area sampling point having the highest concentration with industry being the highest and the background being the lowest in the order of industrial>roadside>commercial>residential>background areas (see chart 1). The contamination concentration also correlates with the distance from the industrial source. Last, the higher mean concentration of heavy metals in snow samples from the industrial area reflects a local pollution source likely resulting from a seasonal dominant northwest wind direction.

The mean concentration of Zn and Pb in the commercial, roadside and industrial snow samples were 24 to 151 times higher than the concentration of background snow samples. Enrichment of heavy metals in the snow has been previously attributed to the wind transportation and deposition of Pb-rich fine aerosols, dust and particulate matter (Owoade et al., 2013; Sakata et al., 2014). Typical operations that emit Pb and Zn pollution in snow are car emissions, industrial emissions and tire rub-off (Vasic et al., 2012; Krastinyte et al., 2013).

The concentration of Pb in the snow samples of residential/parkland area (SSB) snow sampling was seven times higher than the concentration in the background samples. Lead (Pb) pollution poses a human health risk. Lead is a probable cancer-causing element, having both short and long-term toxic effects on children exposed to Pb. Lead is associated with neurological effects and mental retardation in children more often than in adults (NIOSH, 1995; ATSDR, 2007). Other trace elements, such as As, Cd, Cr, Ni and Mn, detected in the snow cover samples of industrial and roadside areas were significantly higher than those collected from commercial, residential/parkland and background sample areas (see chart 1). The enriched concentration of these heavy metals in urban snow, for example As, has been linked to anthropogenic emissions from non-ferrous metal production, smelting, steel industry and scrap metal recycling (Siudek et al., 2015).

Figure 4: Average Concentration of Heavy Metals Distribution in Snow Samples in MIA and SSBN and Non-Industrialized Neighborhood



4.3 Correlation Coefficient Analysis of Heavy Metals in Snow Cover

In this study, the Spearman rank coefficient analysis was used to indicate probable relationships that could exist between Pb, As, Cd, Cr, Ni, Hg, Zn and Mn across the snow sample sites in Mission Industrial Area and South St. Boniface. The Spearman rank correlation, as shown in Table 4.2, revealed As, Cd, Zn, Mn and Hg to be moderately to strongly correlated with each other. The Spearman rank coefficient ranged from 0.541 to 1.000, which is very high, at the 0.01 statistical significance level. Also, a positive statistically significant correlation was observed between Pb, Cd, As, and Cr at 0.697 to 0.867, below the 0.01 level statistical significance level. The correlation coefficient suggests a common anthropogenic source of the heavy metals across the snow sampling sites. All heavy metals concentrations in the snow sampling site have a strong correlation coefficient, except for Ni, with weak or no correlation with other heavy metals investigated in the study. Studies by Yang et al. (2016) and Sakai et al. (1988) in industrial and residential areas reported a positive correlation for Pb and Zn in snow cover and topsoil samples as an indicator of atmospheric deposition of heavy metals. Similarly, Siudek et al.’s (2015) studies of heavy metal deposition in snowpack found a strong positive correlation between Pb and Zn ($r = 0.93$, $p < 0.05$).

Table 4.1: Spearman Rank Correlations for Heavy Metals in Snowpack

			Pb	As	Cr	Cd	Ni	Zn	Mn	Hg
Spearman's rho	Pb	Correlation Coefficient	1.000							
		Sig. (2-tailed)	.							
		N	17							
	As	Correlation Coefficient	.341	1.000						
		Sig. (2-tailed)	.233	.						
		N	14	14						
	Cr	Correlation Coefficient	.943**	.420	1.000					
		Sig. (2-tailed)	.000	.135	.					
		N	17	14	17					
	Cd	Correlation Coefficient	.867**	.697**	.883**	1.000				
		Sig. (2-tailed)	.000	.006	.000	.				
		N	17	14	17	17				
	Ni	Correlation Coefficient	.549	.190	.432	.577*				
		Sig. (2-tailed)	.052	.535	.140	.039				
		N	13	13	13	13				
	Zn	Correlation Coefficient	1.000**	1.000**	.500	1.000**	1.000**			
		Sig. (2-tailed)	.	.	.667	.	.			
		N	3	3	3	3	3			
	Mn	Correlation Coefficient	.877**	.541*	.923**	.943**	.429	.500	1.000	
		Sig. (2-tailed)	.000	.046	.000	.000	.144	.667	.	
		N	17	14	17	17	13	3	17	
	Hg	Correlation Coefficient	.858**	.704**	.840**	.980**	.610*	1.000**	.902**	1.000
		Sig. (2-tailed)	.000	.005	.000	.000	.027	.000	.000	.
		N	17	14	17	17	13	3	17	17

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The Spearman rank correlation was adopted due to this non-parametric test not requiring a normal distribution, and these environmental contaminants being a non-normal distribution. The heavy metals concentration in snow samples were subjected to normality test using Shapiro-Wilk test for distribution (Table 4.3). From the tests of normality results below, both the Kolmogorov-Smirnov and Shapiro-Wilk tests indicated a significant result for all heavy metals p-value < 0.05. Hence, p-values < 0.05, as shown in the Kolmogorov-Smirnov and Shapiro-Wilk test, indicate that the data for heavy metals concentrations in snowpack samples were not normally distributed.

Table 4.2: Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	df	Sig.
Pb	.316	23	.000*	.481	23	.000*
As	.209	23	.0108	.812	23	.001*
Cr	.333	23	.000*	.612	23	.000*
Cd	.349	23	.000*	.521	23	.000*
Ni	.269	23	.000*	.673	23	.000*
Zn	.361	23	.000*	.426	23	.000*
Mn	.324	23	.000*	.632	23	.000*
Hg	.490	23	.000*	.356	23	.000*

a. Lilliefors Significance Correction

- significant at <0.01

4.3.1 Result of One-way ANOVA for Heavy Metals in Snowpack Across Sampling Sites

For the test of one-way ANOVA, mean concentrations of each heavy metal were transformed using natural log on Microsoft Excel 2016 because the data were not normally distributed (see Table 2 in Appendix B). One-way analysis of variance (ANOVA) was used to test for the significant difference in the concentration of the heavy metals in snowpack sample sites (industrial, roadside, commercial and residential sites). A p-value of 0.05 or less was adopted to prove statistically significantly different (Jenyo-Oni & Oladele, 2016). The result of one-way ANOVA for heavy metal concentrations against the sample sites showed p-value = 0.398, at the 0.05 significant level. The result showed non-statistically significant mean differences between group means of heavy metals concentration.

Table 4.3: One-way ANOVA for means comparison of heavy metals concentration between Snow Sample Sites

ANOVA					
Concentration					
	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	14.023	3	4.674	.773	.520
Within Groups	151.149	25	6.046		
Total	165.172	28			

4.4 Heavy Metals Accumulation in Snow Cover: comparison with other study locations

Table 4.4 of this chapter compared and summarized the concentrations of the heavy metals in the accumulated snow in this study with those reported by authors that investigated various types of snow samples in different geographical locations. The mean concentration of Zn at 545.5 µg/l, in snow samples for the MIA, shows higher pollution levels than for other elements analyzed in this study. The mean concentration for an industrial area in this study for Zn was 5 to 10 times higher than the values 53 µg/l and 101.1 µg/l reported by Sakai et al. (1988) and Pilecka et al. (2017). Lower concentrations of Zn in the snow cover of the industrial area in Jelava, Latvia and inner urban areas of Sapporo City, Japan, were reported. The Zn pollution in these studies was directly associated with industrial emissions and other urban-related anthropogenic air pollutants. Similarly, the mean concentration of Zn (78.85 and 53.35 µg/l) in roadside and nearby commercial areas in this study fall within the range (29.0 – 143.0 µg/l) detected by Loranger et al. (1996) in the snow cover of an urban expressway in Montreal, Canada.

The mean concentration of Pb (30 µg/l) measured in industrial snow cover of Winnipeg was approximately seven times lower than the mean value of 205.5 µg/l observed by Engelhard et al. (2007) in Innsbruck, Austria. Both the industrial sample in Winnipeg and the mean concentration of Pb (1.4 µg/l) in the residential/parkland snow samples in Winnipeg were significantly higher than the concentration (0.011 µg/l) reported by Barbante et al. (2003) in snow deposits in Central Greenland. The concentration of Pb detected in the industrial snow cover sample in this study ranged between 10 and 85.8 µg/l, which is lesser than the Pb concentration reported in the melted snow-cap heavy metals (Kristynte et al., 2013). The high concentrations of Zn and Pb in snow samples of this study agreed with the findings of other studies that industrial emissions and urban-related traffic contribute to the accumulation of heavy metals in snow cover (Sakai et al., 1988; Vasic et al., 2012; Telloli, 2014; Siudek et al., 2015).

Heavy metals concentration in snow cover samples of Winnipeg, Canada are compared to other locations scrap metal recycling operations in Table 4.4.

Table 4.4 Comparison of some selected heavy metals concentration in snow cover samples of Winnipeg , Canada and other locations

Study Site and Year	Type of Snow	Pb	As	Cd	Cr	Ni	Hg	Zn	Mn	References
Winnipeg, 2019	Industrial	30.10	0.330	0.620	4.290	3.700	0.06	545.5	30.00	This study
Winnipeg, 2019	Roadside	5.550	0.480	0.080	2.200	1.800	ND	78.50	11.20	This study
Winnipeg, 2019	Commercial	4.750	0.300	0.060	1.000	0.860	ND	53.40	30.90	This study
Winnipeg, 2019	Residential/Parkland	1.420	0.090	0.030	0.300	0.940	ND	18.60	6.100	This study
Winnipeg, 2019	Background	0.20	ND	ND	0.220	0.740	ND	8.300	3.600	This study
Sapporo, Japan 1988	Background	2.30	NA	0.050	0.100	NA	NA	3.400	2.500	Sakai et al. (1988)
Sapporo, Japan 1988	Inner Urban	34.1	NA	0.360	9.300	NA	NA	53.00	513.0	Sakai et al. (1988)
Montreal, Canada, 1993	Urban/Crossroad	-	-	-	-	-	-	29-143	-	Loranger et al. (1996)
Central, Greenland	Mountain	0.010	-	-	-	-	-	0.000	-	Barbante et al. (2003)
Alaska, USA, 2002	Mountain	0.600	0.090	0.020	NA	0.110	NA	0.800	NA	Douglas & Stum, 2004
Selawik, Alaska, 2002	Mountain	0.350	0.190	0.010	NA	0.620	NA	1.700	NA	Douglas & Stum, 2004
Innsbruk, Austria, 2006	Urban	205.0	-	3.870	-	-	-	1320.0	-	Engelhard et al. (2007)
Utah, USA, 2009-2010	Mountain	2.300	0.820	NA	0.770	0.680	NA	7.700	NA	Carling et al. (2012)
Cerro Colorado, Chile, 2003, 2008, and 2009	Urban	19.48	0.550	0.720	0.010	0.700	NA	29.60	NA	Cereceda-Balic et al. (2012)
Poznan, Poland 2015	Urban	4.930	0.710	0.080	0.400	3.770	NA	13.20	NA	Suidek et al. (2015)

The mean concentrations of As in melted snow cover in the study's sampling sites ranged between 0.09and 0.33 µg/l, respectively. This concentration is 2 to 10 times lower than the 0.7 µg/l mean value observed by Siudek et al. (2015) in Poznan, Central Poland for an industrial snow sample area that was linked to polluted air masses from urban/industrial air emissions. Winnipeg's As mean value exceeded Douglas and Stum's (2004) mean value of 0.09 µg/l in snow cover across Northwestern Alaska, USA. The lower value reported by Douglas and Stum, (2004) is the lowest mean value reported for arsenic in the study's residential/parkland snow sampling site

The variations between the As concentrations reported in the identified studies are linked to different anthropogenic operations peculiar to each study area and other site characteristics, such as meteorology and the sampling period (Siudek et al., 2015). According to Sanchez-Rodas et al. (2007), non-ferrous metal production is the most significant human-made source of arsenic emissions in an urban/industrial area atmosphere. For example, the higher mean concentration of arsenic in $PM_{2.5}$ air samples was found to be over 300 times (0.20-0.47 µg/m3) above the WHO guidelines of 0.00066 µg/m^3 in scrap metal smelting electric arc furnace emissions by Owoade et al. (2013). Tirez et al.'s (2015) study of arsenic speciation in PM_{10} and $PM_{2.5}$ air monitoring shows trivalent arsenic as the most toxic arsenic to humans and the dominant species in $PM_{2.5}$.

The mean values of Ni (0.860 - 3.712 µg/l) in Winnipeg was significantly higher than the average value (0.72 µg/l) reported by Cereceda-Balic et al. (2012) of Ni enrichment in snow precipitation of Cerro Colorado, Chile. Also, the Ni value in this study is higher than the value (0.68 µg/l) reported by Carling et al. (2012) in the snowpack of Utah, USA. A similar value (3.77 µg/l) for Ni in Winnipeg was reported by Suidek et al. (2015), in Poznan, Central Poland. The previous measurement of heavy metals in scrap metal recycling and smelting particulate matter has elevated the concentration of Ni in fine particulate matter that is likely to be transported beyond the emission source (Owoade et al., 2015).

Mean concentrations of Cd, (0.03-0.62 µg/l) detected in the study's urban snow sample is significantly lower than the mean value of 3.87 µg/l reported by Elgenhard et al. (2007) in the urban snow sample of Innsbruck, Austria. The mean Cd value of 0.62 µg/l of snow cover samples along the fence-line of scrap metal recycling operations in Winnipeg is slightly higher than the mean value of 0.04 µg/l reported by Siudek et al. (2015) in snow deposits in Poland. Mean values of Cd in most snow sampling sites in Winnipeg 0.03, 0.06, and 0.08 µg/l ranged within the values detected by Douglas and Stum (2004), Gabrielli et al. (2006) and Siudek et al. (2015). The highest Cd value of 0.62 µg/l detected in the industrial snow sample of this study was similar to the value of 0.72 µg/l observed in Chile by Cereceda-Balic et al. (2012).

Mean values of Cr (0.300 – 4.29 µg/l) detected in the snow cover samples of Winnipeg show higher variations than Cr values observed in other snow pollution studies. Specifically, the value of Cr at 4.29 µg/l in snow samples near recycling operations was significantly higher than the values of 0.01, 0.40, and 0.77 µg/l, reported by Carling et al. (2012), Cereceda-Balic et al. (2012) and Suidek et al. (2015). In contrast, the study of heavy metals in inner urban snow in Japan (Sakai, 1988) detected the mean value of Cr at 9.30 µg/l; over two times the maximum mean value of 4.29 µg/l observed in Winnipeg.

4.5 Evaluation of Heavy Metals Pollution in Accumulated Snow Deposit

The concentration of heavy metals in snow samples in an urban and industrial landscape is widely reported as an indicator of atmospheric deposition of air pollutants into the ecosystem (Sakai, 1988; Elik, 2001; Baltrenaite et al., 2014; Nawrot et al., 2016). Accumulation of heavy metals in snow cover is a potential source of soil pollution, ground/surface water contamination and human health risk (Dossi et al. 2007; Engelhard et al. 2007). Hence, to determine the presence of air-bound heavy metals in snow, pollution load indices were calculated for each heavy metal analyzed in snow samples at various sampling points in the study area. Previous studies have used various pollution indices for assessing the level of enrichment of heavy metals in wet precipitate/water-sediment and to describe the potential adverse effect (Sakai et al., 1988; Ridgway and Schimmield, 2002; Yang et al., 2015; Pobi et al., 2019). To this end, this study evaluated heavy metals pollution indices by calculating the contamination factor (*cf*), degree of contamination (*cd*) and pollution load index of heavy metals concentration in snow cover samples at different sampling sites.

According to Hakanson (1980) and Backman et al. (2008), a contamination factor (*cf*) is determined by the ratio obtained from the division of the concentration of each heavy metal in the snow sample against the concentration of heavy metals in the background snow sample.

$$cf = \text{mean conc. of heavy metals from the study area} \Big/_{mean\ conc.\ of\ background\ sample}$$

---------------------------------- (1)

Calculated *cf* in this is interpreted according to Hakanson 1980 as $cf \leq 1$ = low contamination; $cf \leq 3$ = moderate contamination; $cf \geq 6$ = considerable contamination, and $cf > 6$ = very high contamination.

Degree of contamination (*cd*): According to Backman et al. (1997), *cd* is used to calculate quality of water or wastewater. *cd* is determined using the formula below:

$cd = \sum_{i=1}^{n} Cfi$ --- (2)

Cfi is the value of the individual contamination factor for each of the selected heavy metals and n is the number of the *cf*s analyzed for individual heavy metal.

Table 4.5: Summary of Contamination Factors, Degrees of Contamination (C_d) and Pollution Load Index (PLI) of heavy metals in snow cover samples from Mission Industrial Area and South St. Boniface in Winnipeg, Canada.

Sampling Site	***Cf***								***Cd***	**PLI**
	Pb	**As**	**Cd**	**Cr**	**Ni**	**Hg**	**Zn**	**Mn**		
Industrial	150.5	0.330	0.620	4.290	19.49	0.060	65.69	8.260	249.2	4.130
Roadside	27.70	0.480	0.080	2.200	10.00	ND	6.430	3.090	50.00	2.170
Commercial	23.70	0.300	0.060	0.990	4.490	ND	9.460	8.500	47.60	1.870
Residential/Parkland	7.090	0.090	0.030	0.300	1.370	ND	2.250	1.670	12.80	0.630
Minimum	7.090	0.090	0.030	0.300	1.370	ND	2.250	1.670	12.80	0.630
Maximum	150.5	0.480	0.620	4.290	19.49	0.060	65.69	8.260	249.4	4.130
Mean	52.27	0.300	0.200	1.940	8.830	0.020	20.95	5.380	89.90	2.200

Heavy metals contamination of snow cover by anthropogenic emissions is presented in Table 4.5 using quantitative indices contamination factor (*Cf*) and degree of contamination (*Cd*). The mean *Cf* value for heavy metals in snow cover samples are in the order of Pb>Zn>Ni>Mn>Cr>Cd>As>Hg. The *Cf* values for Pb, Ni, and Zn in the industrial, roadside and commercial snow sampling sites revealed a very high contamination factor. The highest *cf* of Pb was observed in the vicinity of the scrap metal as shown in Table 4.5. The concentration in Winnipeg found in this study is over 5 to 21 times higher than the *Cf* values of residential/parkland, commercial and roadside snow cover samples. The *Cf* value for Pb in the residential/parkland snow sample revealed a high level of contamination, while the *Cf values* for other heavy metals in the residential/parkland area revealed low and moderate contamination from Zn and Mn (Table 4.5). The *Cf* values revealed that anthropogenic emissions, most probably scrap metal recycling activities and roadside traffic emissions, are attributable to the high levels of heavy metals contamination in the snow cover (Figure 4.1).

Similarly, the Cd values at all snow sampling sites revealed a very high degree of contamination (Table 5). The *Cd* values across the sampling site range between 13 to 250. The lowest *Cd* value (13) was in the residential/parkland area, which was over four times higher than *Cd* > 3 = high degree of contamination (Table 4.4). The very high degree of contamination in the residential/parkland snow sample site can be attributed to the high contamination factor of Pb, which was the only heavy metal out of the eight heavy metals observed in melted snow cover samples with the highest level of contamination factor (Figure 4.1).

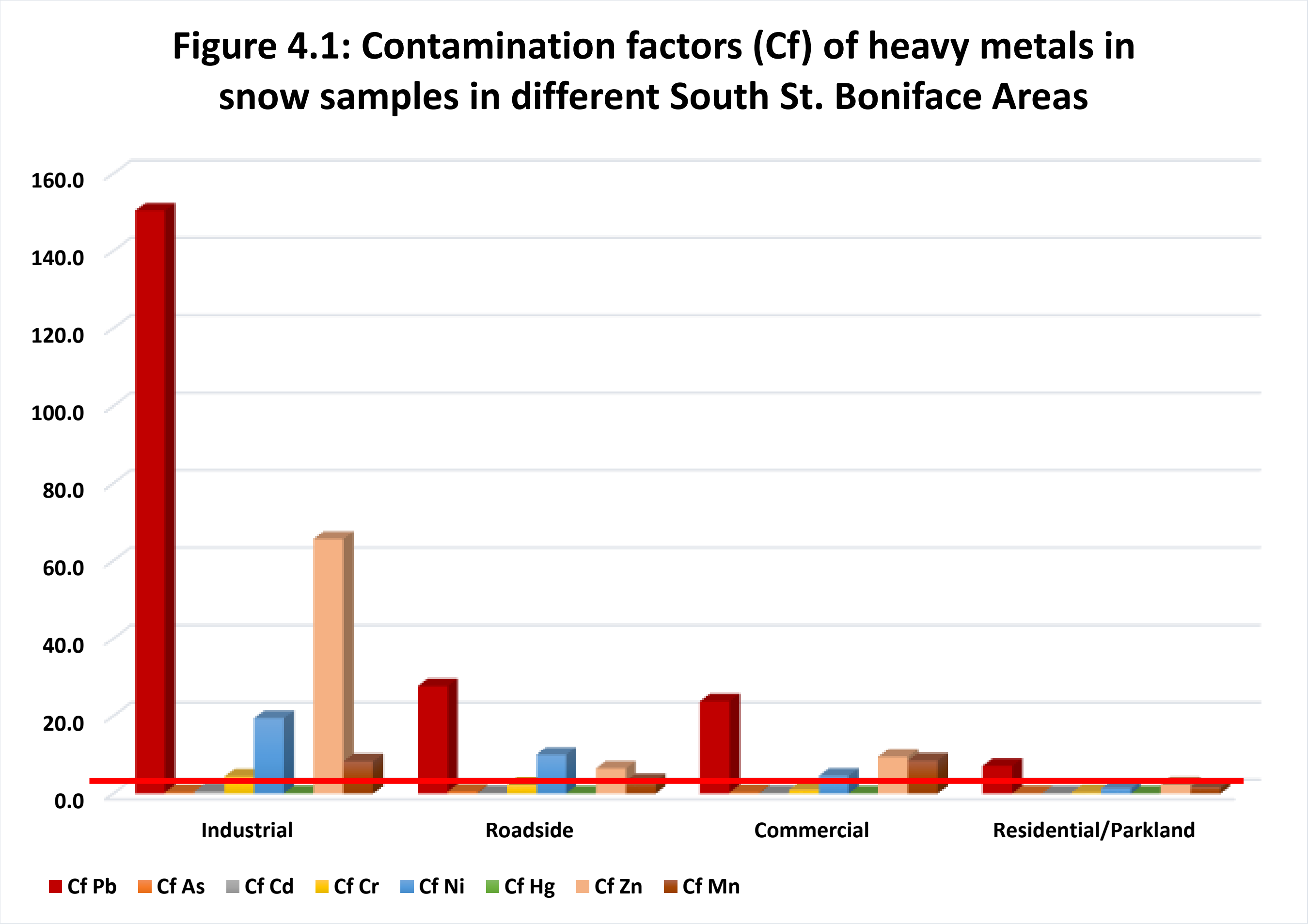


Figure 4.1: Contamination factors (Cf) of heavy metals in snow samples in different South St. Boniface Areas

Table 4.6: Contamination Factor legend according to the Contamination Index

Contamination Index	**Contamination Factor (*Cf*)**
$Cf \leq 1$	Low contamination
$Cf \leq 3$	Moderate contamination
$Cf \leq 6$	Considerable level of contamination
$Cf > 6$	Very high contamination

4.5.1 One-way ANOVA of Contamination Factor (Cf) of Heavy Metals for Snow Sample Sites

One-way analysis of variance (ANOVA) was used to test for the significant difference of contamination factor (*Cf*) for each heavy metals in snowpack sample sites (industrial, roadside, commercial and residential sites). A probability of 0.05 or less was adopted to be statistically significantly different (Jenyo-Oni & Oladele, 2016). The result of one-way ANOVA for heavy metal concentrations against the sample sites showed p-value = 0.148, which is above the 0.05 significant level. The result showed non-statistically significant mean differences between group means of heavy metals concentration.

Table 4.5.1: One-way ANOVA for means comparison of heavy metals concentration between Snow Sample Sites

ANOVA					
Cf					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4314.384	3	1438.128	1.929	.148
Within Groups	20877.748	28	745.634		
Total	25192.132	31			

4.5.2 Discussion of Contamination Factor (*Cf*) in Snowpack

Heavy metals have been investigated globally as toxic environmental contaminants in the air, water, soil and for their bioaccumulation in the food chain (Arshad et al., 2015; Owoade et al., 2015). Air emissions from industrial operations, consisting of aerosols and toxic heavy metals, such as Pb, Cr, Cd, Ni, and As, have been implicated in atmospheric pollution and subsequent deposition and accumulation in urban/industrialized winter snowpack (Loranger et al., 1996; Engelhard, 2007). In general terms, snowflakes bind Pb, Cd, Ni, As, and Cr, with their presence in snow, even at trace concentrations, indicate contamination. Hence, various environmental pollution studies have monitored elements of atmospheric aerosols and particulate deposits in snowpack drawn from industrialized/urbanized settings (Sakai et al., 1988; Elik, 2002; Suidek et al., 2015).

In this study, heavy metals contamination levels in accumulated snow were analyzed and evaluated using pollution indices (Hakanson 1980; Backman, 2008). The contamination factor (*cf*) was adopted to measure contamination levels of each heavy metals (Pb, As, Cr, Cd, Ni, Hg, Zn, and Mn) in the snow sampling points (industrial, roadside, commercial and residential). The contamination factor shows a very high contamination level of heavy metals across all the sampling sites in the order of industrial>roadside>commercial>residential. Across all the sampling points, lead had the highest contamination factor of 151, which was over 20 times higher than other snow sampling points. Similarly, high *cf* was also reported for Zn, Ni, and Mn.

The extremely high *cf* observed for lead in the snow sampling sites showed the deposition of metal particles on snowpack from the scrap metal shredding operation. This is likely attributed to the wide use of lead in industry and the presence of lead in most recycled non-ferrous scrap metals. (OSHA, 2008; USEPA, 2009; WHO, 2019). Although regulations and operating licenses of auto dismantlers and automobile shredders prohibit recycling lead-acid batteries and subsequent sorting and removal of battery terminals before shredding, other pathways of lead particle emission from scrap metals, such as lead pipes, leaded-steel components, cast-metal parts or lead-based coating ,cannot be easily removed through magnetic sorting or visual examination (OSHA, 2008; USEPA, 2009). Thus, these lead components can result in the emissions of significant concentrations of lead particles during scrap metal shredding. Lead particle dispersion is influenced by local wind currents, with subsequent deposition/accumulation in air, water and soil, as well as the surface area of snow in the winter season.

Zinc and Ni have the second and third highest contamination factors after Pb in snow cover, indicating local industrial emission and subsequent accumulation. A high level of Zn in snow cover can be linked to the spread of dust and fumes in scrap metal recycling/shredding operations entering into the atmosphere (OSHA, 2008). According to the United States Geological Survey (2001), the major sources of Zn emissions in scrap metal recycling are Zn sheet, brass, and die casting scrap. Similarly, Zn emissions and subsequent contamination load in snow can also be attributed to unsorted automobile tires fed into the scrap metal shredder. According to Smolders and Degryse (2002), 0.4 to 4.3% of tires are composed of Zn. The high contamination factor for Ni from the scrap metal shredding/recycling fence-line can be attributed to the presence of dust and fumes emitted from the shredding of welding plates, stainless steel, copper-nickel and aluminum alloys (OSHA, 2008).

The result of *cf* analysis of snowpack samples was characterized by a high concentration of Pb, Ni, Zn, and Mn, which is a fingerprint similar to the air and metals particle emissions expected by scrap metal shredding and recycling operations. The findings of heavy metals contamination are supported by Jensen et al.'s (2000) study. Their investigation of a 25-year-pld scrap metal recycling plant's surface soil and groundwater revealed very high concentrations of Pb, Cu, Zn, Cd, Cr, and Ni.

4.6 Degree of Contamination in Snowpack

Degree of contamination (*Cd*) in this study for each sampling site is computed as the sum of *cfi* for each heavy metal above the mean concentration of background sample. According to Backman et al. (1997), (*Cd* value) is described as:

$Cd \leq 1$ = low; ≤ 1 $Cd \leq 3$ = medium; and $Cd > 3$ = high.

Table 4.6: Degree of Contamination Index

Contamination Index	**Degree of Contamination (*Cd*)**
$Cd \leq 1$	Low contamination (*Cd)*
$Cd \leq 3$	Medium degree of contamination (*Cd*)
$Cd > 3$	High degree of contamination (*Cd*)

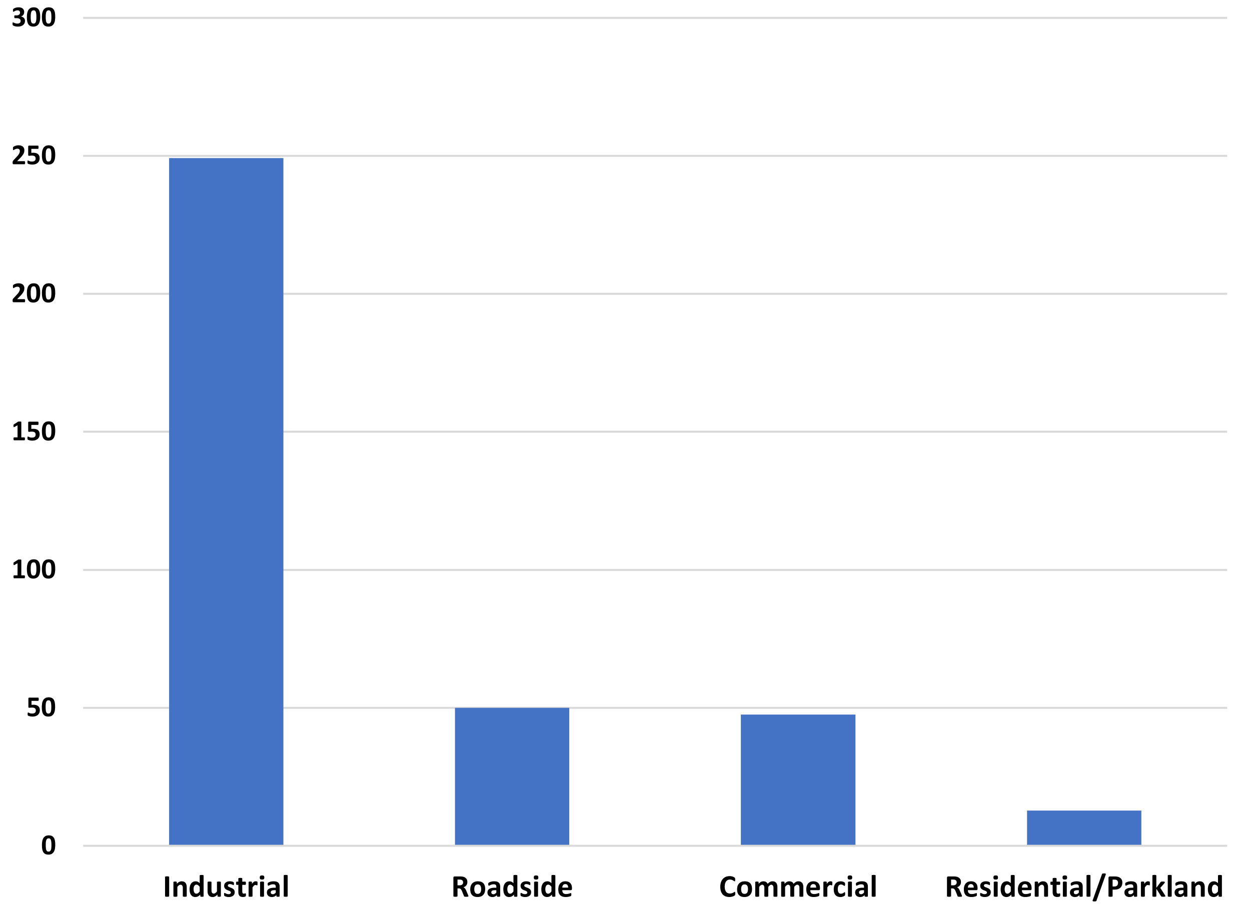


Figure 4.2: Degree of Contamination *(Cd) in* Snow Cover in different areas of South St. Boniface

4.7 Pollution Load Index

According to Tomlinson et al. (1980) and as used by Pobi et al. (2019), the Pollution Load Index (PLI) is used to provide a simple and comparative means of assessing soil, sediment or water quality. "*PLI is represented as geometric mean of cf value of n number of heavy metals estimated at the contaminated site by using the following equation*" – Pobi et al. (2019):

$$\text{PLI} = \sqrt[n]{cfi * cf2 * cf3 * cf4 * cf4 * cf5 * cf6 * cf7 * cf8} \text{---------------------------- (3)}$$

where n is the number selected of heavy metals (n = 8 in this study) and *cf* is the contamination factor of individual heavy metals present in the snow cover samples. PLI ≤ 0 signifies absence of pollutants, PLI value > 0-1 shows the background level of pollutants in snow cover and PLI > 1 represents gradual deterioration of the sampling site caused by increased heavy metals concentrations in snow deposition during the winter season (Gupta et al., 2013).

When PLI for heavy metals in the snow cover samples were computed across different snow sampling sites that are zoned differently (industrial, commercial, residential, parkland) for anthropogenic impacts in the study area (Table 4.7). The PLI values in melted snow cover samples ranged from 0.6 to 4.1. The lowest PLI value (0.6) in the residential area shows heavy metals contamination as the presence of background level of pollutants. The PLI for industrial, roadside and commercial snow sample sites are 4.1>2.2>1.9, indicating deterioration of the sampling sites by heavy metals pollution (Table 4.7 and Figure 4.3).

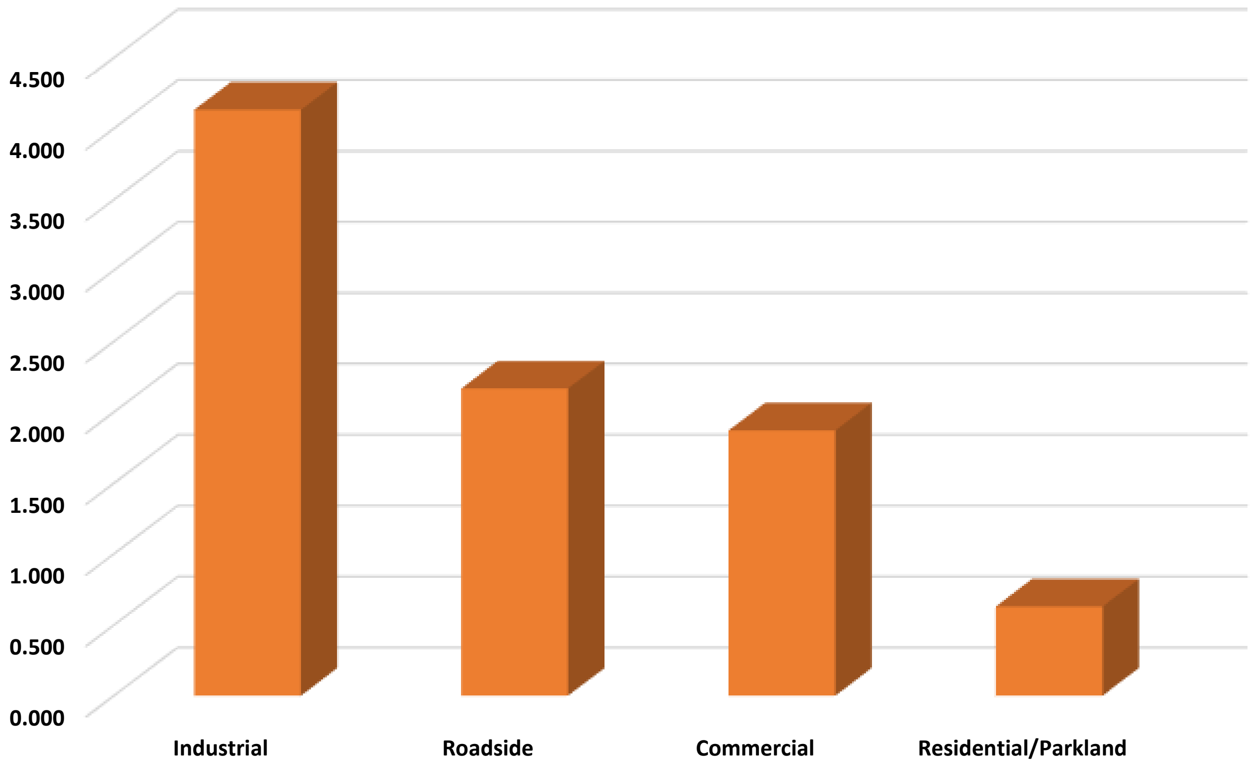


Figure 4.3: Pollution Load Index (PLI) for different South St. Boniface Areas

Table 4.7: PLI Index

Contamination Index	**PLI**
PLI ≤ 0	Absence of pollutants
PLI > 0 – 1	Presence of background level of pollutants
PLI >1	Deterioration of sampling sites

4.8 Practical Implication of Heavy Metals Evaluation in Snow Cover

Investigation of heavy metals in snow cover as an indicator of industrial and urban air pollution has been reported by different authors in the temperate regions of the world. Fine particles and other air pollutants transported from their local sources of emissions by prevailing winds during wintertime can contribute to total heavy metals variation during snowfall events and snow cover (Gabrielli et al., 2008). For example, a snowcap heavy metals study by Krastinyte et al. (2013) measured heavy metals in melted snow cap samples and the inherent snow dust. The heavy metals analysis of the snow dust revealed the enriched concentration of heavy metals in the order of Pb > Cr > Cu > Cd and a very strong correlation was reported among the metals (Krastinyte et al., 2013). The pollution load index (PLI) at the industrial site is eight times (8x) the residential load and twice (2x) the roadside level.

The pollution evaluation indices in this study revealed a high contamination factor and deterioration of snow quality possibly caused by anthropogenic emissions, notably in the perimeter of scrap metal recycling operations. The pollution indices, notably contamination factor and degree of contamination, show very high levels of Pb > Zn > Mn > Hg from the analysis of snow samples drawn from the fence-line of scrap metal shredding/recycling operations in the Mission Industrial Area. Similarly, studies have reported that the heavy metals pathway into snow cover or snowpack is basically from technogenic processes and deposition or binding of fine particles settling on the surface area of snow during the winter season (Sakai et al., 1988; Krastinyte et al., 2013). Heavy metals in accumulated snow do not pose immediate human health and environmental risks in that form unless the snow is eaten. Snow, however, serves as a temporary retention medium for heavy metals and other atmospheric air pollutants throughout the winter season before enriched and accumulated pollutants in snow start melting in early spring between mid-to-late April and early

May (Telmer et al., 2004; Schevchenko et al., 2017). Consequently, melted snow water and the enriched pollutants runoff can contribute to an environmental load of organic and inorganic pollutants in soil and surface water.

4.9 Summary

Heavy metals were sampled in the snow to determine particulate matter emissions from industrial operations in South St. Boniface. Different pollution indices, including contamination factor, degree of contamination, and pollution load index, indicated a high level of heavy metals pollution in deposited snow cover for Winter 2018. Higher concentrations of lead, zinc, nickel and a trace amount of mercury were found in the snow cover samples from industrial, roadside and commercial areas above the values of background snow samples. The concentration of the eight heavy metals found in snow samples is highest in the order of Industrial>Roadside>Commercial>Residential. This shows that the major source of the heavy metals' concentrations observed in the snow samples of Mission and South St. Boniface originate from industry followed by vehicle traffic. This conclusion is supported by the result of the statistically significant and strong positive correlation between Pb, Cd, Hg and Zn concentrations in all snow samples drawn from Mission Industrial Area and South St. Boniface.

CHAPTER FIVE

5.0 Result and Discussion of Respirable Fine Particulate Matter ($PM_{2.5}$) in Mission Industrial Area and South St. Boniface

This chapter presents the results from measuring the level of fine particulate matter ($PM_{2.5}$) near the fence-line of Industrial Metals Inc. The summary statistics for the $PM_{2.5}$ monitored in the upwind and downwind directions of the facility are presented in Table 5.1 and 5.2. Table 5.1 presents the daily mean and standard deviation, along with the morning and afternoon mean values of $PM_{2.5}$ at the upwind prevailing wind direction of the recycling operations. Table 5.2 summarizes the daily mean value and standard deviation of downwind $PM_{2.5}$. A comparison of daily mean values, plus hourly minimum and maximum values for daily respirable fine particulate matter ($PM_{2.5}$) were compared to the Canadian Ambient Air Quality Standards (CAAQS), as shown in Figures 5.1 and 5.2, respectively. The CAAQS values adopted for comparison are 19 µg/m3.

5.1 Upwind Values of $PM_{2.5}$ near Fence-line of Scrap Metal Recycling Activities

Upwind values of $PM_{2.5}$ (Table 5.1) monitored in this study were reported to indicate air quality level during early morning and late afternoon hours before and after scrap metal recycling in the Mission Industrial Area. Hence, one-hour morning and one-hour afternoon upwind measurements were recorded with the Dylos 1700 Air Quality Monitor. The lowest upwind values of respirable particulate matter observed were 0.25 and 1.35 $\mu g/m^3$ and highest values of 20.21 and 19.23 $\mu g/m^3$ morning and afternoon, respectively, at each of the daily prevailing wind direction of the fence-line of the scrap metal recycling operations. Higher values of upwind $PM_{2.5}$ at 10.7 and 24.7 $\mu g/m^3$ were observed on the 8th and 23rd of August 2018, respectively, indicating pollution by a city-wide wildfire. Aside from the fire's impact, the daily average of $PM_{2.5}$ for other upwind monitoring days between mid-June and early November 2018 ranged between 0.80 and 16.4 µg/m^3, which was below the 28 µg/m^3 CCME guideline.

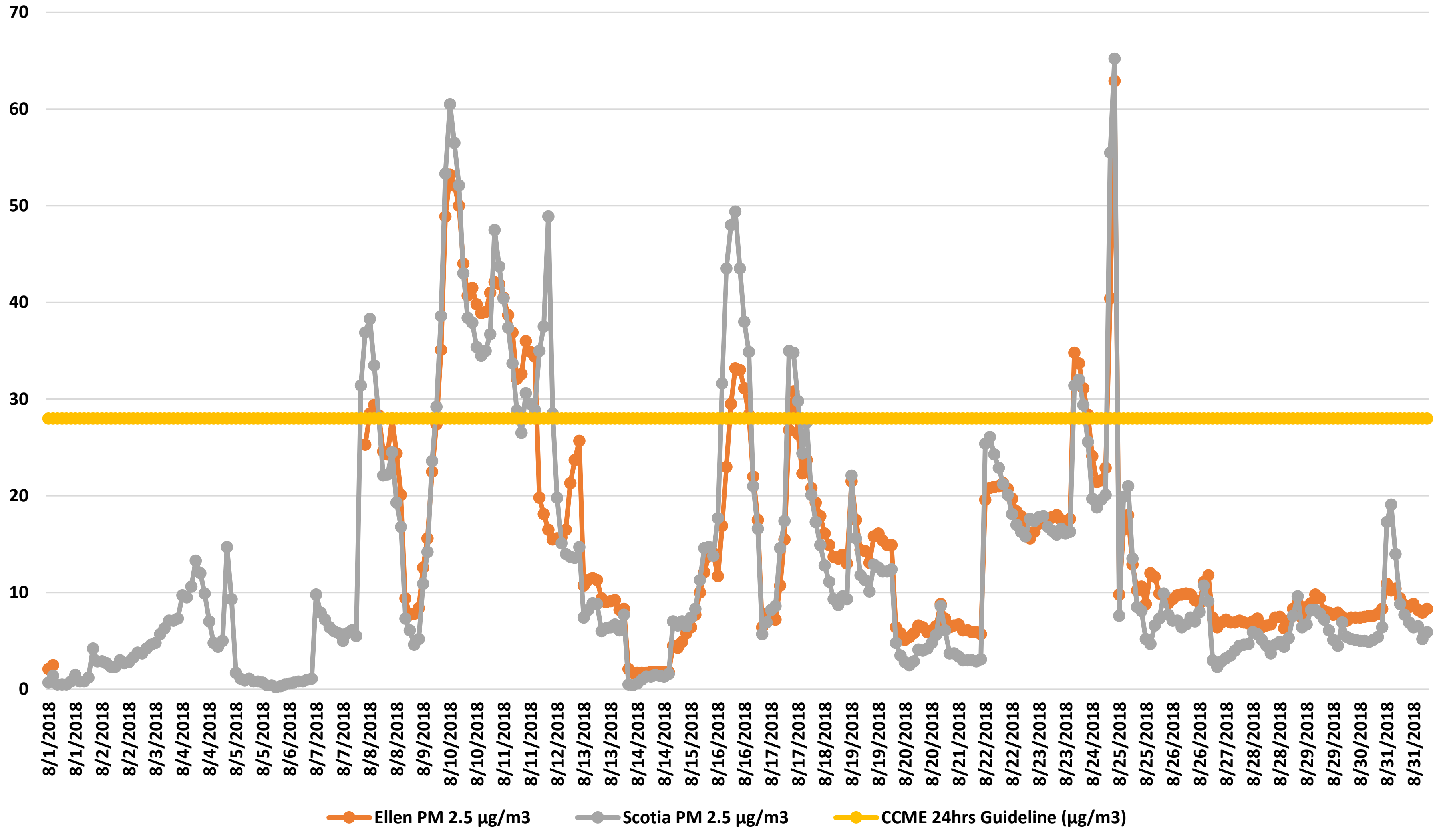
Table 5.0: Daily Mean and Standard Deviation of Upwind PM$_{2.5}$ in Mission Industrial Area (days = 36)

Monitoring Dates	Daily Mean (Standard Deviation)	Morning Mean	Afternoon Mean
13-Jun-18	2.65 (0.58)	3.06	2.23
14-Jun-18	2.94 (0.39)	2.66	3.22
21-Jun-18	3.14 (1.09)	3.91	2.36
26-Jun-18	3.06 (0.95)	2.39	3.73
28-Jun-18	3.57 (0.63)	2.94	4.20
03-Jul-18	2.59 (0.83)	2.02	3.17
16-Jul-18	2.08 (0.39)	1.80	2.35
17-Jul-18	2.00 (0.23)	1.84	2.16
23-Jul-18	16.4 (18.5)	29.51	3.35
24-Jul-18	2.75 (0.64)	2.30	3.20
30-Jul-18	6.49 (5.29)	10.23	2.75
01-Aug-18	2.49 (1.44)	3.51	1.47
02-Aug-18	2.70 (0.71)	2.20	3.19
07-Aug-18	5.37 (1.89)	6.71	4.03
08-Aug-18	**18.6** (2.3)	**20.2**	**16.9**
14-Aug-18	0.80 (0.78)	0.25	1.35
17-Aug-18	**19.7 (0.69)**	**20.21**	**19.23**
23-Aug-18	17.65 (9.86)	24.61	10.69
27-Aug-18	8.04 (5.18)	4.38	11.70
29-Aug-18	3.60 (2.83)	1.60	5.60
30-Aug-18	7.29 (2.79)	9.26	5.31
04-Sep-18	5.34		
10-Sep-18	4.51 (2.81)	6.50	2.52
11-Sep-18	5.30 (2.71)	3.38	7.22
18-Sep-18	3.55 (0.41)	3.35	3.76
25-Sep-18	3.39 (1.40)	4.38	2.39
26-Sep-18	6.73 (6.45)	2.16	11.29
02-Oct-18	4.95 (6.13)	0.61	9.29
04-Oct-18	1.61 (0.22)	1.45	1.76
16-Oct-18	2.30 (0.51)	1.94	2.66
17-Oct-18	2.81 (0.76)	2.27	3.34
25-Oct-18	1.60	1.60	

29-Oct-18	1.82 (1.87)	0.49	3.14
30-Oct-18	1.23	1.23	
01-Nov-18	3.31 (1.96)	1.92	4.70
05-Nov-18	2.45 (0.93)	1.84	3.15

The highest daily upwind mean value was observed on the August 17, 2018, caused by the wildfire smoke waves from British Columbia and northern Manitoba-Ontario border area, which led to the deterioration of outdoor air quality in Southern Manitoba (CBC, 2018). Wildfire smoke waves have been identified as having significant influence on summertime air quality in Canada and the Western United States, leading to short-term exponential increase in the ambient concentrations of $PM_{2.5}$ (Environment Canada, 2014; O'Dell et al., 2019). Despite the episodic occurrences, deterioration of air quality by wildfire smoke is often accompanied by regional advisory on health risks associated with exposure to respirable $PM_{2.5}$. Air monitoring stations at Ellen and Scotia Street, Winnipeg, reported extreme hourly daytime mean values for $PM_{2.5}$ in August 2018, which ranged between 10.7 and 62.9 $\mu g/m^3$ and 11.4 and 65.2 $\mu g/m^3$ in Chart 2. (Manitoba Air Quality, 2018).

Figure 5.1: $PM_{2.5}$ Values at Winnipeg's Ellen and Scotia Air Monitoring Stations, August 2018.



5.2 $PM_{2.5}$ Downwind Fence-line Measurement near Scrap Metal Recycling Operations

The descriptive statistics for downwind mass concentration of $PM_{2.5}$ during scrap metal recycling operations and number of monitoring hours appear in Table 5.2. This table presents the daytime mean for three to eight hours $PM_{2.5}$, standard deviation and minimum and maximum hourly values of daytime monitoring hours (8:30 am to 4:00 pm). Daily mean values of respirable fine particulate matter ($PM_{2.5}$), hourly minimum and maximum values of $PM_{2.5}$ and threshold values of Canadian Ambient Air Quality Standards (CAAQS) are compared .

The daily mean values of $PM_{2.5}$ measured at the downwind north, south, west, and east fence-line of scrap metal recycling operations range between 1.9 ± 0.85 and 38.1 ± 20 $\mu g/m^3$ between 13 June and 18 December 2018. Monthly values for $PM_{2.5}$ show a significant variation during the periods of air monitoring at the fence-line sampling points of the recycling facility. In June, fine respirable particulate matter ranged between 5.2 ± 2.03 and 14.5 ± 6.7 $\mu g/m^3$, which are lower than the threshold values of 19 and 28 $\mu g/m^3$ of CAAQS, as shown in Appendix II. Furthermore, the hourly minimum and maximum values for daily air monitoring in June was between 3.3 - 8.4 ug/m^3 and 7.61 - 25.6 ug/m^3, which were below the threshold values limit for management action.

Higher values of daily downwind $PM_{2.5}$ were observed between July and October 2018. The daily mean value in July ranged between 1.86 ± 0.85 and 25.4 ± 9.71 ug/m^3. In July, two days daily mean values observed 20.4 and 25.4 ug/m^3; both within the threshold values of 19 and 28 $\mu g/m^3$ of CAAQS for poor ambient air quality (see Chart 2). Hourly minimum and maximum values for daily downwind $PM_{2.5}$ in July was between 1.09 and 12.7 ug/m^3 and 3.51 – 36.01 ug/m^3, respectively.

Table 5.1: Descriptive Statistics of Downwind Respirable Particulate Matter ($PM_{2.5}$) and CAAQS 24-hours Guideline

Monitoring Dates	Daily Mean (SD)	CAAQS 24-hours Guideline	Standard Deviation	Hourly Min	Hourly Max
13-Jun	10.8	28	1.43	9.58	13.2
14-Jun-18	5.80	28	1.27	3.99	8.27
21-Jun-18	13.6	28	7.32	7.31	16.6
26-Jun-18	14.5	28	6.73	7.61	**25.6**
28-Jun-18	5.18	28	2.03	3.34	8.36
03-Jul-18	9.21	28	3.54	3.8	14.3
16-Jul-18	16.7	28	7.59	8.55	32.0
17-Jul-18	1.86	28	0.85	1.18	3.51
23-Jul-18	**25.4**	28	9.71	12.7	**36.0**
24-Jul-18	**20.4**	28	10.8	1.09	**33.1**
30-Jul-18	14.3	28	4.75	7.18	**21.7**
01-Aug-18	8.29	28	4.23	4.37	14.8
02-Aug-18	12.8	28	3.87	6.70	**19.2**
07-Aug-18	12.4	28	4.35	7.18	16.1
08-Aug-18	**27.3**	28	7.93	17.6	**39.8**
14-Aug-18	2.55	28	0.82	1.50	4.09

Daily mean values of $PM_{2.5}$ exceeding the CAAQS for poor air quality zone at the scrap metal recycling operation hours were frequently observed between August and October 2018. Daily mean values of $PM_{2.5}$ observed in August ranged from 2.55 ± 0.82 and 28.9 ± 15.4 ug/m^3. Scrap metal shredding and other operations were sporadic during August 2018, which was due to the annual maintenance of the automobile shredder. Daily mean values indicating poor air quality were observed in three out of 11 monitoring days in August, at 27.2, 21, and 28.9 ug/m^3, respectively, which were within and slightly exceeding the 19 and 28 ug/m^3 CAAQS.

Table 5.2: Descriptive Statistics of Downwind Respirable Particulate Matter ($PM_{2.5}$) and CAAQS 24-hours Guideline

Monitoring Dates	Daily Mean	CCME 24-hrs Guideline	Standard Deviation (SD)	Hourly Min	Hourly Max
17-Aug-18	15.5	28	7.52	4.51	25.4
20-Aug-18	14.6	28	3.29	9.02	17.86
23-Aug-18	14.0	28	3.08	10.5	19.1
27-Aug-18	**21.0**	28	5.46	13.9	28.6
29-Aug-18	**28.9**	28	15.4	17.4	**60.2**
30-Aug-18	13.3	28	7.06	6.15	27.9
04-Sep-18	15.7	28	1.67	14.0	18.1
10-Sep-18	**28.1**	28	10.1	17.4	**42.2**
11-Sep-18	17.7	28	14.6	3.49	**42.7**
18-Sep-18	12.7	28	12.7	2.16	**40.5**
25-Sep-18	**36.3**	28	16.5	16.6	**55.5**
26-Sep-18	**32.7**	28	21.7	12.6	**63.4**
02-Oct-18	6.66	28	1.37	5.01	8.51
04-Oct-18	13.4	28	11.5	3.64	**35.7**
16-Oct-18	**38.1**	28	20.7	16.5	**67.4**
17-Oct-18	22.4	28	11.2	6.80	**34.3**
25-Oct-18	11.3	28	9.59	5.61	22.4
29-Oct-18	10.6	28	8.10	1.00	22.2
30-Oct-18	2.77	28	0.39	2.36	3.21
01-Nov-18	14.4	28	3.49	10.9	20.5
05-Nov-18	13.0	28	5.60	4.75	20.5
06-Dec-18	15.2	28	3.42	6.21	16.4
14-Dec-18	12.6	28	5.75	8.36	18.2
18-Dec-18	8.74	28	2.17	4.58	11.5

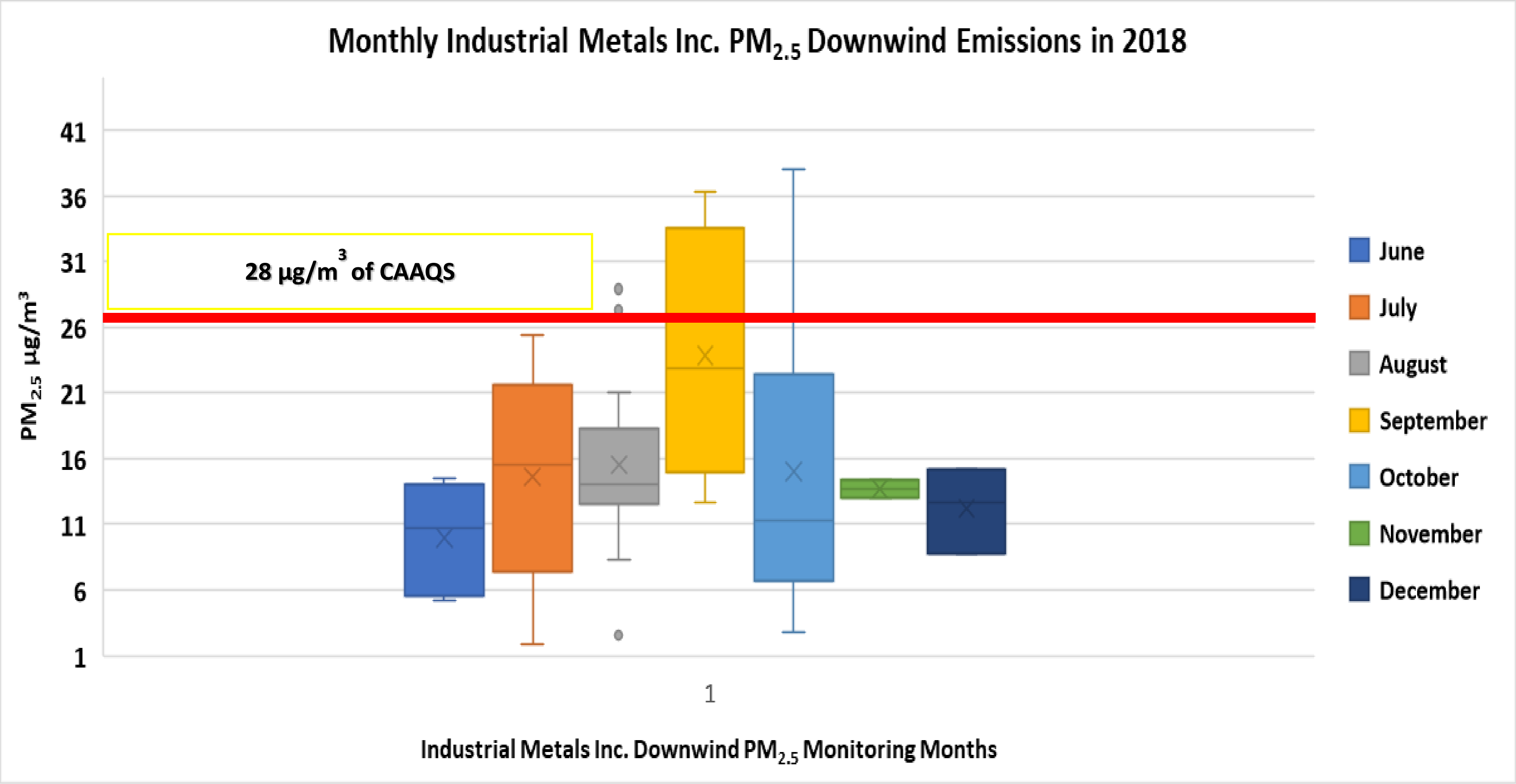


Figure 5.2: Emissions of Fine Respirable Particulate Downwind from Industrial Metals Inc. Over Seven Months of Sampling

5.3 Result of One-way ANOVA for $PM_{2.5}$ Downwind Emissions from Scrap Metal Shredding.

The hourly mean differences of $PM_{2.5}$ values measured at the downwind fence-line scrap metal shredding emission monitoring points were analysed with a one-way ANOVA ($PM_{2.5}$ hourly values vs downwind cardinal points as groups factors) and the Tukey's HSD multiple comparison. The statistically significant difference was defined at level of $p < 0.05$ (Pei et al., 2016). The result of the one-way ANOVA, shown in Table 5.4, showed a statistically significant difference between the 243-hourly means of $PM_{2.5}$ comparing the five downwind monitoring points of Industrial Metals Inc., where F(3, 40) = 14.66 and p-value = 0.00). Furthermore, the Tukey HSD multiple comparison of means showed a statistically mean significant difference between $PM_{2.5}$ levels for the four grouped downwind monitoring points: Northwesterly-Northeast-Southwest-Southeast (p = 0.000).

Table 5.3: One-way ANOVA for $PM_{2.5}$ Downwind from Industrial Metals

ANOVA					
$PM_{2.5}$					
	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	5257.195	3	1752.398	14.656	.000*
Within Groups	28696.774	240	119.570		
Total	33953.969	243			

*** Significant at p> 0.01 level**

5.4 Result and Discussion of Respirable Fine Particulate Matter ($PM_{2.5}$) in South St. Boniface

This section determines if the levels of fine particulate matter ($PM_{2.5}$) in residential areas of South St. Boniface are in conformity with CAAQS. The summary statistics of $PM_{2.5}$, measured on different streets in Dufresne Avenue of South St. Boniface, are presented in Tables 5.5 and 5.6, respectively. The tables show the daily mean and standard deviation of $PM_{2.5}$ measured in St. Boniface, hourly minimum and maximum values of daily $PM_{2.5}$, CAAQS 2015 24-hours value (28 ug/m^3) for poor quality and threshold value (19 ug/m^3) for “action for preventing CAAQS exceedance”.

The daily mean values of respirable fine particulate matter ranged between 0.79 ± 0.14 ug/m^3 and 27.9 ± 6.45 ug/m^3 between 15 June and 14 December 2018 in the residential areas. The highest daily mean value was observed during the peak in three out of eight monitoring days in August, showing 21.9 ± 1.08 ug/m^3, 25.6 ± 5.85 ug/m^3 and 27.9 ± 6.45 ug/m^3, which were within the CAAQS 28 ug/m^3 and 19 ug/m^3 threshold guidelines for poor air quality zone (see Table 5.4 and Figure 5.3). These highest values observed were caused by the wildfire smoke waves from British Columbia, Alberta and Ontario moving into Winnipeg and other parts of Southern Manitoba in early and late August 2018[4].

Smoke plumes from wildfire, with a subsequent increase of outdoor $PM_{2.5}$ and short-term human exposure can worsen health conditions in vulnerable populations and other distant geographical populations. According to Le et al. (2014), elevated outdoor concentration of $PM_{2.5}$ from wildfire smoke contribute to a 49.6% increase rate of respiratory and cardiovascular diagnoses compared to the absence of forest fire smoke. Diagnosed respiratory and cardiovascular risks include

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[4] https://www.ctvnews.ca/canada/b-c-forest-fire-smoke-blankets-calgary-reaches-winnipeg-1.4056080.

chronic obstructive pulmonary disease (COPD), asthma, chest pain and bronchitis (Sutherland et al., 2005; Ovadevnaite et al., 2006; Johnston et al., 2006). Smoke from wildfires have atmospheric residence time that could last for days (Andrea, 1990). As such, numerous epidemiological studies have identified health risks and increased rate of hospitalization from short-term exposure to respirable fine particles, especially among elderly and other individuals with pre-existing lung and heart diseases (Ruckerl et al., 2011; Le et al., 2014).

In contrast to the three days of wildfire smoke in August 2018, monitoring months with high outdoor $PM_{2.5}$ values in South St. Boniface observed on other monitoring days were lower than the CAAQS. Daily mean values of respirable $PM_{2.5}$ observed in June and July ranged between 1.14 ± 0.2 ug/m^3 to 4.54 ± 0.3 ug/m^3, respectively, which was five to 20 times lower than the CAAQS threshold values for air quality exceedance (see Figure 5.3). Similarly, $PM_{2.5}$ values for September to December monitoring months ranged between 1.5 ± 0.53 ug/m^3 and 9.81 ± 3.87 ug/m^3, respectively, lower than the 19 and 28 ug/m^3 threshold values of CAAQS air quality and management action to prevent air exceedance (see Figure 2b).

Table 5.4: Descriptive Statistics of Ambient Respirable Particulate Matter ($PM_{2.5}$) and CAAQS 24-hours Guideline in Dufresne Avenue

Monitoring Dates	**Monitoring Hours**	**Dylos Daily Mean (ug/m^3)**	**Standard Deviation (SD)**	**Winnipeg Monitoring Daily Mean (ug/m^3)**	**Hourly Min (ug/m^3)**	**Hourly Max (ug/m^3)**	**24hrs CAAQS (ug/m^3)**	**24hrs CAAQS Exceedance (ug/m^3)**
15-Jun-18	5	3.42	1.09	4.91	1.81	4.29	28	19
18-Jun-18	5	4.43	0.93	5.46	3.37	6.09	28	19
27-Jun-18	6	3.61	0.45	3.24	2.89	4.24	28	19
05-Jul-18	7	3.03	0.45	2.61	2.62	3.78	28	19
06-Jul-18	8	1.14	0.20	3.98	0.96	1.48	28	19
11-Jul-18	8	4.38	1.36	1.86	2.90	6.26	28	19
12-Jul-18	8	3.33	0.60	6.89	2.67	4.09	28	19
13-Jul-18	7	3.00	0.85	6.3	1.87	4.35	28	19
18-Jul-18	8	4.04	0.88	5.08	3.04	5.68	28	19
19-Jul-18	7	4.54	0.30	6.55	3.98	4.80	28	19
03-Aug-18	8	3.36	0.83	NS	1.76	4.40	28	19
09-Aug-18	7	6.97	2.22	13.14	4.46	9.70	28	19
10-Aug-18	7	**21.9**	1.08	43.3	20.37	23.09	28	19
13-Aug-18	7	6.08	3.10	9.88	0.83	10.19	28	19
15-Aug-18	8	5.45	0.49	8.13	4.83	6.23	28	19
16-Aug-18	8	**27.9**	6.45	27.14	16.07	35.01	28	19
21-Aug-18	8	5.14	3.29	6.38	2.42	10.26	28	19

28-Aug-18	8	**25.6**	5.85	6.98	16.71	34.51	28	19

Table 5.5: Descriptive Statistics of Ambient Respirable Particulate Matter ($PM_{2.5}$) and CAAQS 24-hours Guideline in Dufresne

Monitoring Dates	Monitoring Hours	Daily Mean (ug/m^3)	Standard Deviation	Winnipeg Monitoring Daily Mean (ug/m^3)	Hourly Min (ug/m^3)	Hourly Max (ug/m^3)	24hrs CAAQS (ug/m^3)	24hrs CAAQS Exceedance (ug/m^3)
05-Sep-18	7	1.50	0.53	2.64	1.08	2.51	28	19
07-Sep-18	8	9.81	3.87	7.58	6.21	16.17	28	19
08-Sep-18	7	1.50	0.53	5.53	1.08	2.51	28	19
12-Sep-18	6	3.34	1.83	2.66	1.23	7.15	28	19
13-Sep-18	8	3.56	3.03	3.86	1.30	8.79	28	19
17-Sep-18	7	3.58	3.08	1.8	1.34	8.91	28	19
20-Sep-18	6	5.21	2.1	3.13	2.69	8.16	28	19
01-Oct-18	7	2.09	0.28	2.25	1.64	2.32	28	19
04-Oct-18	8	6.36	1.43	2.45	5.01	8.49	28	19
09-Oct-18	6	2.52	0.89	1.99	1.49	4.21	28	19
10-Oct-18	3	2.55	0.43	1.78	2.19	3.16	28	19
18-Oct-18	6	3.39	0.76	3.53	2.48	4.50	28	19
22-Oct-18	7	0.79	0.14	4.3	0.63	1.04	28	19
24-Oct-18	6	3.92	0.38	4.3	3.28	4.46	28	19
31-Oct-18	6	0.84	0.19	1.86	0.58	1.19	28	19
06-Nov-18	6	2.66	0.65	2.38	2.07	4.56	28	19

08-Nov-18	6	3.29	1.03	1.83	0.97	5.27	28	19
01-Dec-18	5	5.36	1.17	5.9	1.28	6.37	28	19
04-Dec-18	5	7.84	2.36	9.93	2.14	9.12	28	19
10-Dec-18	7	3.28	0.91	8.39	1.09	7.54	28	19
11-Dec-18	6	2.71	0.67	12.18	1.20	5.32	28	19
12-Dec-18	7	4.14	1.72	12.69	2.61	8.67	28	19
13-Dec-18	7	5.37	1.88	5.21	2.27	6.45	28	19

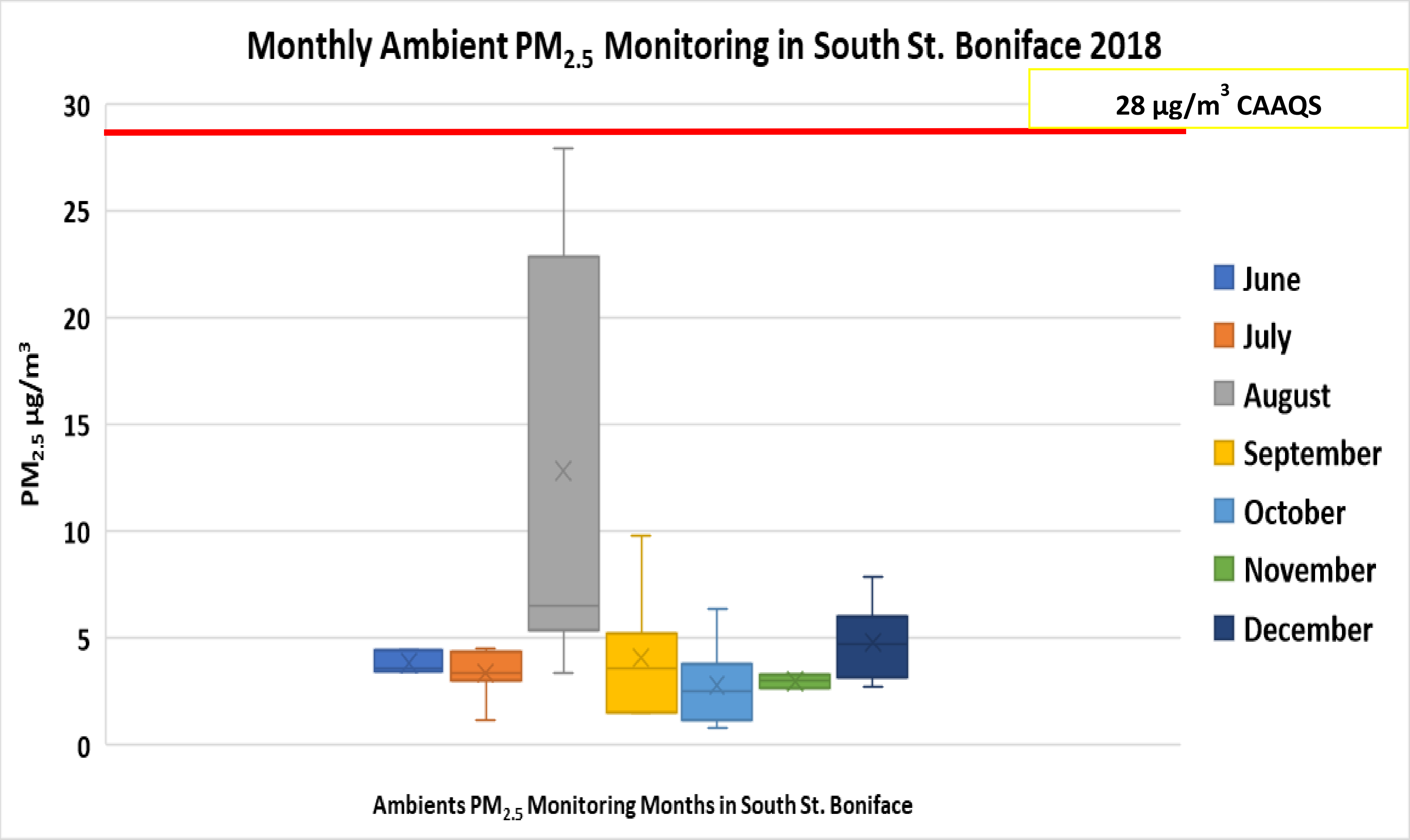


Figure 5.3: Emissions of Fine Respirable Particulate in the South St. Boniface Area over Seven Months of Sampling.

5.5 Result of One-way ANOVA for $PM_{2.5}$ in Dufresne Avenue, South St. Boniface.

The hourly mean differences of $PM_{2.5}$ values measured between the four streets air monitoring points in Dufresne Avenue, South St. Boniface, were analysed with a one-way ANOVA ($PM_{2.5}$ hourly values vs streets as groups factors) and the Tukey's HSD multiple comparison. The statistically significant difference was defined at level of $p < 0.05$ (Pei et al., 2016). The result of the one-way ANOVA, in Table 5, showed a statistically significant difference between the 256-hourly means of $PM_{2.5}$ for monitoring Dufresne Avenue compared to other streets, where F(3, 256) = 4.406 and p-value = 0.005. Furthermore, the Tukey HSD multiple comparison of means showed a statistically mean significant difference between $PM_{2.5}$ levels for three out of four monitoring streets (Kavanagh-Cherrier (p = 0.033); Kavanagh-Doucet (p=0.037).

Table 5.6: One-way ANOVA for $PM_{2.5}$

ANOVA					
PM2.5					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	526.977	3	175.659	4.406	.005*
Within Groups	10205.433	256	39.865		
Total	10732.409	259			

5.6 Summary

Aside from the city-wide elevated $PM_{2.5}$ values due to wildfire observed in August, daily average $PM_{2.5}$ for other upwind monitoring days between mid-June and early November 2018 ranged between 0.80 and 16.4 $\mu g/m^3$ which was below the 28 $\mu g/m^3$ CCME guideline. The $PM_{2.5}$ emissions from the scrap metal recycling shredder had sporadic daytime exceedance levels above the Canadian Ambient Air Quality Standards for poor air quality zone and threshold values of management action. Ambient particulate matter monitoring in the residential area and traffic corridors measured average daytime $PM_{2.5}$ values 10 to 18 times below the poor air quality zone for CAAQS. The ambient $PM_{2.5}$ showed a moderate correlation with the $PM_{2.5}$ values station report of the Manitoba Air Monitoring Station, Ellen Street, Winnipeg. Summer forest fire smoke waves in Winnipeg contributed to a significant increase in ambient $PM_{2.5}$ values for the residential neighborhood of South St. Boniface during three days' monitoring in August 2018.

CHAPTER SIX

6.0 Industrial Noise and Residential Noise Monitoring in Mission Industrial Area and South St. Boniface.

Noise emission levels from scrap metal recycling activities, environmental noise in residential areas and roadside traffic-related noise were measured and compared with applicable regulatory guidelines. Noise monitoring in this study was designed to investigate compliance with the provision of noise nuisance from scrap metal shredding as mentioned in the operating environmental licence. Hence, Tables 6.0 and 6.1 present the summary statistics for noise levels recorded during the operating hours of scrap metal recycling operations in the Mission Industrial Area from 16 July to 18 December 2018. The daily mean for continuous A-weighted equivalent (LAeq) for noise emission in the industrial area range from 55.5 to 83.0 dB(A); daily median values for continuous noise measurement range from 59.1 to 89.3 dB(A). Daily minimum noise levels logged by the Sound Level Meter range from 44.9 to 69.3 dB(A), while the daily maximum noise levels range between 65.4 to 121 dB(A).

Various factors observed during the noise monitoring were responsible for the differences between the values of noise recorded. For example, the lowest daily mean LAeq 55.5 dBA was recorded in this study during intermittent operation and frequent shut down of the scrap metal shredder. Also, the distance of noise measurement to the noise emission source contributed to the highest daily mean LAeq 83.00 dB(A), recorded at approximately 60 meters away from the metal shredder, characterized with continuous intermittent and impulsive noise (CUPE, 2006). Also, instantaneous noise maximum levels between 86.5 to 121 dB(A) from the scrap metal shredder were frequently caused by metals clanging at the shredder feed and loud explosions.

Table 6.0: Summary Statistics of Noise Levels Adjacent to Scrap Metal Recycling Operations

Monitoring Dates	Sampling Point	Mean LAeq (dBA)	Standard Deviation	$LAeq_{Min}$	$LAeq_{peak}$	Median	Winnipeg Bylaw Standard
16-Jul-18	East Downwind	64.3	2.91	50.1	83.9	79.2	55dBA
23-Jul-18	West Downwind	78.7	6.09	64.6	94.4	85.3	55dBA
24-Jul-18	West Downwind	79.7	7.14	62.3	95.1	82.7	55dBA
25-Jul-18	NS	NS	NS	NS	NS	NS	55dBA
26-Jul-18	North Downwind	58.9	5.59	44.9	79.7	62	55dBA
30-Jul-18	SW Downwind	79.8	9.26	64.8	94.5	81.3	55dBA
01-Aug-18	North Downwind	67.4	3.29	56.1	90.2	85.6	55dBA
02-Aug-18	SW Downwind	75.0	2.4	55.8	86.5	80.1	55dBA
04-Aug-18(Weekend)	South East Downwind	50.3 (4-hrs)	4.34	39.6	73.4	48.7	55dBA
07-Aug-18	SW Downwind	71.6	2.88	59.6	87.5	73.4	55dBA
08-Aug-18	North Downwind	83.00	5.26	64.1	95.6	88.2	55dBA
11-Aug-18(Weekend)	South Downwind	46.0 (4-hrs)	3.36	38.2	73.1	50.3	55dBA
14-Aug-18	North Downwind	54.1	4.20	45.7	87.3	61.8	55dBA
18-Aug-18 (Weekend)	South Downwind	51.4	2.25	40.4	69.3	56.2	55dBA
20-Aug-18	SW Downwind	66.2	4.47	52.5	77.7	61.5	55dBA
23-Aug-18	North Downwind	59.3	2.30	55.2	72.1	60.2	55dBA
2018-08-25 (Weekend)	North West Downwind	42.8	2.16	37.2	68.3	49.3	55dBA
27-08-2018	North Downwind	67.8	3.81	56.6	80.8	70.4	55dBA
29-Aug-18	West Downwind	80.1	2.95	69.3	89.5	81.7	55dBA
30-Aug-18	SW Downwind	75.2	2.22	60.9	84.5	78.5	55dBA
01-Sep-18 (Weekend)	North Downwind	47.8	4.41	44.1	62.1	52.3	55dBA

Table 6.1: Summary Statistics of Fence-line Industrial Noise Levels of Scrap Metal Recycling Operations

Monitoring Dates	Sampling Point	Mean LAeq dB(A) (7-8hrs)	Standard Deviation	LAeq$_{Min}$ dB(A)	LAeq$_{peak}$ dB(A)	Median dB(A)	Winnipeg Bylaw Standard
03-Sep-18	NS	NS	NS	NS	NS	NS	55dBA
04-Sep-18	West Downwind	79.5	3.94	67.2	94.2	86.8	55dBA
2018-09-08 (Weekend)	South Downwind	43.4	2.77	39.3	70.4	48.5	55dBA
10-Sep-18	West Downwind	79.8	3.62	66	98.5	88.2	55dBA
11-Sep-18	West Downwind	79.67	4.28	63.3	90.1	84.3	55dBA
2018-09-15 (Weekend)	North Downwind	50.1	3.16	40.3	65.7	52.1	55dBA
18-Sep-18	West Downwind	78.6	3.70	64.7	90.1	80.2	55dBA
25-Sep-18	West Downwind	78.9	5.01	62.2	90.7	85.3	55dBA
26-Sep-18	West Downwind	80.8	4.04	63.1	91.1	79.3	55dBA
02-Oct-18	East Downwind	57.4	2.87	51.4	72.5	60.8	55dBA
04-Oct-18	South West Downwind	75.3	5.34	54.3	88.6	77.6	55dBA
06-Oct-2018 (Weekend)	West Downwind	43.2	2.87	36.22	72.3	47.2	55dBA
15-Oct-18	West Downwind	81.2 (3.5hrs)	4.85	64.5	121	89.3	55dBA
16-Oct-18	North West Downwind	77.6	3.63	60.1	98.2	82.7	55dBA
17-Oct-18	NorthWest Downwind	81.8	7.32	64.7	96.2	79.4	55dBA
2018-10-20 (Weekend)	South East Downwind	40.4	3.27	35.6	58.6	43.5	55dBA
25-Oct-18	South East Downwind	54.7	4.15	50.5	66.8	62.7	55dBA
2018-10-27 (Weekend)	South West Downwind	42.1	2.88	36.7	64.7	48.3	55dBA
29-Oct-18	South East Downwind	56.8	3.23	49.3	72.1	60.2	55dBA
30-Oct-18	South West Downwind	68.1	5.27	51.8	65.4	64.7	55dBA
01-Nov-18	South Downwind	58.9	3.96	47.6	80	60.2	55dBA
05-Nov-18	South East Downwind	57.2	4.11	49.2	69	61.4	55dBA
06-Dec-18	South West Downwind	64.8	2.73	55.6	79.7	66.3	55dBA
14-Dec-18	South West Downwind	66.5	3.15	54..2	86.2	66.2	55dBA
18-Dec-18	South Downwind	65.0	2.50	54.7	78.1	64.7	55dBA

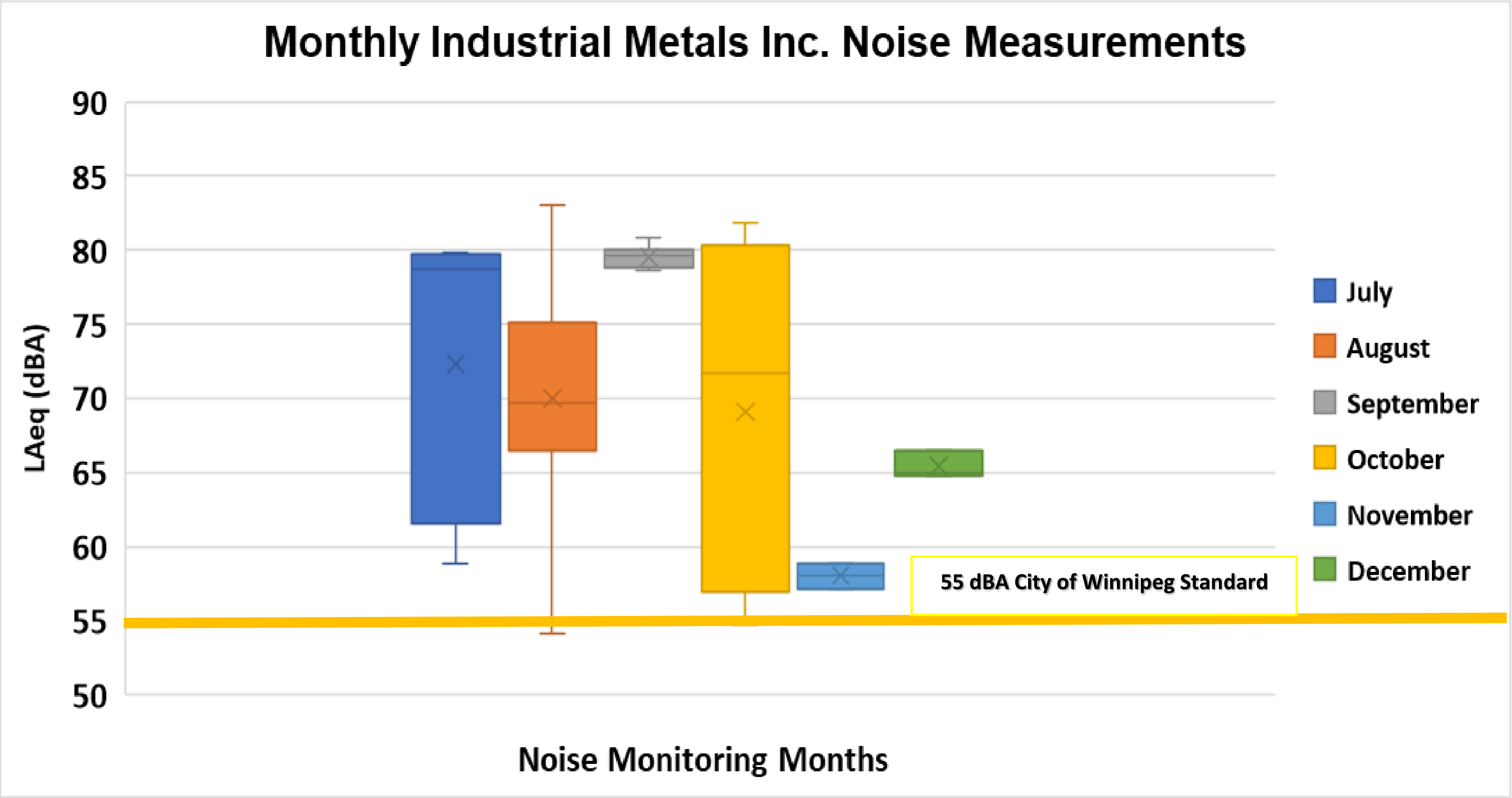


Figure 6.1: Noise Measurements in Decibels (dBA) Downwind from Industrial Metals Inc. Over Seven Months

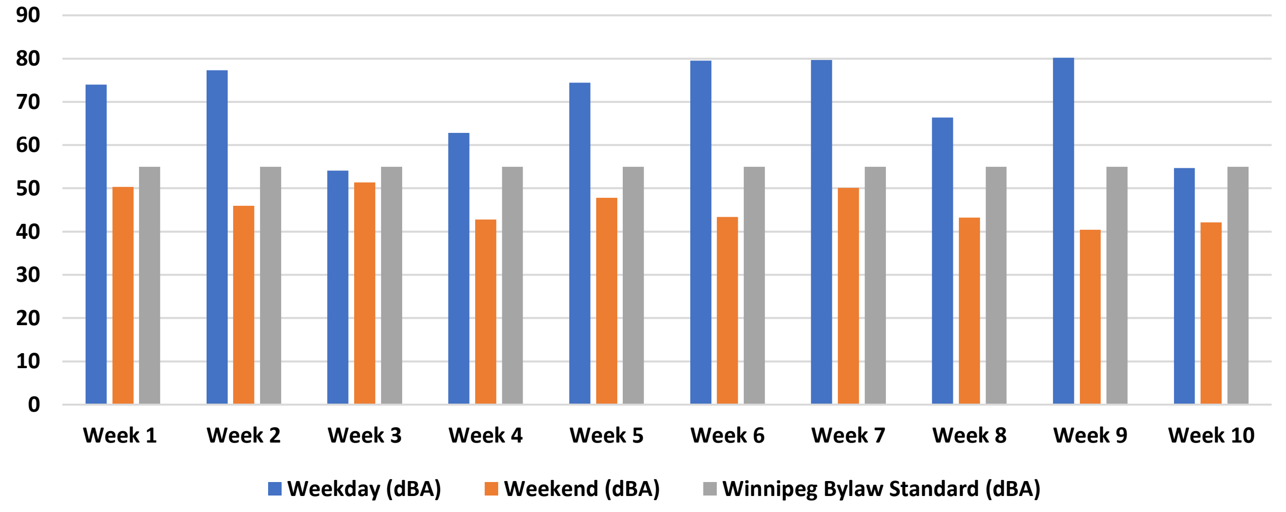
Temporal variations of noise levels were monitored by comparing the average weekdays' noise level measured during shredding operations with the average weekend noise level when the shredder was inactive. Average weekday noise levels were computed from the first week in August to the last week of October 2018. Weekend noise level measurements were recorded from the first Saturday of August to the last Saturday of October 2019. Figure 6.1 compared the average weekday daily means with LAeq, weekend (Saturday) 4 hrs mean noise levels and City of Winnipeg 55 dBA daytime threshold limit for noise emissions from equipment/machinery.

As shown in Figure 6.2, the average weekdays’ daily mean LAeq noise values ranges between 54.1 dBA and 80.2 dBA from scrap metal recycling operations. The average weekend noise level ranges between 40.4 dBA and 51.4 dBA when the shredder operations were shut down for weekends. Comparing the minimum and maximum values recorded for both the weekdays and weekends, the mean noise level reduction was 14.1 dBA to 28.8 dBA recorded for non-operational hours. The mean noise reduction value from logged weekend noise values when compared to the 55dBA guidelines ranged between 3.6 dBA and 14.6 dBA. A few activities, such as moving of scrap metals and occasional loud bangs on the scrapyard, as well as loud sounds from train wheels and horns, were observed from the adjacent rail tracks during weekend monitoring.

Table 6.2: Average Weekdays Daily Mean LAeq and Weekend Noise Levels in Mission Industrial Area

Monitoring Week	Weekday (dBA)	Weekend (dBA)	Winnipeg Bylaw Standard (dBA)
Week 1	74.01	50.3	55
Week 2	77.3	46	55
Week 3	54.1	51.4	55
Week 4	62.8	42.8	55
Week 5	74.4	47.8	55
Week 6	79.5	43.4	55
Week 7	79.7	50.1	55
Week 8	66.4	43.2	55
Week 9	80.2	40.4	55
Week 10	54.7	42.1	55

Figure 6.2: Comparison of Weekdays and Weekend Noise Threshold Values in Mission Industrial Area (August to October 2018)



6.1 Result and Discussion of Residential Noise Monitoring South St. Boniface Neighborhood.

The noise survey measured the ambient noise levels in residential areas and scrap metal recycling areas. The daily ambient noise quality levels observed in the four streets in Dufresne Avenue, South St. Boniface, adjacent to the scrap metal recycling operations in Mission Industrial Area, are represented in Tables 6.3 and 6.4, respectively. From these tables, the daily mean variation of LAeq, LAeq minimum and LAeq maximum (5-8 hours LAeq), median noise value and noise level environmental standard are shown. The tables also present a monitoring point and daytime prevailing wind direction for each noise monitoring day.

The daily mean LAeq for ambient noise levels in Dufresne Avenue ranges between 44.8 dBA to 57.8 dBA; daily median values for continuous noise measurement range from 48.3 dBA to 62.4 dBA. Also, the daily minimum ambient noise levels logged on the SLM range between 36.2 dBA to 53.5 dBA, while the daily maximum noise levels range between 52.7 dBA to 72.4 dBA. The noise survey conducted for this study showed episodic ambient noise levels above Winnipeg's 55dBA standard noise level. Ambient noise in July and August 2018 ranges between 44.83 dBA to 49.80 dBA and 48.2 dBA to 51.7dBA, respectively, which was lower than 55dBA daytime neighbourhood liveability standard. The daily LAeqpeak recorded between July and December ranges between 52.5 dBA to 72.4 dBA. The ambient noise levels and the maximum values recorded were typically sounds from residents' dogs barking, air conditioner fans, noise from passing vehicles' engines, train horns and aircraft noise (Berglund et al., 1999).

Table 6.3: Summary Statistics of Ambient Noise Levels in Dufresne Avenue, South St. Boniface, Winnipeg

Monitoring Dates	Sampling Point	Daily Mean LAeq (dBA)	Standard Deviation	LAeqMin (dBA)	LAeqpeak (dBA)	Median (dBA)	Winnipeg Bylaw Standard (dBA)
12-Jul-18 (Thur)	Giroux Street (SW)	46.7	2.67	44.8	56.3	50.3	55
13-Jul-18 (Fri)	Kavanagh Street (SW)	45.3	2.21	45.3	60.1	52.5	55
18-Jul-18 (Wed)	Kavanagh Street (NW)	47.8	2.54	47.8	58.2	48.3	55
19-Jul-18 (Thur)	Doucet Street (SW/NW)	49.21	2.17	49.2	71	57.1	55
27-Jul-18 (Thur)	Cherrier Street (W)	49.8	3.27	50.1	62	53.4	55
03-Aug-18 (Fri)	Doucet Street (SW)	50.2	2.26	43.1	60.9	51.6	55
04-Aug-18 (Weekend)	Cherrier Street (SE)	42.2	2.07	37.6	48.2	41.3	55
09-Aug-18 (Thur)	Giroux Street (SW)	48.8	3.22	46.2	58	56	55
10-Aug-18 (Fri)	Kavanagh Street (W)	46.7	4.86	49.3	60.2	58.3	55
11-Aug-18 (Weekend)	Giroux Street (S)	43.5	3.72	38.4	59.2	48.7	55
15-Aug-18 (Wed)	Doucet Street (SW)	47.2	5.55	48.3	56.4	50.6	55
16-Aug-18 (Thur)	Giroux Street (W)	48.4	4.38	43.4	59	54	55
18-Aug-18 (Weekend)	Kavanagh Street (S)	44.7	2.31	37.3	55.7	48.2	55
21-Aug-18 (Thur)	Doucet Street (W)	49.7	5.71	47.8	61.9	59.7	55
24-Aug-18 (Fri)	Cherrier Street (NW)	48.2	3.56	44.6	52.5	52.4	55
25-Aug-18 (Weekend)	Cherrier Street (NW)	43.9	4.16	40.4	50.6	48.2	55
05-Sep-18 (Wed)	Doucet Street (NE)	54.7	3.01	46.6	62	57.5	55
06-Sep-18 (Thur)	Kavanagh Street (NE)	**56.3**	3.86	53.5	65.7	61.4	55
08-Sep-18(Weekend)	Kavanagh Street (S)	45.1	1.82	35.6	46.5	44.5	55

Daily mean LAeq ambient noise levels in September and October range between 45 dBA to 56dBA and 47 dBA and 58 dBA, respectively. The daily mean LAeq exceedance of 55.8 dBA and 56.3dBA, twice in September, was slightly higher than the 55 dBA noise standard. In October 2018, the one-time daily mean LAeq exceedance of 57.5 dBA was 2.5 dBA higher than the standard for neighbourhood liveability. The daily median noise values observed for the monitoring days when ambient noise levels exceeded the city's standards in September and October were 60.5 dBA, 61.4 dBA and 61.8 dBA, respectively.

The noise monitoring survey periods were limited in November and December due to the seasonal changes in temperature to the freezing point and snowfalls that may affect the functionality of the SLM. As a result, noise monitoring days were limited to two days in November and six days in December. The daily mean LAeq for these noise monitoring months ranges between 47.5 dBA to 54.3 dBA in November and 46.8 to 57.6 dBA in December. One day out of the eight daily mean LAeqs was 57.6 dBA (1 December 2018) recorded in November and December exceeded the 55 dBA standard for neighbourhood liveability. Figure 6.3 shows the noise levels in South St. Boniface Residential Areas over seven months of monitoring.

The highest daily mean LAeqs measured in September, October and December 2018 at the noise monitoring streets in South St. Boniface can be attributed to various factors. The prevailing wind direction for the monitoring days of exceedance was predominantly from the North/North-East direction of the residential areas located downwind of the scrap metal recycling operations. Increased background ambient noise levels between 6 dBA to 7 dBA have been reported to be more prevalent in the downwind direction of a sound emission source (Mckenzie et al., 2002; Evans and Cooper, 2012). Also, the distance of the two streets with exceedances, Kavanagh and Cherrier, were within 1000 meters from the scrap metal recycling operations (Evans and Cooper, 2012).

Table 6.4: Summary Statistics of Ambient Noise Levels in Dufresne Avenue, South St. Boniface, Winnipeg

Monitoring Dates	Sampling Point	Daily Mean LAeq (dBA)	Standard Deviation	LAeqMin (dBA)	LAeqMax (dBA)	Median (dBA)	Winnipeg Bylaw Standard
12-Sep-18 (Wed)	Kavanagh Street (NW)	50.1	6.47	52.8	72.4	53.1	55
13-Sep-19 (Thur)	Cherrier Street (W)	49.1	3.33	46.6	57	55.4	55
15-Sep-18 (Weekend)	Cherrier Street (N)	44.2	2.77	38.1	59.2	41.2	55
17-Sep-18 (Mon)	Doucet Street (ENE)	50.4	4.86	47.5	61	52.7	55
20-Sep-18 (Thur)	Cherrier Street (NE)	**55.8**	6.31	50.2	66	60.5	55
22-Sep-18 (Weekend)	Doucet Street (SE)	44.7	2.28	46. 5	58	49.7	55
01-Oct-18	Giroux Street (SE)	49.2	3.24	42.8	62.1	51.3	55
06-Oct-18 (Weekend)	Giroux Street (W)	42.6	2.68	36.1	58.2	51.2	55
09-Oct-18	Cherrier Street (NW)	50.1	4.51	40.3	60.7	53.1	55
10-Oct-18	Kavanagh Street (NE)	**57.5**	3.46	49.5	68.3	61.8	55
18-Oct-18	Kavanagh Street (SW)	46.8	2.73	37.4	58.7	47.3	55
20-Oct-2018 (Weekend)	Cherrier Street (SE)	39.4	2.01	33.7	61.2	42.3	55
22-Oct-18	Doucet Street (NW)	51.6	7.32	46.9	62.4	53.8	55
24-Oct-18	Cherrier Street (SE)	48.2	3.47	41.2	58.6	47.4	55
2018-10-27 (Weekend)	Giroux (NW)	40.6	2.16	38.3	59.3	42.8	55
31-Oct-18	Giroux (NW)	49.4	1.87	41.7	62.4	49.2	55
06-Nov-18	Kavanagh Street (N)	54.3	5.29	43.5	68.3	58.5	55
08-Nov-18	Doucet Street (NW)	47.5	1.78	40.6	56.9	47.1	55
01-Dec-18	Cherrier (NE)	**57.6**	6.4	49.2	70.1	62.4	55
04-Dec-18	Kavanagh (SW)	51.3	3.12	46.2	59.4	56.7	55
10-Dec-18	Doucet Street (NW)	50.1	4.06	43.1	62.8	52.9	55
11-Dec-18	Kavanagh Street (S)	47.9	2.21	39.4	54.5	48.6	55
12-Dec-18	Giroux Street (SE)	46.8	3.75	36.2	52.7	46.1	55
13-Dec-18	Cherrier Street (SW)	48.2	3.01	39.7	53.2	45.3	55

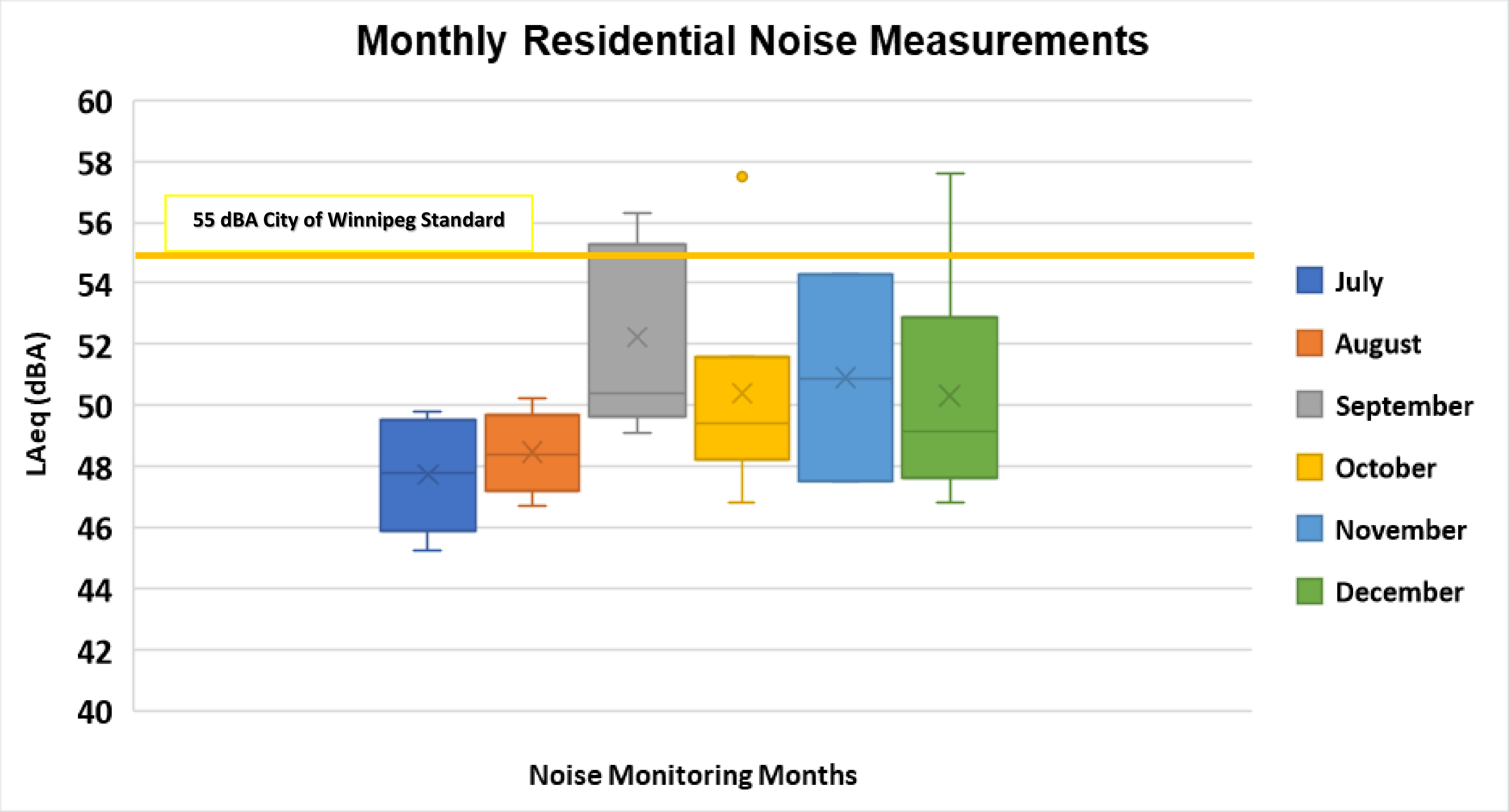


Figure 6.3: Noise Levels in South St. Boniface Residential Areas over seven months of monitoring.

6.3 Result of Roadside Traffic-Related Noise in Dufresne Avenue, South St. Boniface, Winnipeg

Traffic-related noise is the most widely investigated source of environmental noise posing human health and social risks (WHO, 2018). Noise emissions from high-traffic density cities/corridors have been reported to spread into residential areas and school environments more so than noise from aircraft or railway engines (Ryu et al., 2017; Ragettli et al., 2016). Hence, this study measured roadside traffic noise on Archibald and Marion Streets linking into Dufresne Avenue and to the noise levels recorded with Winnipeg's neighbourhood liveability noise standard.

The summary statistics for traffic corridor noise measured in this study are presented in Table 6.5. The tables show the daily morning and afternoon mean value of LAeq1hr, standard deviation, LAeq minimum and maximum and the noise threshold limit for roadside noise established by World Health Organization (Wen et al., 2019). The morning LAeq1hr measured for the roadside noise level ranges between 62.6 dBA and 77.4dBA, the LAeq peak ranges between 72.5 dBA and 84.6 dBA, while the median value ranges between 57.5 dBA and 78.2 dBA. The LAeq1hr roadside noise levels showed exceedances of 70.1 dBA to 77.4 dBA for 11 out of 25 mornings of continuous one-hour measurement recorded, which are above the 70 dBA WHO guideline. Afternoon LAeq1hr ranges between 62.7 dBA and 78.1 dBA, showing 13 out of 25 afternoon sampling periods above the 70 dBA WHO guideline for traffic-related noise. Similarly, a roadside noise study by Wen et al. (2019) reported an exceedance of 74.2 dB(A), which was within the range of threshold values reported for morning and afternoon roadside noise exceedance in South St. Boniface.

Table 6.5: Summary Statistics of Roadside Noise Levels in Dufresne Avenue, South St. Boniface, Winnipeg

		Morning LAeq1hr (dBA)				Bylaw Standard	Afternoon Mean LAeq1hr (dBA)			
Monitoring Dates	**Sample Point**	**LAeq1hr (SD)**	**LAeqMin**	**LAeqPeak**	**Median**	**(dBA)**	**LAeq1hr (SD)**	**LAeqMin**	**LAeqPeak**	**Median**
12-Jul-18	Archibald 1	70.1 (8.35)	53.2	78.6	66.8	70	74.7 (6.82)	56.4	76.1	74.6
13-Jul-18	Archibald 2	73.4 (6.22)	51.7	81.4	72.5	70	78.1 (5.49)	48.2	82.6	75.5
18-Jul-18	Archibald 1	68.1 (7.46)	52.3	79.6	71.3	70	70.3 (7.17)	53.6	73.7	65
19-Jul-18	Marion 1	69.8 (8.14)	49.5	77.3	59.6	70	76.8 (8.42)	51.3	78.1	74.9
27-Jul-18	Archibald 3	62.6 (5.37)	48.3	75.4	70.1	70	65.5 (7.33)	50.1	74.8	68.3
03-Aug-18	Marion 2	77.7 (6.19)	55.1	80.6	68.8	70	78.2 (7.51)	58.6	82.7	75.9
09-Aug-18	Archibald 3	71.8 (6.05)	52.7	78.2	64	70	69.6 (5.26)	52.2	74.5	70.5
10-Aug-18	Archibald 4	70.2 (8.61)	57	76.9	62.7	70	75.9 (6.72)	52.6	76.8	73.6
15-Aug-18	Archibald 1	69.7 (7.55)	48.3	82.5	69.5	70	71.3 (8.36)	50.3	78	75.8
16-Aug-18	Archibald 2	70.4 (8.73)	51.6	84.6	70.8	70	63.1 (5.10)	49.7	73.7	69.2
21-Aug-18	Marion 2	72.6 (6.41)	50.8	78.5	57.5	70	77.5 (6.07)	56.9	80.9	74.6
24-Aug-18	Archibald 2	65.8 (5.86)	49.2	77.4	68.3	70	73.4 (5.24)	52.8	75.2	73.8
05-Sep-18	Archibald 1	67.5 (7.36)	52.8	80.7	69.6	70	65.2 (6.30)	51.7	72.4	67.4
07-Sep-18	Marion 1	76.8 (8.65)	54.5	81.3	70.8	70	75.5 (8.47)	54.2	79.2	73.1
12-Sep-18	Archibald 3	68.2 (7.34)	49.1	76.7	60.5	70	74.9 (5.19)	47.4	76.8	72.6
13-Sep-18	Archibald 3	65.7 (6.25)	50.2	73.6	69.8	70	64.8 (5.36)	57	68.2	62.8
17-Sep-18	Marion 2	73.2 (6.07)	51.6	79.8	66.4	70	74.1 (7.23)	50.8	79	68.6
20-Sep-18	Archibald 1	66.5 (4.93)	48.4	80.2	70.2	70	67.5 (6.17)	52.5	68.6	66.2
01-Oct-18	Archibald 1	64.8 (5.12)	50.8	78.2	58.7	70	68.3 (5.83)	54.5	73.4	60.4
09-Oct-18	Archibald 3	66.1 (7.28)	51.5	74	69.4	70	65.7 (6.91)	58.6	70.6	59.1
10-Oct-18	Archibald 1	63.9 (7.46)	49.1	72.5	70.8	70	66.4 (7.37)	51.3	71.5	66.3
18-Oct-18	Archibald 1	67.2 (5.01)	52.8	79.3	67.3	70	62.7 (5.21)	50.5	68.2	61.7
22-Oct-18	Marion 1	77.4 (8.78)	53.7	84.6	78.2	70	73.5 (6.14)	49.2	77.6	72.5
24-Oct-18	Archibald 3	64.1 (5.24)	47.5	78.3	69.8	70	65.8 (7.26)	55.1	68.1	60.9
31-Oct-18	Archibald 2	68.5 (7.32)	50.9	75.8	70.7	70	68.1 (5.49)	53.7	72.3	62.5

*SD: Standard Deviation; LAeqMinimum.

6.4 Result of Weekdays and Weekend Ambient Noise Levels in Residential Area

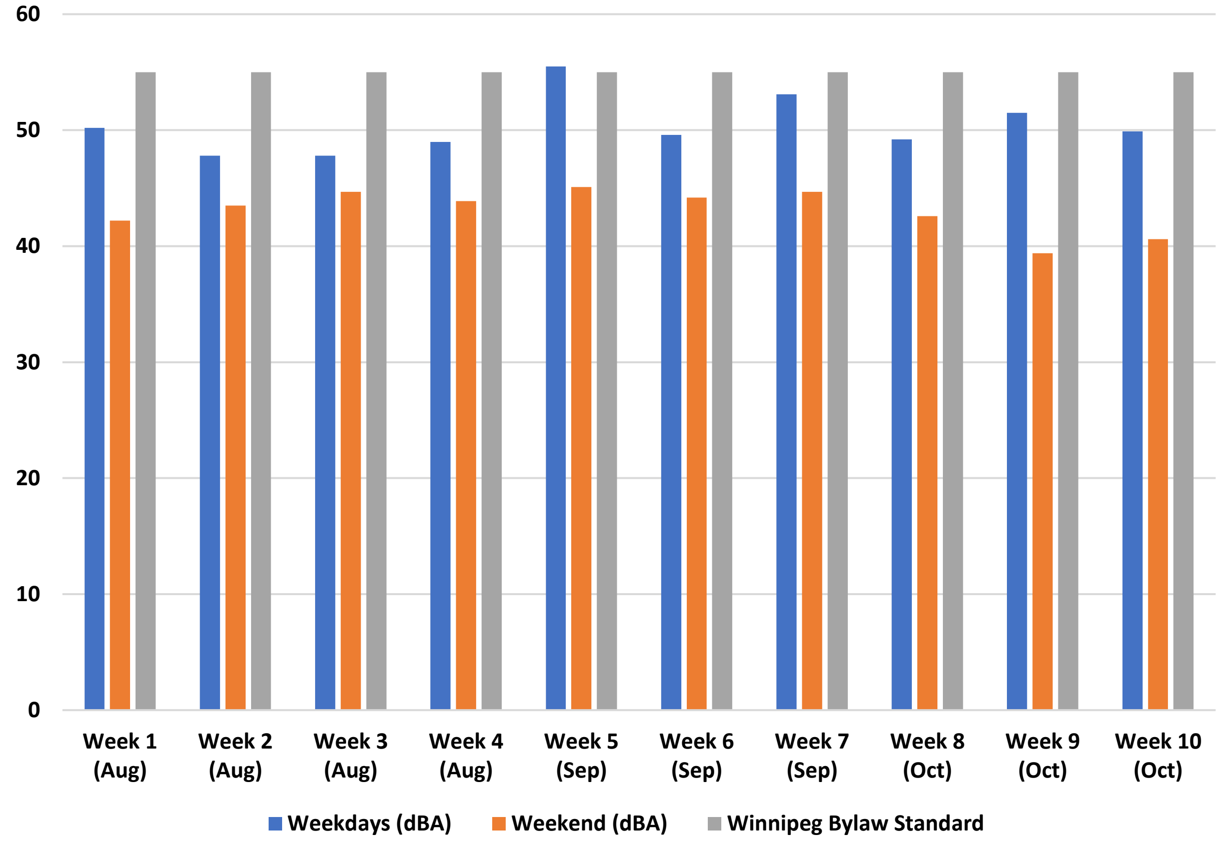
Variations of ambient noise levels for weekdays and weekends were compared to see the difference with the LAeq noise levels caused by human activities during busy days of the week. Average weekday ambient noise levels were computed for the first few weekdays in August to the last weekdays of October 2018. Weekend noise level measurements were recorded from the first Saturday of August to the last Saturday of October 2019 in the residential area on properties where noise levels were recorded in the weekdays. Figure 6.4 shows the graphical representation of average weekdays daily mean LAeq, weekend (Saturday) ambient noise levels in Dufresne Avenue and Winnipeg's 55 dBA daytime for neighborhood liveability.

As shown in Table 6.6, the average weekdays' daily mean LAeq noise values ranges between 47.8 dBA and 55.5 dBA from scrap metal recycling operations. Average weekdays' ambient noise level ranges between 39.4 dBA and 45.1 dBA with minimal human activities, such as roadside traffic, car engines and sporadic intermittent noise from adjacent industrial operations. Comparing the minimum and maximum values recorded for both the weekdays and weekends, the mean noise level reduction from 8.4 dBA to 10.4 dBA was observed from the mean ambient noise levels.

Table 6.6: Summary of Weekdays and Weekends Ambient Noise Values in St. Boniface

No. of Weeks	Weekdays (dBA)	Weekend (dBA)	Winnipeg Bylaw Standard (dBA)
Week 1 (Aug)	50.2	42.2	55
Week 2 (Aug)	47.8	43.5	55
Week 3 (Aug)	47.8	44.7	55
Week 4 (Aug)	49	43.9	55
Week 5 (Sep)	55.5	45.1	55
Week 6 (Sep)	49.6	44.2	55
Week 7 (Sep)	53.1	44.7	55
Week 8 (Oct)	49.2	42.6	55
Week 9 (Oct)	51.5	39.4	55
Week 10 (Oct)	49.9	40.6	55

Figure 6.4: Comparison of Weekdays and Weekend Noise Threshold Values in Mission Industrial Area (August to October 2018)



6.7 Discussion of Industrial Noise Pollution and Ambient Noise Level in Mission Industrial Area and South St. Boniface

The daily mean LAeq measured across all the noise monitoring points established outside the property line of the metal shredder ranged between the crucial finding of the noise measurements of this study which spanned 54.1 ± 4.20 dBA and 83.0 ± 5.26 dBA. Noise emission levels recorded from the shredder were above noise emission levels recorded from the shredder were above the 55 dBA guideline over 90% of the monitoring days. These noises measured at the shredder then provide environmental noise to proximate residential neighbourhoods (Berglund et al., 1999; King et al., 2012).

According to Evans and Cooper (2012), the noise emitted from sound energy sources can increase background noise levels by 6 dBA to 7 dBA at over 1000 meters downwind from the emitting source. The potential downwind increase of background noise level reported by Evans and Cooper, (2012) was observed in the ambient daily LAeq occasionally in Dufresne Avenue with a northeast wind direction from the shredder's location. Annoyance, the most prevalent response to increased ambient noise levels in residential areas, is widely reported in various community noise studies globally (Basner et al., 2014).

The episodic increase of ambient LAeq observed in the residential areas - 50 dBA to 56.7 dBA - in Dufresne Avenue, due to the intermittent sounds originating from the scrap metal shredder, may increase annoyance levels (WHO Community Noise Guideline, 1999). Increased annoyance manifests as negative responses, such as displeasure, anger and exhaustion, to the intermittent sounds from the scrap shredder (Fritschi et al., 2011; Grelat et al., 2016). The severe occurrence of annoyance in adults and children caused by noise may affect overall well-being and health; consequently, annoyance due to an increase in ambient noise levels may contribute to the global burden of disease (Basner et al., 2014).

An important finding of the study’s noise monitoring was the episodic peak noise levels recorded by the SLM ranges between 98 dBA to 120.1 dBA on neighbouring properties beside the fence-line of the scrap metal shredder. These peak noise periods were characterized by loud explosions and metallic projectiles flying into neighbouring properties, which may constitute a public hazard. The peak 120.1 dBA in this study exceeded EPA’s 114 dBA for peak noise levels, which may increase a one-time individual’s exposure and risk of noise-induced hearing loss (Yao et al., 2017). Chronic exposure of LAeq noise levels of 75 dBA to 85 dBA in the industrial area, as recorded in the study’s noise monitoring survey, may lead to noise-induced hearing loss (Basner et al., 2014).

Last, fence-line noise monitoring of the scrap metal shredding and recycling operations provides impetus to recommend and institute source noise emissions control strategies. The peak noise levels of 65.1 dBA to 83 dBA measured in this study were similar to the noise levels of 74 dBA to 82 dBA from a scrap metal shredder in California, USA (Saxelby, 2012). The noise control strategy by Saxelby (2012) introduced building a noise enclosure on the scrap metal shredder hopper which reduced the noise pollution level by 26 dBA on the nearest residential property.

6.6 Summary of findings

The noise survey captured noise pollution levels from industrial operations including the scrap metal’s auto shredder, ambient noise levels in residential areas and traffic-related noise. In the residential area within the proximity of industrial operations, daytime ambient noise levels exceeded the 55 dBA community noise guidelines for the daily mean for four of the 33 samples. All samples reached the maximum level for exceeding the sound level. In summary, the highlights of the noise survey are:

1. The daily mean of daytime ambient noise level four of the 33 noise samples exceeded the 55 dBA community noise guideline.
2. Episodic peak noise levels constitute risks to public health, particularly hearing loss.
3. Recommendations for noise control strategies can be found in the research by Saxelby et al. (2012).

CHAPTER SEVEN

7.0 Mapping of Respirable Particulate Matter ($PM_{2.5}$), Heavy Metals, and Noise Monitoring Data

This chapter presents the spatial analysis of the air and noise monitoring, as well as the snowpack analysis in Mission Industrial area and Dufresne Avenue, South St. Boniface. A Geographic Information System (GIS) is applied to link environmental measurements to the geographical locations where such measurements were recorded (Foresman, 1986; Enock and Gelcano, 2015; Bilasco et al., 2017). A GIS is a computer-based system designed to store, manipulate and edit, analyze and present visualized maps in layers and patterns at all scales (Enock and Mulaku, 2015). GIS in this chapter is deployed to estimate and visualize the natural and artificial occurrences in the environment. Spatial analysis of environmental media measurements using GIS has global recognition and applications in the field of environmental science and management, notably, among researchers and government agencies (Esri, 2019).

The GIS spatial analysis tool, specifically, the interpolation technique for mapping on ArcGIS, has been used by different studies to map out environmental measurements, such as acoustic noise and air pollutants as points data (Akintuyi et al., 2015; Oyedepo et al., 2019). Varieties of spatial interpolation techniques are available, but the most widely used is the Kriging interpolation provided in the toolbox of the ArcGIS desktop (Janssen et al., 2008; Liu et al., 2017). The Kriging interpolation for mapping and visualization for pollution hotspots has been used in ambient air quality, noise pollution and population exposure studies for spatial decision support and for facilitating the decision-making process (Janssen et al., 2008; Liu et al., 2017). Hence, kriging interpolation in this study combines the hourly $PM_{2.5}$ and A-weighted sound levels (dBA) data and the heavy metals concentration in snowpack with GPS coordinates to produce spatial maps in the Mission Industrial Area and South St. Boniface, Winnipeg.

7.1 Spatial Data Collection Procedure

The primary data was recorded during the collection period of June 2018 to March 2019 at the scrap metal recycling operation areas and Dufresne Avenue (Figure 7.1).

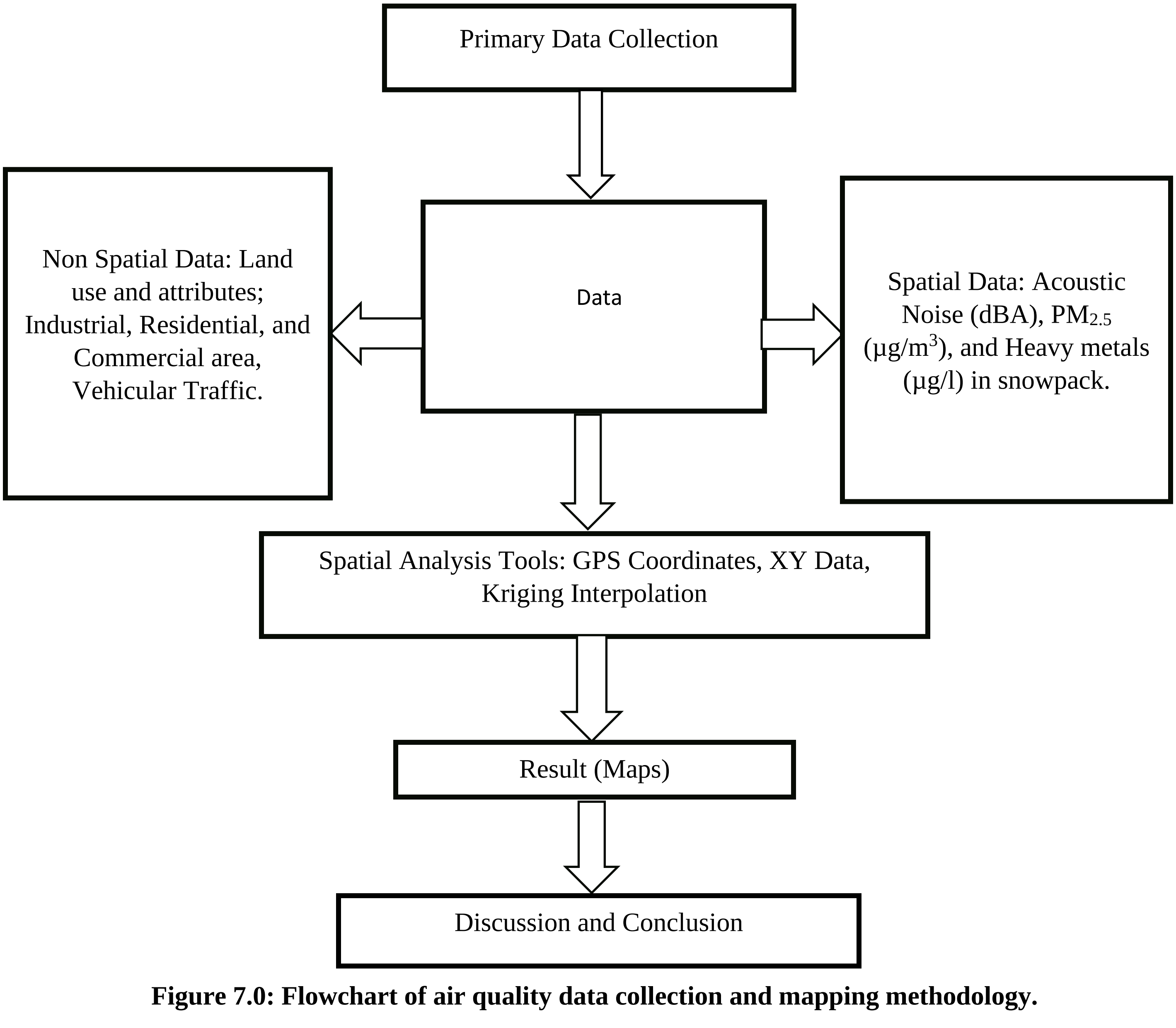


Figure 7.0: Flowchart of air quality data collection and mapping methodology.

7.2 METHODS

7.2.1 $PM_{2.5}$ Air Monitoring Procedure

Dylos DC1700 is a viable and affordable $PM_{2.5}$ air quality monitoring instrument. Dylos DC1700 was applied to measure fence-line emission from scrap metal recycling operations in MIA and to monitor the ambient concentration of $PM_{2.5}$ at Dufresne Avenue and in the South St. Boniface neighbourhood. Downwind $PM_{2.5}$ monitoring followed a fence-line measurement of fugitive emissions from the automobile shredder. Five monitoring points were established based on the prevailing wind direction from the installed meteorological real-time instrument: downwind of the south, north, west, east and southwest prevailing daily and hourly wind directions. Measurements were gathered daily during the metal shredder's operating hours of 8:30 AM to 4:30 PM.

Two to three weekdays (7:40 AM to 5:00 PM) each week for six months from July 2018 to December 2018. I monitored with the Dylos DC1700 outdoor $PM_{2.5}$ mass concentration in the South St. Boniface residential areas. The air monitoring sites covered: roadsides, parklands, front lawns and gardens. Daily daytime monitoring started with roadside measurements, approximately 2m away from the road entering each street, to record traffic-related emissions between 07:40 am to 08:40 pm. Subsequent residential daytime hourly measurements were taken at different households that signed up for air monitoring near their property (09:00 am to 03:30 pm). The wind rose in Figure 7.2 shows the wind direction and speed in the study area. The scrap metal shredding operations monitoring points were located on the north-east part of the cardinal wind direction, while the residential area points were located on the south-southwest cardinal wind direction (see

Fig. 7.3)

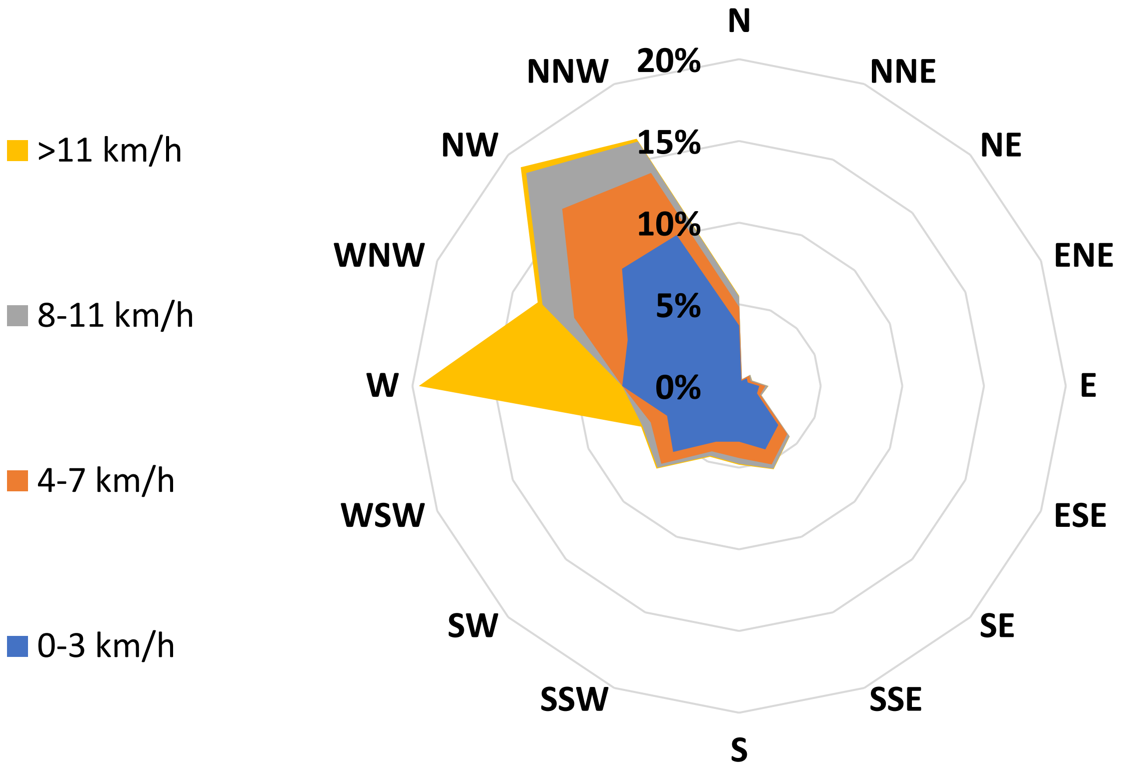
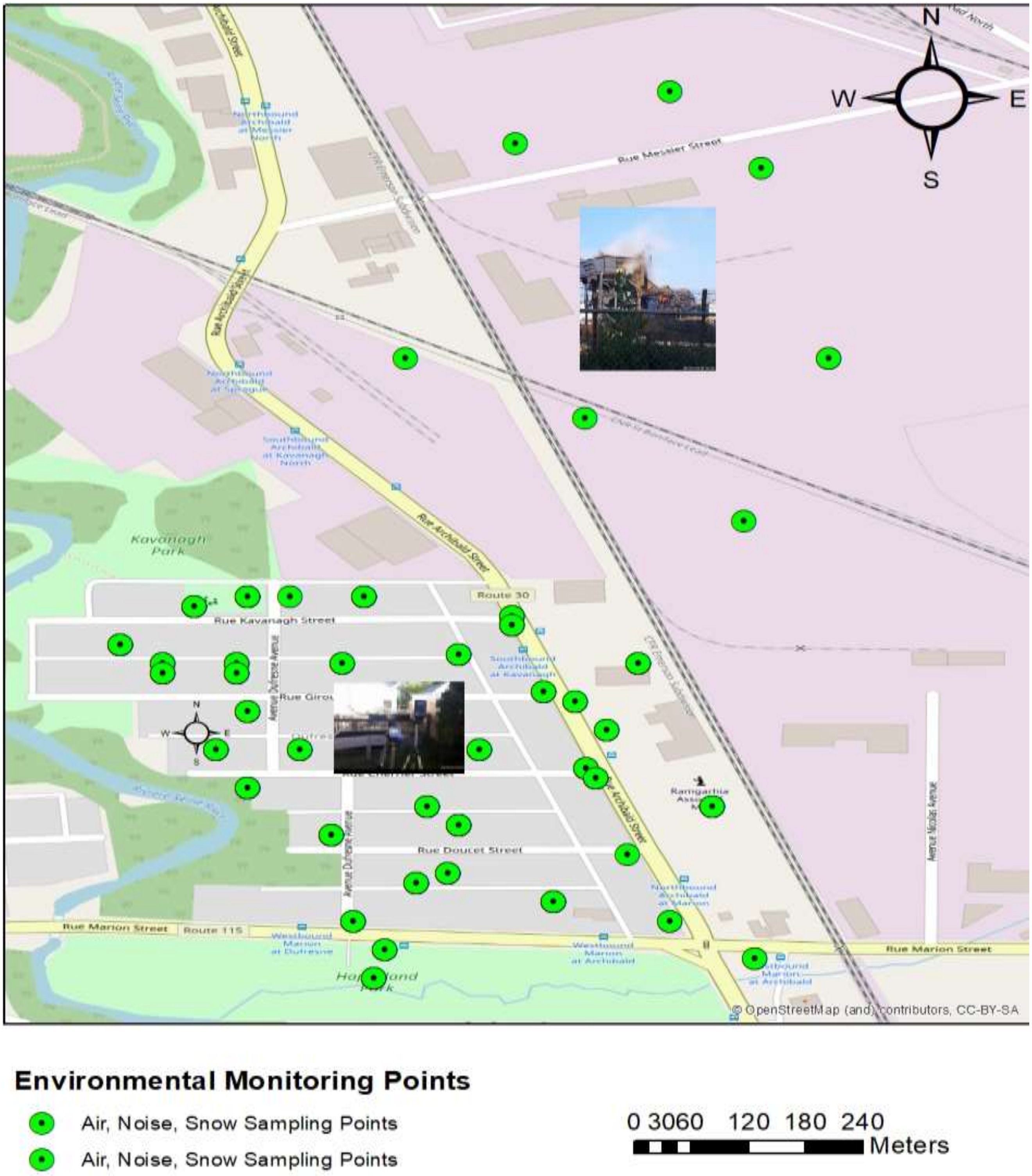


Figure 7.2: Wind Rose for Wind Speed and Wind Direction Measurement from Mission Industrial Watchdog Weather Station. (6 June to 2 November 2018)



Map 7.0a: Map showing the environmental monitoring points in the study area.

7.3 Respirable Fine Particulate ($PM_{2.5}$) Mapping

The presence and dispersion of fine particulate matter of aerodynamic 2.5µm and other air pollutants in the ambient air varies spatially and temporally (Chen et al., 2016; Guo et al., 2019). The variation in the presence of these air pollutants is visualized in the maps or time-series data (Liu et al., 2017). Specifically, mapping of air pollutants has been used to visualize the local and regional level of air pollutants, hotspots denoting areas of higher pollution levels, and population exposure (Bari and Kindzierski, 2016). Thus, spatial analysis of $PM_{2.5}$ hourly data measured at the scrap metal recycling fence-line areas and the residential sampling points was conducted using ArcGIS software (Janseen et al., 2008).

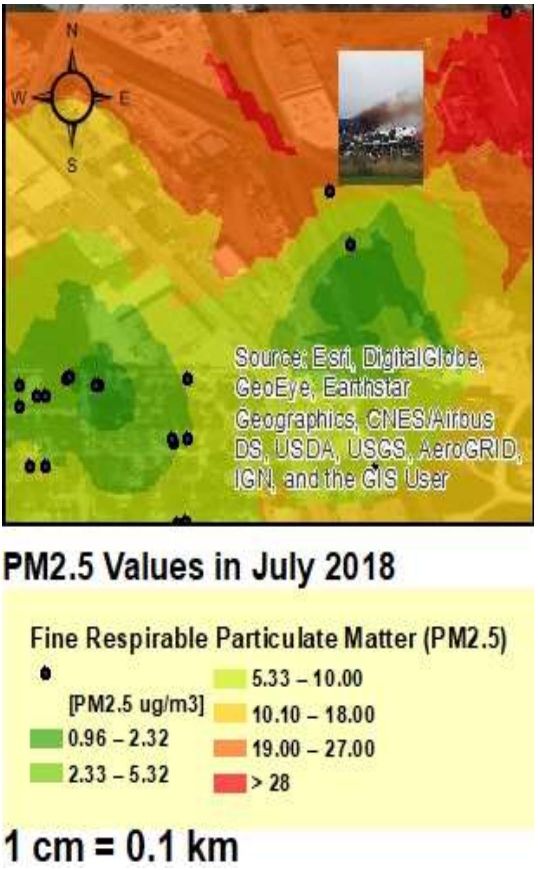
These maps were interpolated using geostatistical kriging analysis and the colour-coding of Canadian Ambient Air Quality Standard (CAAQS) for management action level for achieving air quality zone (Table 7.0).

Table 7.0 CAAQS Air Management Threshold Values and Actions

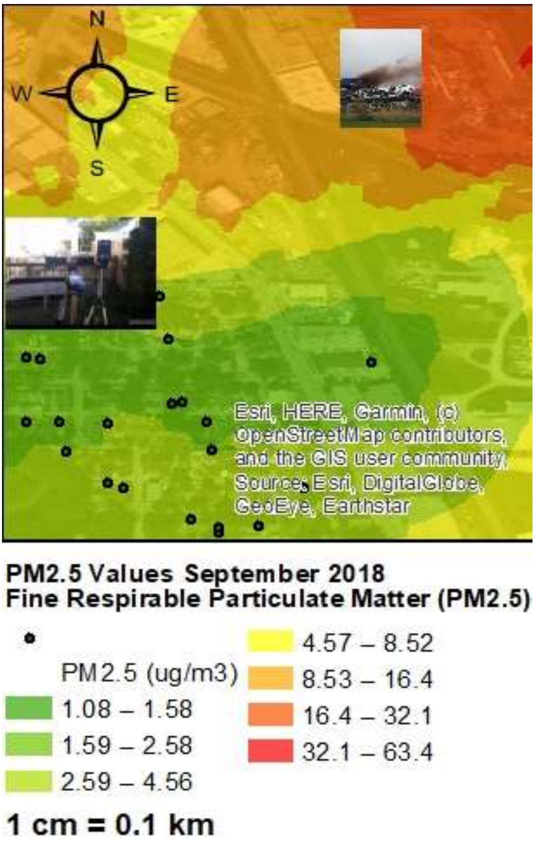
Canadian Ambient Air Quality Standards (CAAQS)					
	$PM_{2.5}$ annual (ug/m3)		$PM_{2.5}$ 24-hour (ug/m3)		
	2015	2020	2015	2020	Management Level & Action
Threshold Values	10	8.8	28	27	Action needed for achieving CAAQS Air Zone
	6.4		19		Action for Preventing CAAQS Exceedance
	4		10		Action Preventing Deterioration of Air Quality
	<4		<10		Actions for Maintaining and Keeping Clean Air Zones

7.4 Results of Mapping Analysis

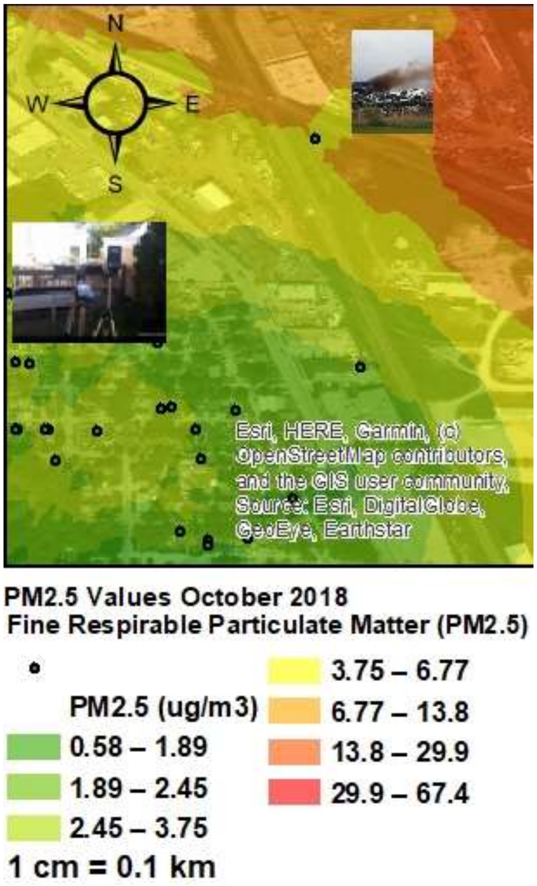
Monthly visualized patterns of respirable particulate matter emission trends at the scrap metal shredding sampling points and ambient levels in South St. Boniface are presented. These interpolated maps (Figure 7.1a to 7.1f) display the patterns and distribution of $PM_{2.5}$ trends based on the prevailing wind direction of the study area (Figure 7.2). The green patterns on the interpolated maps indicate sampling areas of satisfactory air quality, that have $PM_{2.5}$ levels of less than 10 µg/m^3, in the residential areas in South St. Boniface. The green pattern displayed in the Industrial Metal Inc. scrap metal shredder, as shown on the July Map, indicate an inaccessible $PM_{2.5}$ monitoring point on the industry site. The yellow patterns on the interpolated maps represent areas where $PM_{2.5}$ levels exceed 10 µg/m^3. This borderline level requires action to prevent deterioration of air quality. The monthly orange patterns show exceedances of $PM_{2.5}$ with levels amounting to 19 to 27 µg/m^3. These high levels are mostly within 100 meters of the fence-line air from the scrap metal shredder. Last, the dark red patterns are areas where episodic hourly emissions exceeded $PM_{2.5}$ > 27 µg/m^3 and reached higher levels of 20.3 to 67.2 µg/m^3 from the scrap metal and 21 to 35 µg/m3 ambient $PM_{2.5}$ levels in the residential area.



Map 7.1a: June 2018 Spatial distribution of Particulate Matter in South St. Boniface	**Map 7.1b: July 2018 Spatial distribution of Particulate Matter in South St. Boniface**



Map 7.1c: August 2018 Spatial distribution of Particulate Matter in South St. Boniface	**Map 7.1d: September 2018 Spatial distribution of Particulate Matter in South St. Boniface**



Map 7.1e: October 2018 Spatial distribution of Particulate Matter in South St. Boniface	**Map 7.1f: November/December 2018 Spatial distribution of Particulate Matter in South St. Boniface**

7.5 Discussion

The high $PM_{2.5}$ levels close to the industry's fence-line was undertaken to monitor scrap metal shredding emissions. The levels found indicate exceedances and deteriorating air quality in the downwind westerly and northwesterly monitoring points, displayed as red and orange patterns on the interpolated maps. The map shows the spatial and temporal patterns of variation of $PM_{2.5}$ levels. For example, the higher levels of $PM_{2.5}$ levels were observed in the north easterly part of the study area. The levels reduced the farther from Industrial Metals but still exceeded the Canadian Ambient Air Quality Standards, at levels reaching 35 $\mu g/m^3$ for residential areas in August 2018. This August hourly $PM_{2.5}$ interpolation, which was caused by the 2018 summer smoke waves that drifted into Southern Manitoba from wildfires in British Columbia and Alberta.

Considering the August exceedance was due to forest fires as an unavoidable exemption in the residential area, other monthly kriging maps display the regular trends of good air quality patterns. The satisfactory air quality patterns observed from the interpolation in the residential area may be linked with the impact of meteorological conditions, dominantly wind direction (Fig 7.1). Scrap metal recycling emissions are transported upwind of the residential area. Therefore, elevations of ambient $PM_{2.5}$ at levels that deteriorate ambient air quality in the residential areas would be mostly caused by regional transboundary movement of smokes and particles (Sapkota et al., 2005; Sofowote and Dempsey, 2015).

7.6 Summary

The interpolated maps presented show that $PM_{2.5}$ high concentrations radiate out from the scrap metal shredder, reducing with distance. The monthly interpolated $PM_{2.5}$ maps expose how the localized emissions from scrap metal recycling shredder had sporadic daytime exceedance levels at the high levels: >19 and 27 $\mu g/m^3$. These levels are above the Canadian Ambient Air Quality Standards for poor air quality zone and threshold values of management action. The green patterns on the interpolated maps showed lower levels of $PM_{2.5}$ (< 10 $\mu g/m^3$) indicating good air quality in the residential area.

CHAPTER EIGHT

8.0 Mapping of Heavy Metals Distribution in Snow

Heavy metals are toxic contaminants present in scrap metals recycling and processing that typically consist of automobiles, metal appliances and other kinds of scrap metals (Nummi, 2015; Masindi and Muedi, 2018). Lead, cadmium, nickel, arsenic, mercury, chromium, zinc and manganese are known as toxic metals with significant human health and environmental risk even at low concentrations. Spatial analysis and mapping are incorporated into environmental studies to identify patterns and origins of heavy metals contaminants (Ha, 2014).

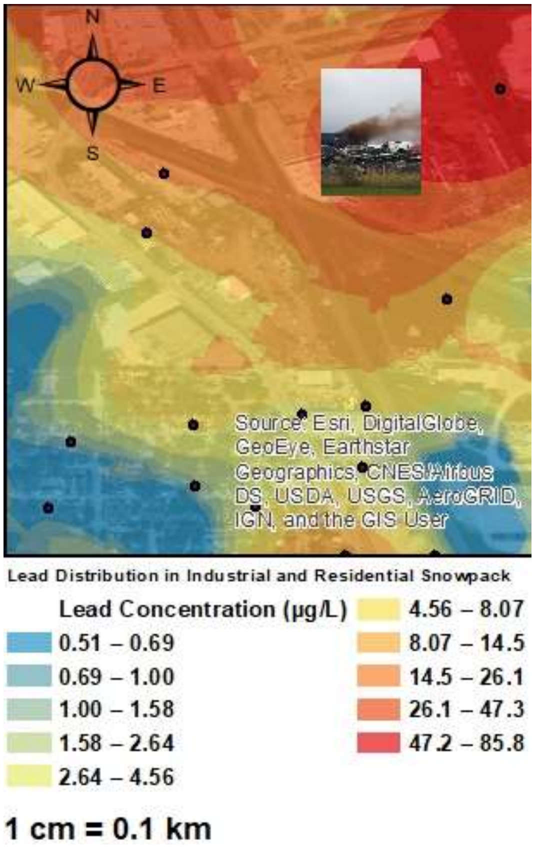
8.1 Snow Sampling Procedure

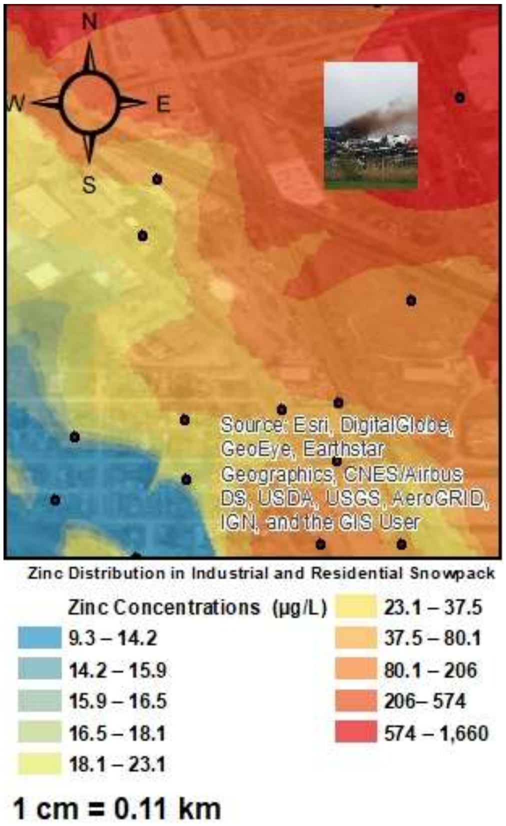
Five composite samples (automobile shredder 1, 2, 3, 4 and 5) were collected from the scrap metal recycling fence-line, downwind of the air monitoring points (south, north, west, east, and southwest). Ten composite samples were taken in the residential/parkland area: two composite samples on each of the four streets and two samples from the two parklands. Four composite snow samples on Archibald and Marion roads and another four composite samples in the commercial areas were also included. The composite samples were collected across the sampling areas on 13 March 2019, between 9:30 AM and 5:50 PM. Composite sampling was adopted to minimize analytical costs and for use as a preliminary descriptive method to determine the presence of heavy metals in accumulated snow cover (Lancaster & Keller-Mcnulty; Johnson and Patil, 2001).

Kriging interpolation is used to interpolate two concentrations of heavy metals close to each other in order to project an aerial view of the metals' spatial distribution (Ziegel, 2001; Mcgrath et al., 2004). The principle behind kriging interpolation is that closer concentrations of heavy metals samples in space are more similar than those at distances further apart. (Ha, 2014). Pivotal to kriging interpolation is “semivariogram”. Semivariogram, in ArcGIS, is used to illustrate the spatial autocorrelation of sampling points and the concentration of heavy metals (ArcGis Pro, 2019). Hence, spatial maps of heavy metals’ concentration in snow samples from the scrap metal shredding and residential area snow sampling points in South St. Boniface were produced using the kriging interpolation. The interpolated maps are presented below for each of the heavy metals’ concentration in the snow samples across the study sites.

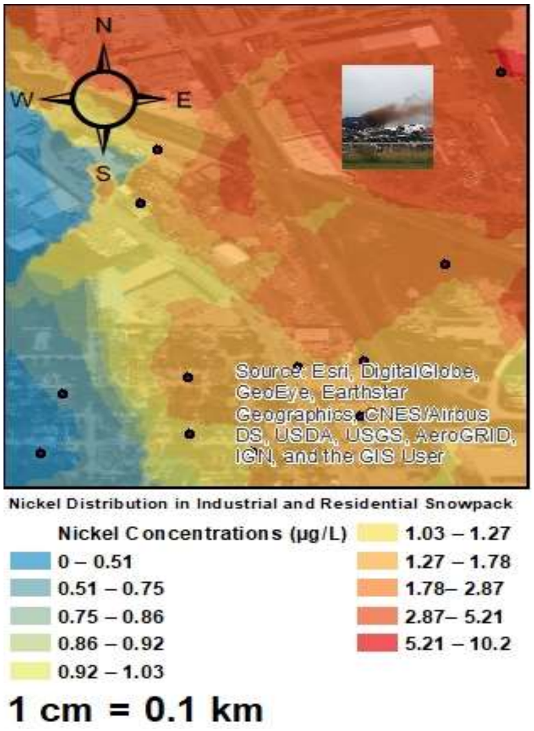
8.2 Result of Kriging Interpolation of Heavy Metals in Snowpack

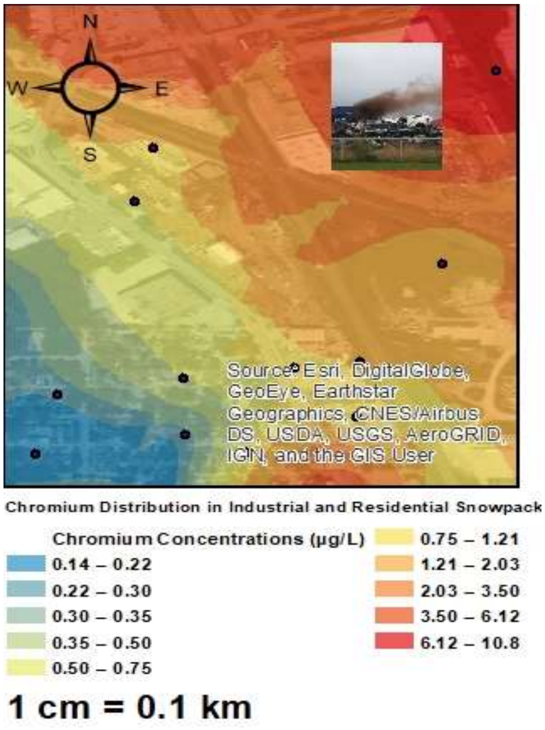
The results of snowpacks kriging for each of the eight maps from 8.1a to 8.1g show that the most deposition is around the shredder in Mission Industrial reducing outside the industrial area of St. Boniface towards the residential area. The findings show highest levels for Pb, Zn, Ni, Cr, and Hg in the northeast cardinal point of the map where the scrap metal shredding industry is located, compared to other sampling points.



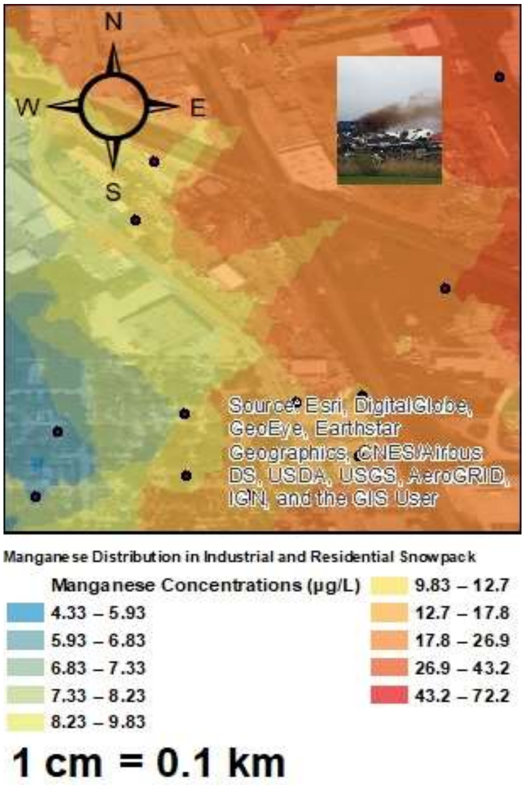


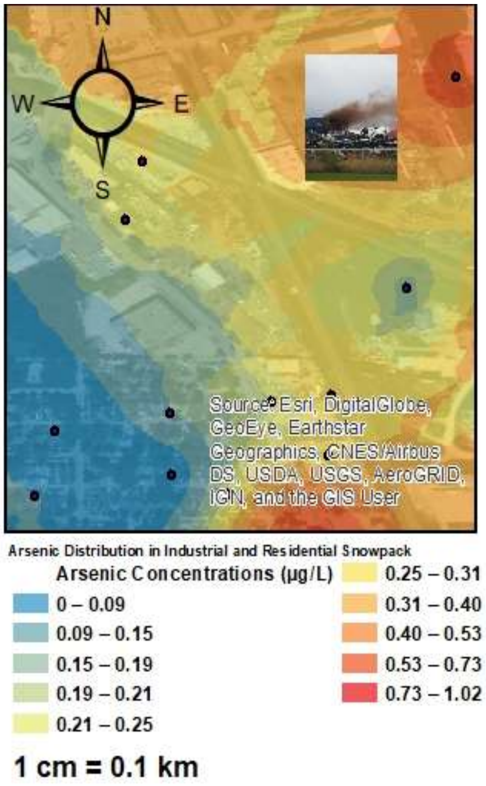
Map 8.1a: Spatial distribution of Lea-d (Pb) in Undisturbed Snowpack in South St. Boniface	**Map 8.1b: Spatial distribution of Zinc (Zn) in Undisturbed Snowpack in South St. Boniface**



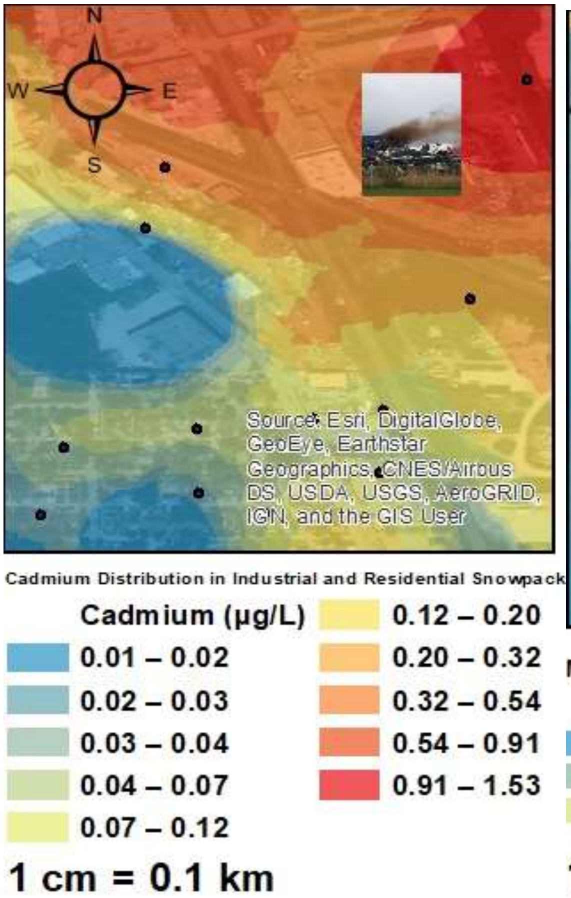


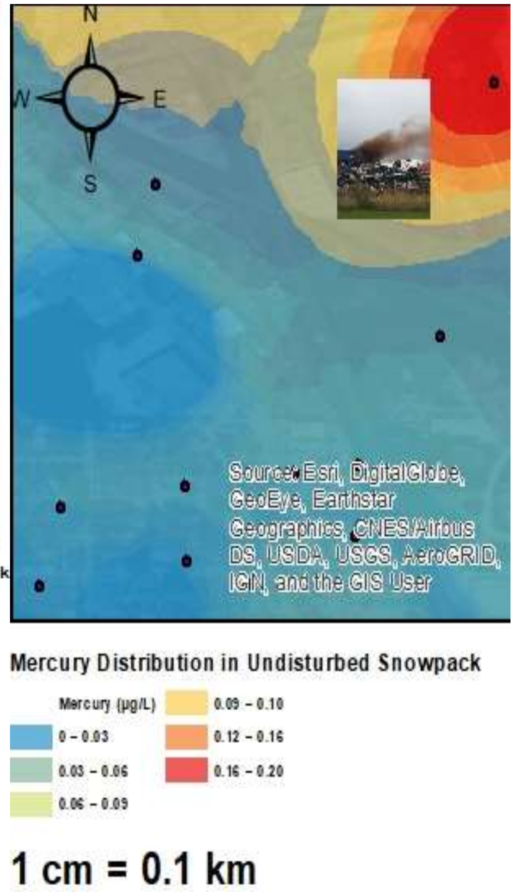
Map 8.1c: Spatial distribution of Nickel (Ni) in Undisturbed Snowpack in South St. Boniface	**Map 8.1d: Spatial distribution of Chromium (Cr) in Undisturbed Snowpack in South St. Boniface**





Map 8.1e: Spatial distribution of Manganese (Mn) in Undisturbed Snowpack in South St. Boniface	**Map 8.1f: Spatial distribution of Arsenic (As) in Undisturbed Snowpack in South St. Boniface**





Map 8.1g: Spatial distribution of Cadmium (Cd) in Undisturbed Snowpack in South St. Boniface	**Map 8.1h: Spatial distribution of Mercury (Hg) in Undisturbed Snowpack in South St. Boniface**

8.3 Discussion

Kriging on ArcGIS is applied to interpolate heavy metals concentrations in snowpack samples to display and understand the aerial viewpoint of the spatial distribution of heavy metals. The maps display spatial views of interpolated heavy metals concentration in the study sites. High concentrations of Pb, Zn, Cr, Cd, Ni and Hg, shown in dark red, appear localized in almost all the maps in the northerly/westerly corner downwind of the scrap metal shredding. In contrast, blue and light blue patterns for each heavy metal in the residential/parkland area have lower concentrations in comparison to the high concentration levels in the hotspot parts of the maps coloured red.

From the observed values of the interpolated maps, Pb, Zn, Ni, Cr, and Hg had the highest heavy metals concentrations in the snowpack samples. The aerial views suggest that scrap metal shredding operations, as displayed in Figures 8.1a, 8.1b, 8.1c, 8.1d, 8.1e, 8.1f, 8.1g, 8.1h are a primary contributor to the presence of these metals in snowpack, with the highest deposition centred at their location. As shown in the interpolated maps of this study, a similar study by Siudek et al. (2015), reported high concentrations of Pb, Ni, Zn and Cr in snow samples. The presence of these metals were linked in this study to local and regional urban/industrialized dust and particle emissions. Furthermore, Ha et al. (2014) interpolated map for heavy metals suggested that high levels of Pb, Cd, and Zn were associated with anthropogenic activities, such as metal foundries and traffic-related emissions.

Mercury (Hg) levels observed (Map 8h) from the interpolated map at the northerly/westerly downwind of the scrap metal shredder further intensified the impact of industrial operations. Mercury is an extremely volatile and persistent toxic heavy metal, which can be transported far distances. Mercury switches in old automobiles and other appliances are the primary source of mercury emissions in scrap metal shredding/recycling operations (Sastry, n.d). Thus, the patterns of interpolated maps for mercury and other heavy metals marked with dark red and orange show and support the anthropogenic deposition resulting from emissions by the scrap metal shredding and recycling operations. Although the map of concentrations do not show perfect concentric rings that decrease with the distance from the scrap metal shredder, a pattern of reduced concentration from the shredder suggest this is a source of emissions.

8.4 Summary

The interpolated maps indicate that the highest concentrations of all metals occur at the scrap metal shredding area of Industrial Metals Inc. and radiate outwards, reducing in concentration with distance. The heavy metals concentration maps reveal that the toxic metals - namely Pb, Ni, Zn, Cr and Hg - deposited in snowpack are highest at Industrial Metals Inc, with levels reducing the further the distance from the shredder.

CHAPTER NINE

9.0 Mapping of Noise Measurements in Mission Industrial and South St. Boniface

This chapter describes the GIS method in interpolating and visualizing the hourly noise levels measured in this study using kriging geostatistical analysis (Aumond et al., 2018). Noise maps were interpolated using geostatistical kriging analysis and detailed colour-coding of various noise threshold guidelines and potential auditory and non-auditory risks/impacts (Table 9.1).

9.1 Noise Monitoring Design and Procedure

The study's noise monitoring design included three monitoring points: industrial, roadside, and residential areas. The sampling duration for each site varied two to three days a week and Saturdays, between 8:45am to 4:30pm, July to December 2018. A digital Sound Level Meter was installed daily on a lightweight camera tripod, downwind of the prevailing wind direction and at least 1.5 meters away from any physical barriers, such as walls or trees, that could inhibit noise propagation. In addition, the noise instrument was set to record the minimum and maximum noise levels; data was logged at five second intervals.

The industrial area noise measurement followed an 8-hours daytime fence-line noise data logging on the SLM during the operating hours of the MIA scrap metal recycling plant. This monitoring design was aimed to measure emission levels along the perimeter outside the plant fence. Intermittent noise was recorded as a qualitative observation (see Fig. 3.5.2a) during daytime monitoring of noise emissions.

Daily residential noise measurement, also known as the community noise survey, was taken at five different points across each street: roadside noise traffic measurement at the entrance of each street at one hour measurements during early morning and late afternoon traffic rush hours 2-3 days/week (7:45 AM to 08:45 AM and 04:00 PM to 05:00 PM). Residential noise monitoring measured outdoor noise levels by staging the SLM on seven houses on each of the four streets in Dufresne Avenue of South St. Boniface. The SLM's location was changed every hour to monitor measurement of spatial and temporal variation of noise levels. The noise levels recorded on the SLM for each of the monitoring sites were downloaded using the manufacturer's SE323 PC installed downloader interface with a USB cable to the PC and saved logged data, daily, saved as a Microsoft Excel file.

Table 9.1: WHO Community Threshold Noise Standards and Health Impacts

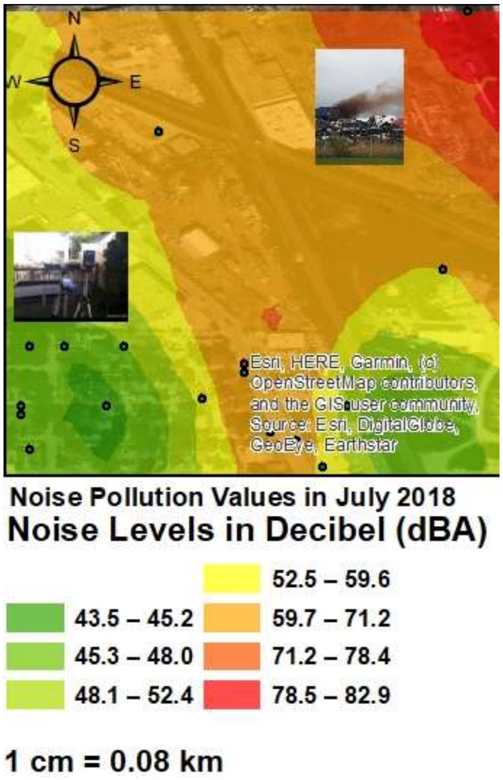
Noise Threshold Guidelines/Standards and Impacts			
Specific Environment (Measurement Point)	**Time of Measurement**	**Threshold Values (dBA)**	**Effects**
Ambient Noise Level (Silence Zone)	Daytime	< 50	
Residential	Daytime	≥ 55	Serious Annoyance
Industrial/Traffic	Daytime	70	Hearing Impairment

Source: Noise Threshold Levels and Impacts are adopted from WHO Community Noise Guidelines (Baeglund et al., 1999).

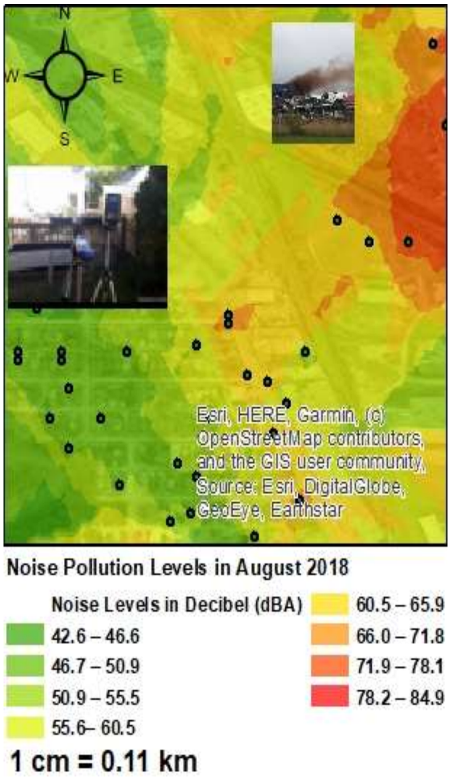
9.2 Results of Noise Map Analysis

Kriging interpolation of hourly noise levels were measured at the scrap metal recycling/shredding fence-line and residential area in South St. Boniface. These monitored noise levels are presented in Figures 9.2 a, b and c. As previously shown in the interpolated maps, five colour patterns were used to visualize and display the patterns of noise levels and the corresponding sampling points.

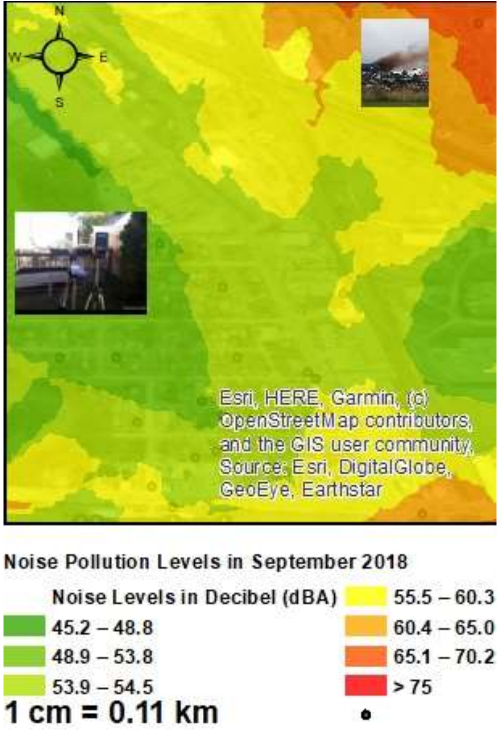
The red and orange patterns on the interpolated maps show the areas of peak noise levels recorded from 70 to 84.9 dBA that was generally observed in all the months interpolated on the northeast direction of the map. These maximum noise levels are typical of intermittent operations of the scrap metal shredder and clanging sounds at the shredder hopper. Noise emissions above the 55 dBA City of Winnipeg guideline recorded at the boundary of the scrap metal operation typically impact nearby residential areas by increasing background noise levels (Baerglund 1999; King et al., 2012; Basner et al., 2014).



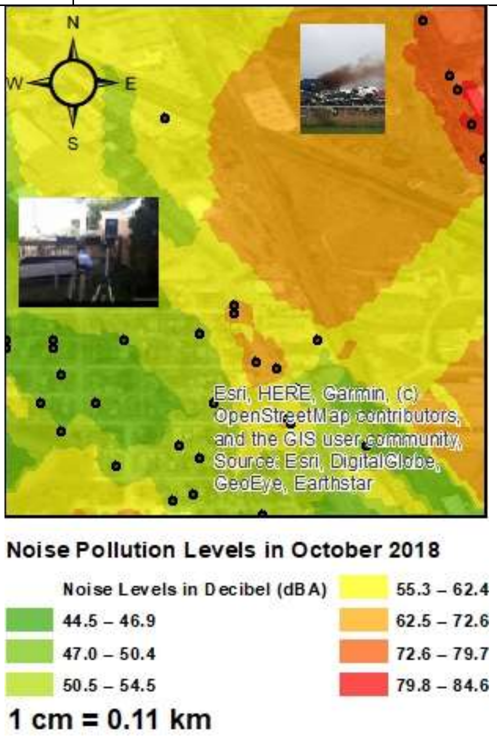
Map 9.1a: July 2018's spatial distribution of Noise Pollution in South St. Boniface



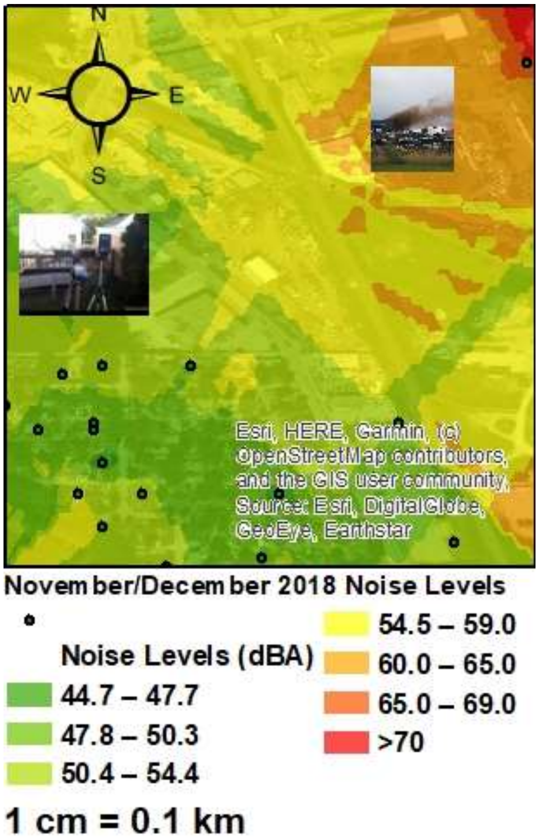
Map 9.1b: August 2018's spatial distribution of Noise Pollution in South St. Boniface



Map 9.1c: September 2018's spatial distribution of Noise Pollution in South St. Boniface



Map 9.1d: October 2018's spatial distribution of Noise Pollution in South St. Boniface



Map 9.1a: November and December 2018's spatial distribution of Noise Pollution in South St. Boniface

The orange and yellow patterns reveal noise levels ranging above 55 dBA to 74.5 dBA. These high levels are associated with negative health impacts. Yellow patterns indicating ≥55 dBA to 58 dBA occurred sporadically in the residential areas showing an episodic increase in ambient noise levels. This episodic noise level was characterized by unpleasant intermittent cracking sounds from the shredder operations, which may increase annoyance (Grelat et al., 2016).

9.3 Summary

The interpolated maps reveal the impact of scrap metal shredding as the major cause of pollution in the study area. The noise maps document industrial noise pollution in the study area, primarily the scrap metal shredder, which is characterized by emissions of sound pressure levels above the City of Winnipeg guideline for neighbourhood liveability. The lower yellow and red patterns observed in August 2018 maps, as compared to other monthly maps in the industrial area, were due to the shredder's annual shutdown maintenance.

CHAPTER TEN

10. Conclusion

This environmental study of Mission Industrial Area and South St. Boniface Neighborhood in Winnipeg monitored fine particulate matter levels, heavy metals in accumulated snow cover and noise levels. The results were analyzed to ascertain the potential environmental impact and risks posed by the scrap metal shredder and other recycling operations in the Mission Industrial Area and the adjacent residential neighborhood. The data collection tools and procedure were implemented using a community-based environmental monitoring platform (CBEM) where local citizens were engaged in the study design. CBEM included: gaining consent of residents to monitor and take snow samples on their property, determining monitoring instruments, selection and siting of strategic monitoring points, installation of monitoring instruments and data collection (English et al., 2017).

10.1. Conclusion of Particulate Matter ($PM_{2.5}$) Monitoring

Air monitoring measured emissions of respirable fine particulate matter ($PM_{2.5}$), an aerodynamic particle size strongly linked to cardiovascular and respiratory diseases and deaths, which did show elevated levels. The $PM_{2.5}$ emissions from the scrap metal recycling shredder provided sporadic daytime exceedance levels above the Canadian Ambient Air Quality Standards (CAAQS) for poor air quality zone and threshold values of management action. Furthermore, ambient particulate matter monitoring in the residential area and traffic corridors measured average daytime $PM_{2.5}$ values of 0.59 $\mu g/m^3$ to 9.81 $\mu g/m^3$, over 2x to 40x below the poor air quality zone for CAAQS.

Thus, daily ambient $PM_{2.5}$ levels in South St. Boniface indicated satisfactory air quality, with the daily highest mean recorded only once in September 2018. Furthermore, the ambient $PM_{2.5}$ showed a moderate correlation with the $PM_{2.5}$ values station report of the Manitoba Air Monitoring

Station, Ellen Street, Winnipeg. Summer forest fire smoke, however, contributed to a significant increase in ambient $PM_{2.5}$ values in South St. Boniface during three days' monitoring in August 2018.

$PM_{2.5}$ air sampling in this study using Dylos DC 1700 PM AQM provides a basis for the level of air quality in the study area. The air sampler, which is a low-cost AQM instrument used in this study does not only contribute to the body of knowledge on research on air quality in South St. Boniface, but it also provides scientific data for residents and local citizens on some of the pollution complaints raised by the residents of South St. Boniface. Also, this instrument and the air monitoring strategies I adopted in this study is an indication that with low-cost AQM, air pollution monitoring can be conducted. However, field data collection and data validation of particulate matter using Dylos AQM in Winnipeg by collocation with government ambient PM monitors could be explored in future research for $PM_{2.5}$ monitoring.

10.2 Analysis of Toxic Heavy Metals in Snowpack

Toxic heavy metals found in particulate matter emissions from industrial operations effectively analyzed in melted and acidified snow cover samples taken at the downwind $PM_{2.5}$ monitoring points of the recycling industry. The pollution indices using contamination factor, degree of contamination and pollution load index indicated high levels of heavy metals pollution in deposited snow cover for Winter 2018. Higher concentrations of lead (Pb), zinc (Zn) and nickel (Ni) were found in the snow cover samples from industrial, roadside and commercial sites above the values of background snow samples. Trace amounts of Mercury (Hg) were observed in the snow analysis of Industrial Metals Inc. that suggest possible presence of mercury switches in ELV fed into the scrap metal shredder hopper. The concentration of the eight heavy metals in the snow samples are in the order of Industrial>Roadside>Commercial>Residential indicating industry is the key source of the emissions followed by vehicular traffic, typically from wear and tears in vehicle components such as brake pads and exhaust emissions.

The major source of the heavy metals' concentrations observed in the snow samples of Mission and South St. Boniface originate from anthropogenic sources according to their distribution. Notably, a high contamination factor was measured for Pb, Zn and Ni in the snow samples of Industrial Metals Inc.'s property line. Observed Hg concentration solely at the scrap metal shredder fence-line suggests deposition of metallic dust and particles in snow cover. This conclusion was supported by the statistically significant strong positive correlation between Pb, Cd, Hg and Zn across the snow sampling sites in Mission Industrial Area and South St. Boniface.

Basically, analyzing toxic heavy metals in particulate matter is conducted through gravimetric analysis on a stacked filter units of an air sampler that traps particulates and laboratory analysis for trace elements analysis (Owoade et al., 2015; Loren et al., 2015; Ogundele et al., 2017). Similarly, elemental analysis of toxic heavy metals in snow pack has been widely studied as an indicator of atmospheric pollution and their subsequent accumulation and deposition in snow surface (Sakai et al., 1988. Elik, 2002; and Suidek et al., 2015). For the objective of this study, elemental analysis of heavy metals in snowpack was adopted as a cost-effective method in Mission Industrial Area and South St. Boniface. Toxic heavy metals concentration using pollution indices: contamination factor (cf), degree of contamination (cd) and pollution load index (PLI) revealed high pollution load of toxic heavy metals and this study suggests scrap metal recycling as the primary source.

Last, despite the small snow sample size of my study, my findings in snow agreed with the findings of Suidek et al. (2015) and PLI of heavy metals in $PM_{2.5}$ by Ogundele et al. (2017). Thus, my study proposed that toxic heavy metals analysis in snowpack is dependable for measuring the degree of air pollution, an accessible and cost-effective community based monitoring method that can be adopted in other industrial communities in Winnipeg.

10.3 Noise Monitoring in Mission Industrial and South St. Boniface

The noise survey in this study captured noise pollution levels from the operation of the scrap metal's auto shredder, ambient noise levels in residential areas and traffic-related noise. The industrial noise levels were measured outside the property line of the scrap metal shredder. A number of daytime ambient noise levels recorded exceeded the 55 dBA community noise guideline in the residential area. Episodic increased daytime noise levels were recorded by the sound level meter from intermittent sounds originating from scrap metal shredder operations with daytime north east wind direction. These episodic increase in noise levels pose non-auditory effects, including mental stress, annoyance and outdoor speech interference. Equally, increased outdoor noise levels in residential areas >55 dBA daytime community standards established by WHO and the City of Winnipeg were linked to increases in cortisol levels, blood pressure levels and blood vessels. Specifically, these noise health impacts were attributed to exposure to noise levels ranging from 55 to 60 dBA during daytime in residential areas (Sorensen et al., 2012).

The episodic peak noise levels recorded by the SLM ranges between 98 dBA to 120.1 dBA on neighboring properties beside the fence-line of the scrap metal shredder. These peak noise periods were characterized with loud explosions and metallic projectiles flying into neighboring properties, which may constitute a public hazard. Furthermore, the peak 120.1 dBA in this study exceeded EPA's 114 dBA for peak noise levels, which may increase one time individual's exposure and risk of noise induced hearing loss (Yao et al., 2017). The noise control strategy undertaken by Saxelby et al. (2012)

requires building noise enclosure on the scrap metal shredder hopper is recommended which can reduce the noise pollution level by 26 dBA on the nearest residential property.

The interpolated maps regarding noise, snowpack and emission show the impact of scrap metal shredding as the major cause of pollution in the study area. The heavy metals' concentration maps show Pb, Ni, Zn, Cr and Hg as toxic metals deposited on snowpack from dust and particulate emissions from scrap metal shredding operations. The monthly interpolated $PM_{2.5}$ maps show the localized emissions from the scrap metal recycling shredder had sporadic daytime exceedance levels (>19 and 27 $\mu g/m^3$) above the CAAQS for the poor air quality zone and threshold values of management action. The green patterns on the interpolated maps indicate the lower levels of $PM_{2.5}$ (< 10 $\mu g/m^3$) indicating good air quality in the residential area. Last, the noise maps visualize the industrial noise pollution in the study area, primarily the scrap metal shredder, which is characterized by emissions of sound pressure levels above the City of Winnipeg's guideline for neighbourhood liveability.

In summary, my study contributed to the increased awareness of local citizens in the South St. Boniface neighbourhood, Winnipeg, Manitoba. The data generated from the air and noise monitoring, snow heavy metals analysis and the spatial analysis of these data using GIS provide a scientific basis for the residents to understand pollution issues. The wind rose generated from the watchdog weather station provided residents information on the local meteorological factors; wind speed and wind direction that are crucial to the dispersion of air and propagation of noise pollution. The findings of this study will serve as an advocacy tool and influencing regulatory actions for South St. Boniface Residents' Association. Notably, the heavy metal pollution load in snowpack near scrap metal shredding property line, the frequent daily average exceedance of noise levels beyond scrap metal property lines and the episodic increase of ambient noise levels in the residential.

10.2 Recommendations

The results from this study revealed significant fine particulate matter, heavy metals and noise pollution from the automobile scrap shredder and scrap metal recycling operations in the Mission Industrial area, Winnipeg. To reduce levels the following are recommended:

1. Enforce engineering control measures required in the City of Winnipeg's noise bylaw standard; specifically, enclose the scrap metal shredder hopper in a sound proof building to reduce noise levels, projectiles and air pollution.
2. After implementing the above engineering control, review to assess whether it is adequate to reduce noise and air pollution from the industrial zone to minimize the environmental and health risks associated with particulates and air-bound heavy metals, as well as noise.
3. The high level of contamination factor reported for Pb, Ni, Zn, Mn and the presence of Hg in the vicinity of the scrap metal shredder demands further investigation into the operating and regulatory procedure of handling/recycling of scrap metals.
4. Future study of toxic heavy metals in Mission Industrial Area is required to identify other industrial operations that may contribute to high contamination and increase pollution load.
5. Regulatory enforcement to ensure compliance of industry by sorting and removal of tires from end-of-life vehicles which are the major source of high Zinc (Zn) contamination load.
6. Conduct a toxicological study of the neighbourhood to determine the impact in Mission Industrial Area.
7. Perform an epidemiology study of the South St. Boniface residence to see what impact this pollution is having on different diseases (e.g., cancer, asthma, COPD, etc.).

References

Ab Manan, N., Noor Aizuddin, A., & Hod, R. (2018). Effect of Air Pollution and Hospital Admission: A Systematic Review. Annals of Global Health, 84(4), 670–678. https://doi.org/10.29024/aogh.2376.

Agency for Toxic Substances and Disease Registry (2012). Public Health Statement for Cadmium. https://www.atsdr.cdc.gov/ToxProfiles/tp5-c1-b.pdf. Date Accessed: 27 May 2019.

Agency for Toxic Substances and Disease Registry (2012). Public Health Statement for Cadmium. https://www.atsdr.cdc.gov/ToxProfiles/tp5-c1-b.pdf. Date Accessed: 27 May 2019.

Air quality guidelines : global update 2005 : particulate matter, ozone, nitrogen dioxide and sulfur dioxide. (2006). Copenhagen, Denmark: World Health Organization. https://apps.who.int/iris/bitstream/handle/10665/69477/WHO_SDE_PHE_OEH_06.02_eng.pdf;jsessionid.

Air quality guidelines : global update 2005 : particulate matter, ozone, nitrogen dioxide and sulfur dioxide. (2006). Copenhagen, Denmark: World Health Organization. https://apps.who.int/iris/bitstream/handle/10665/69477/WHO_SDE_PHE_OEH_06.02_eng.pdf;jsessionid.

Akintuyi, A., Raji A, S., and Wunude, E. (2014). GIS-BASED ASSESSMENT AND MAPPING OF NOISE POLLUTION IN BARIGA AREA OF LAGOS STATE, NIGERIA. Sokoto Journal of the Social Sciences 4:1. : https://www.researchgate.net/publication/275034987.

Ana, G.R.E, Derek, G., Shendell, Brown, G. E., & Sridhar, M. K. C. (2009). Assessment of Noise and Associated Health Impacts at Selected Secondary Schools in Ibadan, Nigeria. *Journal of Environmental and Public Health, 2009*(2009), 186–191. https://doi.org/10.1155/2009/739502.

Anderson, R. (1981). Nutritional role of chromium. Science of the Total Environment, 17(1):13–29. https://doi.org/10.1016/0048-9697(81)90104-2.

Andreae, M. (1990). Biomass burning in the tropics: Impact on environmental quality and global climate. Population. Development Rev., 16:268–291.

Arshad, N., Hamzah, Z., Wood, A., Saat, A., & Alias, M. (2015). Determination of heavy metals concentrations in airborne particulates matter (APM) from Manjung district, Perak using energy dispersive X-ray fluorescence (EDXRF) spectrometer. In AIP Conference Proceedings (Vol. 1659). AIP Publishing LLC. https://doi.org/10.1063/1.4916878.

Atarodi, Z., Alinezhad, J., Amiri, R., Safari, Y., Yoosefpour, N., & Atarodi, Z. (2018). Data for atmospheric arsenic deposition: A case study- northeast of Iran. Data in Brief, 19, 660–664. https://doi.org/10.1016/j.dib.2018.05.119.

ATSDR (2005). Toxicological Profile for Nickel. Atlanta, GA: US Public Health Service, Agency for Toxic Substances and Disease Registry. Available online at https://www.atsdr.cdc.gov/toxprofiles/tp15.pdf. Date Accessed: 18 June 2019.

Aumond, P., Can, A., Mallet, V., De Coensel, B., Ribeiro, C. and Botteldooren, D. (2018). Kriging-based spatial interpolation from measurements for sound level mapping in urban areas. *The*

Journal of the Acoustical Society of America, *143*(5), 2847–2847. https://doi.org/10.1121/1.5034799.

Ayanlade, A., & Oyegbade, E. (2016). Influences of wind speed and direction on atmospheric particle concentrations and industrially induced noise. SpringerPlus, 5(1):1–13. https://doi.org/10.1186/s40064-016-3553-y.

Babbie, E.R. (2010). The Practice of Social Research. 12th ed. Belmont, CA: Wadsworth Cengage. https://libguides.usc.edu/writingguide/quantitative. Date accessed: 27 May 2019.

Babisch, W. (2011). Cardiovascular effects of noise. Noise and Health, 13(52), 201–204. https://doi.org/10.4103/1463-1741.80148.

Bari, M., & Kindzierski, W. (2016). Fine particulate matter ($PM_{2.5}$) in Edmonton, Canada: Source apportionment and potential risk for human health. *Environmental Pollution*, *218*, 219–229. https://doi.org/10.1016/j.envpol.2016.06.014

Basner, M. (2008). Nocturnal aircraft noise exposure increases objectively assessed daytime sleepiness. Somnologie - Schlafforschung Und Schlafmedizin, 12(2):110–117. https://doi.org/10.1007/s11818-008-0338-8.

Basner, M., & Basner, M. (2010). PRACTICAL GUIDANCE FOR RISK ASSESSMENT OF TRAFFIC NOISE EFFECTS ON SLEEP. Noise & Vibration Bulletin, 64–64. Retrieved from http://search.proquest.com/docview/753660807/.

Basner, M., Müller, U., Elmenhorst, E., & Basner, M. (2011). Single and combined effects of air, road, and rail traffic noise on sleep and recuperation. Sleep, 34(1), 11–23. https://doi.org/10.1093/sleep/34.1.11.

Basner, M., Babisch, W., Davis, A., Brink, M., Clark, C., Janssen, S., & Stansfeld, S. (2014). Auditory and non-auditory effects of noise on health. Lancet (London, England), 383(9925): 1325–1332. doi:10.1016/S0140-6736(13)61613-X.

Bell, R.W. & Hipfner, J.C. (1997). Airborne Hexavalent Chromium in Southwestern Ontario, Journal of the Air & Waste Management Association, 47:8, 905-910, https://doi.org/10.1080/10473289.1997.10464454.

Bennett, B.J. (1994). Environmental nickel pathways to man. In: Sunderman, F.W. Jr., ed. Nickel in the human environment. Lyon, International Agency for Research on Cancer, 487–495.

Berglund B., Lindvall T., Schwela, D.H. (1999). Guidelines for community noise. World Health Organization , Geneva, 1999. Available online at www.who.int. BS Enhttps://doi.org/10.1177/0143624406074468".

Berglund, Birgitta, Lindvall, Thomas, Schwela, Dietrich H & World Health Organization. Occupational and Environmental Health Team. (1999). Guidelines for community noise. World Health Organization. https://apps.who.int/iris/handle/10665/66217.

Bergman, M.M. (2008). Advances in Mixed Methods Research. Advances in Mixed Methods Research. London: SAGE Publications Ltd. https://doi.org/10.4135/9780857024329.

Bilaşco, Ş., Govor, C., Roşca, S., Vescan, I., Filip, S., & Fodorean, I. (2017). GIS model for identifying urban areas vulnerable to noise pollution: case study. *Frontiers of Earth Science*, *11*(2), 214–228. https://doi.org/10.1007/s11707-017-0615-6.

Brook, R.D., Rajagopalan, S., Pope Jr., C.A., Brook, J.R., Bhatnagar, A., Diez-Roux, A.V., Holguin, F., Hong, Y., Luepker, R.V., Mittleman, M.A., Peters, S.A., Siscovick, D., Smith Jr., S.C., Whitsel, I., Kaufman, J.D., 2010. Particulate matter air pollution and cardiovascular disease. An update to the scientific statement from the American Heart Association. Circulation 121, 2331–2378. http://dx.doi.org/10.1161/CIR.0b013e3181dbece1.

Cadelis, G., Tourres, R., and Molinie, J. (2014). Short-term effects of the particulate pollutants contained in Saharan dust on the visits of children to the emergency department due to asthmatic conditions in Guadeloupe (French Archipelago of the Caribbean). *PLoS One*. 2014;9(3):e91136. Published 2014 Mar 6. http://doi:10.1371/journal.pone.0091136.

Cakmak, S., Dales, R., Kauri, L., Mahmud, M., Van Ryswyk, K., Vanos, J., … Weichenthal, S. (2014). Metal composition of fine particulate air pollution and acute changes in cardiorespiratory physiology. Environmental Pollution, 189:208–214. https://doi.org/10.1016/j.envpol.2014.03.004.

Canadian Broadcasting Corporation, (2018). B.C. forest fire could impact Manitoba's air quality for the rest of August: Air quality advisories, burn bans remain in effect for southwestern Manitoba. Available online: https://www.cbc.ca/news/canada/manitoba/air-quality-manitoba-bc-forest-fires-1.4787412. Date Accessed: 17 August 2018.

Canadian Council Ministers of the Environment (CCME) (2014). Canadian Ambient Air Quality Standards. https://www.ccme.ca/en/current_priorities/air/caaqs.html. Date Accessed: 6 August, 2019.

Canadian Union of Public Employees (CUPE), (2006). What is Noise and Types of Noise? Available Online: https://cupe.ca/noise. Date Accessed: 24 September 2019.

Carling, G., Fernandez, D., & Johnson, W. (2012). Dust-mediated loading of trace and major elements to Wasatch Mountain snowpack. *Science of the Total Environment*, *432*, 65–77. https://doi.org/10.1016/j.scitotenv.2012.05.077.

Carvlin, G., Lugo, H., Olmedo, L., Bejarano, E., Wilkie, A., Meltzer, D., … Seto, E. (2017). Development and field validation of a community-engaged particulate matter air quality monitoring network in Imperial, California, USA. Journal of the Air & Waste Management Association, 67(12), 1342–1352. https://doi.org/10.1080/10962247.2017.1369471.

Cempel, M., Nikel, G., and Cempel, M. (2006). Nickel: A Review of Its Sources and Environmental Toxicology. Polish Journal of Environmental Studies, 15(3):375–382. Retrieved from http://search.proquest.com/docview/19290466/.

Centre for Disease Control, (2009). Cognitive Impairment: A Call for Action Now! Available online at: https://www.cdc.gov/aging/pdf/cognitive_impairment/cogimp_poilicy_final.pdf. Date Accessed: 28 July 2019.

Cereceda-Balic, F., Palomo-Marin, M.R., Bernalte, E., Vidal, V., Christie, J., Fadic, X., Guevara, J.L., Miro, C., and Pinilla, G. (2012). Impact of Santiago de Chile urban atmospheric pollution on anthropogenic trace elements enrichment in snow precipitation at Cerro Colorado, Central Andes. Atmospheric Environment. 47:51–57. https://doi:10.1016/j.atmosenv.2011.11.045.

Chan, W.H. and Lusis, M.A. (1986). Smelting operations and trace metals in air and precipitation in the Sudbury Basin. Advances in environmental science & technology, 17: 113–143.

Chen, T., He, J., Lu, X., She, J., & Guan, Z. (2016). Spatial and Temporal Variations of PM2.5 and Its Relation to Meteorological Factors in the Urban Area of Nanjing, China. *International journal of environmental research and public health*, *13*(9), 921. doi:10.3390/ijerph13090921.

Cheng, H., Zhou, T., Li, Q., Lu, L., & Lin, C. (2014). Anthropogenic Chromium Emissions in China from 1990 to 2009.(Research Article). PLoS ONE, 9(2). https://doi.org/10.1371/journal.pone.0087753.

Choi, Y-H., & Kim, K. (2014). Noise-Induced Hearing Loss in Korean Workers: Co-Exposure to Organic Solvents and Heavy Metals in Nationwide Industries. PLoS ONE 9(5):e97538. https://doi.org/10.1371/journal.pone.0097538.

Clark, C., Crombie, R., Head, J., van Kamp, I., van Kempen, E., & Stansfeld, S. (2012). Does Traffic-related Air Pollution Explain Associations of Aircraft and Road Traffic Noise Exposure on Children's Health and Cognition? A Secondary Analysis of the United Kingdom Sample From the RANCH Project. American Journal of Epidemiology, 176(4):327–337. https://doi.org/10.1093/aje/kws012.

Clements, A. L., Griswold, W. G., Rs, A., Johnston, J. E., Herting, M. M., Thorson, J., … Hannigan, M. (2017). Low-Cost Air Quality Monitoring Tools: From Research to Practice (A Workshop Summary). Sensors (Basel, Switzerland), 17(11), 2478. doi:10.3390/s17112478

Cohen, A., Brauer, M., Burnett, R., Anderson, H., Frostad, J., Estep, K., … Forouzanfar, M. (2017). Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. The Lancet, 389(10082), 1907–1918. https://doi.org/10.1016/S0140-6736(17)30505-6.

Cong, Z., Kang, S., Zhang, Y., & Li, X. (2010). Atmospheric wet deposition of trace elements to central Tibetan Plateau. Applied Geochemistry, 25(9):1415–1421. https://doi.org/10.1016/j.apgeochem.2010.06.011.

Dang-Vu, T., Mckinney, S., Buxton, O., Solet, J., & Ellenbogen, J. (2010). Spontaneous brain rhythms predict sleep stability in the face of noise. Current Biology, 20(15), R626–R627. https://doi.org/10.1016/j.cub.2010.06.032.

Das, R., Khezri, B., Srivastava, B., Datta, S., Sikdar, P., Webster, R., & Wang, X. (2015). Trace element composition of PM2.5 and PM10 from Kolkata – a heavily polluted Indian metropolis. Atmospheric Pollution Research, 6(5), 742–750. https://doi.org/10.5094/APR.2015.083.

Denkhaus, E., & Salnikow, K. (2002). Nickel essentiality, toxicity, and carcinogenicity. Critical Reviews in Oncology and Hematology, 42(1), 35–56. https://doi.org/10.1016/S1040-8428(01)00214-1.

Douglas, T.A., & Sturm, M. (2004). Arctic haze, mercury and the chemical composition of snow across northwestern Alaska. Atmospheric Environment. 38:805–820. httpsdoi:10.1016/j.atmosenv.2003.10.042.

Drew, K., Macfarlane, R., & Oiamo, T. (2017). *Environmental Noise Study in the City of Toronto* . Toronto, ON, CA: Toronto Public Health.

Dylos Corporation, (2019). DC1700-PM PM2.5/PM10 AQM. http://www.dylosproducts.com/dcpmaqm.html. Date Accessed: 14 May 2019.

Elmenhorst, E., Elmenhorst, D., Wenzel, J., Quehl, J., Mueller, U., Maass, H., … Basner, M. (2010). Effects of nocturnal aircraft noise on cognitive performance in the following morning: dose–response relationships in laboratory and field. International Archives of Occupational and Environmental Health, 83(7):743–751. https://doi.org/10.1007/s00420-010-0515-5.

English, P., Olmedo, L., Bejarano, E., Lugo, H., Murillo, E., Seto, E., … Northcross, A. (2017). The Imperial County Community Air Monitoring Network: a model for community-based environmental monitoring for public health action. (Brief Communication)(Report). Environmental Health Perspectives, 125(7):074501. https://doi.org/10.1289/EHP1772.

Enock, A.W. & Galcano, C.M. (2015). Noise Pollution Mapping Using GIS in Nairobi, Kenya. *Journal of Geographic Information System*, *7*(5):486–493. https://doi.org/10.4236/jgis.2015.75039.

Environment Canada (2013). National Pollutant Release Inventory Online Data Search - Facility Reported Data.

Environment Canada, (2014). Canadian Meteorological Centre Smoke Forecasting System: Firework 2014. Date Accessed: http://firesmoke.ca/national-forum/2014/08-Davignon-FireworkForecasting.pdf.

Envista Manitoba Air Quality (2018). Outdoor concentration of $PM_{2.5}$ in Winnipeg, Manitoba. https://web43.gov.mb.ca/EnvistaWeb/Default.ltr.aspx.

Eom, S. Y., Choi, J., Bae, S., Lim, J. A., Kim, G. B., Yu, S. D., … Kwon, H. J. (2018). Health effects of environmental pollution in population living near industrial complex areas in Korea. Environmental health and toxicology, 33(1), e2018004. doi:10.5620/eht.e2018004

Esri (2019). GIS Solutions for Environmental Management: Mapping Your Environmental Management Strategy. Retrieved 28 October 2019.

Evans, T. and Cooper, J. (2012). Influence of wind direction on noise emission and propagation from wind turbines. Australian Acoustical Society Conference Acoustics 2012, Acoustics, Development, and the Environment, 582–586.

Forbes, P.B.C. (2015). "Chapter 1: Perspectives on the Monitoring of Air Pollutants". In Barcelo, D. (ed.). Monitoring of Air Pollutants: Sampling, Sample Preparation and Analytical Techniques. Comprehensive Analytical Chemistry. 70. Elsevier. pp. 3–9. ISBN 9780444635532. Date Accessed: 31 May 2018.

Foresman, T. (1986). Mapping, monitoring, and modelling of hazardous waste sites. *Science of the Total Environment*, *56*(C):255–263. https://doi.org/10.1016/0048-9697(86)90330-X.

Fritschi L, Brown AL, Kim R, Schwela DH, Kephalopoulos S, (2011). Burden of disease from environmental noise. Bonn: World Health Organization.

Fung, K., Luginaah, I., & Gorey, K. (2007). Impact of air pollution on hospital admissions in Southwestern Ontario, Canada: generating hypotheses in sentinel high-exposure places. *Environmental Health : a Global Access Science Source*, *6*, 18.

Fuster, V. (2014). Global Burden of Cardiovascular Disease: Time to Implement Feasible Strategies and to Monitor Results. Journal of the American College of Cardiology, 64(5), 520–522. https://doi.org/10.1016/j.jacc.2014.06.1151.

Given, L.M. (2008). The SAGE Encyclopedia of Qualitative Research Methods. Los Angeles: SAGE Publications. ISBN 1-4129-4163-6.

Goines, L., Hagler, L., & Goines, L. (2007). Noise pollution: a modem plague. Southern Medical Journal, 100(3), 287–294. Retrieved from http://search.proquest.com/docview/70329220/.

Grannas, A.M. (2014). Encyclopedia of Snow, Ice and Glaciers. Springer, 138–139.

Grelat, N., Houot, H., Pujol, S., Levain, J., Defrance, J., Mariet, A., & Mauny, F. (2016). Noise Annoyance in Urban Children: A Cross-Sectional Population-Based Study. *International Journal of Environmental Research and Public Health*, *13*(11), 1–13. https://doi.org/10.3390/ijerph13111056.

Guo, H., Gu, X., Ma, G., Shi, S., Wang, W., Zuo, X. and Zhang, X. (2019). Spatial and temporal variations of air quality and six air pollutants in China during 2015–2017. *Scientific Reports*, *9*(1), 1–11. https://doi.org/10.1038/s41598-019-50655-6.

Gupta S, Satpati S, Saha RN, Nayek S (2013) Assessment of spatial and temporal variation of pollutants along a natural channel receiving industrial wastewater. International Journal of Environmental Engineering 5(1):52–69.

Gyr, S., & Grandjean, E. (1984). Industrial noise in residential areas: effects on residents. International Archives of Occupational and Environmental Health, 53(3):219–231. https://doi.org/10.1007/BF00398815.

Ha, H., Olson, J., Bian, L., & Rogerson, P. (2014). Analysis of heavy metal sources in soil using kriging interpolation on principal components. *Environmental Science & Technology*, *48*(9), 4999–5007. https://doi.org/10.1021/es405083f.

Halperin, D. (2014) "Environmental noise and sleep disturbances: A threat to health?." Sleep science (Sao Paulo, Brazil), 7(4):209-12. https://doi:10.1016/j.slsci.2014.11.003.

Han, I., Symanski, E., & Stock, T. (2017). Feasibility of using low-cost portable particle monitors for measurement of fine and coarse particulate matter in urban ambient air. Journal of the Air & Waste Management Association, 67(3), 330–340. https://doi.org/10.1080/10962247.2016.1241195.

Harding, A., Frost, G., Tan, E., Tsuchiya, A., & Mason, H. (2013). The cost of hypertension-related ill-health attributable to environmental noise. Noise and Health, 15(67):437–445. https://doi.org/10.4103/1463-1741.121253.

Hazelwood, K., Drake, P., Ashley, K., & Marcy, D. (2004). Field Method for the Determination of Insoluble or Total Hexavalent Chromium in Workplace Air. Journal of Occupational and Environmental Hygiene, 1(9):613–619. https://doi.org/10.1080/15459620490493810.

He, Z.L., Yang, X.E. and Stoffella, P.J. (2005). Trace elements in agroecosystems and impacts on the

Herawati, N., Suzuki, S., Hayashi, K., Rivai, I.F. and Koyoma, H. (2000). Cadmium, copper and zinc levels in rice and soil of Japan, Indonesia and China by soil type. Bulletin of Environmental Contamination and Toxicology. 64:33-39.

Hogan, C. Michael (2010). Heavy metal. Encyclopedia of Earth. National Council for Science and the Environment. E. Monosson and C. Cleveland (eds.). Washington DC.

Hongmei Xu, Steven Sai Hang Ho, Junji Cao, Benjamin Guinot, Haidong Kan, Zhenxing Shen, … Rujin Huang. (2017). A 10-year observation of PM2.5-bound nickel in Xi'an, China: Effects of source control on its trend and associated health risks. Scientific Reports, 7(1), 41132. https://doi.org/10.1038/srep41132.

Hrsak, J., Sega, K., Balăgović, I., & Hrsak, J. (2000). Lead, manganese, and cadmium content in PM10 and PM2.5 particle fractions--a pilot study. Arhiv Za Higijenu Rada i Toksikologiju, 51(2), 243–247. Retrieved from http://search.proquest.com/docview/72448383/

Hrsak, J., Sega, K., Balăgović, I., & Hrsak, J. (2000). Lead, manganese, and cadmium content in PM10 and PM2.5 particle fractions--a pilot study. Arhiv Za Higijenu Rada i Toksikologiju, 51(2), 243–247. Retrieved from http://search.proquest.com/docview/72448383/ https://www.cancer.gov/about-cancer/causes-prevention/risk/substances/nickel. Date accessed: 6 June 2019.

Huang, L., Yu, C. H., Hopke, P. K., Lioy, P. J., Buckley, B. T., Shin, J. Y., & Fan, Z. T. (2014). Measurement of Soluble and Total Hexavalent Chromium in the Ambient Airborne Particles in New Jersey. Aerosol and air quality research, 14(7):1939–1949. https://doi:10.4209/aaqr.2013.10.0312.

Hughes, M. F., Beck, B. D., Chen, Y., Lewis, A. S., & Thomas, D. J. (2011). Arsenic exposure and toxicology: a historical perspective. Toxicological sciences : an official journal of the Society of Toxicology, 123(2):305–332. http://doi:10.1093/toxsci/kfr184.

Hygge, S., Evans, G., & Bullinger, M. (2002). A Prospective Study of Some Effects of Aircraft Noise on Cognitive Performance in Schoolchildren. Psychological Science, 13(5), 469–474. https://doi.org/10.1111/1467-9280.00483.

IARC monographs on the evaluation of carcinogenic risk to human. 100C. Lyon: International Agency for Research on Cancer; 2012.

International Agency for Research on Cancer (2012). Nickel and Nickel Compounds, IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Volume 100C. Lyon, France: World Health Organization. https://monographs.iarc.fr/wp-content/uploads/2018/06/mono100C-10.pdf. Date accessed: February 15 2019.

International Agency for Research on Cancer; (2012). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, No. 100C. NICKEL AND NICKEL COMPOUNDS. Available from: https://www.ncbi.nlm.nih.gov/books/NBK304378/. Date Accessed:28 February 2019.

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., & Beeregowda, K. N. (2014). Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary toxicology*, *7*(2):60–72. httpsdoi:10.2478/intox-2014-0009.

Janssen, S., Dumont, G., Fierens, F., & Mensink, C. (2008). Spatial interpolation of air pollution measurements using CORINE land cover data. *Atmospheric Environment*, *42*(20), 4884–4903. https://doi.org/10.1016/j.atmosenv.2008.02.043.

Jenyo-Oni, A. & Oladele, A. (2016). Heavy Metals Assessment In Water, Sediments And Selected Aquatic Organisms In Lake Asejire, Nigeria. *European Scientific Journal*, *12*(24). https://doi.org/10.19044/esj.2016.v12n24p339.

Jiao, W., Hagler, G., Williams, R., Sharpe, R., Brown, R., Garver, D., … Buckley, K. (2016). Community Air Sensor Network (CAIRSENSE) project: evaluation of low-cost sensor performance in a suburban environment in the southeastern United States. Atmospheric Measurement Techniques, 9(11):5281–5292. https://doi.org/10.5194/amt-9-5281-2016.

Johnson, G., & Patil, G. (2001). Cost analysis of composite sampling for classification. Environmental and Ecological Statistics, 8(2), 91–107. https://doi.org/10.1023/A:1011374330176.

Johnston, F.H.; Webby, R.J.; Pilotto, L.S.; Bailie, R.S.; Parry, D.L.; Halpin, S.J. Vegetation fires, particulate air pollution and asthma: A panel study in the Australian monsoon tropics. Int. J. Environ. Health Res. 2006, 16, 391–404.

Kampa, M., & Castanas, E. (2008). Human health effects of air pollution. Environmental Pollution, 151(2):362–367. https://doi.org/10.1016/j.envpol.2007.06.012.

Kim, K., Shon, Z., Mauulida, P., and Song, S. (2014). Long-term monitoring of airborne nickel (Ni) pollution in association with some potential source processes in the urban environment. Chemosphere, 111:312–319. https://doi.org/10.1016/j.chemosphere.2014.03.138.

Kimbrough, D., Cohen, Y., Winer, A., Creelman, L., & Mabuni, C. (1999). A Critical Assessment of Chromium in the Environment. Critical Reviews in Environmental Science and Technology, 29(1):1–46. https://doi.org/10.1080/10643389991259164.

King, G., Roland-Mieszkowski, M., Jason, T., & Rainham, D. G. (2012). Noise levels associated with urban land use. *Journal of urban health : bulletin of the New York Academy of Medicine*, *89*(6), 1017–1030. doi:10.1007/s11524-012-9721-7.

Kitsa, V., Lioy, P., Chow, J., Watson, J., Shupack, S., Howell, T., & Sanders, P. (1992). Particle-Size Distribution of Chromium: Total and Hexavalent Chromium in Inspirable, Thoracic, and Respirable Soil Particles from Contaminated Sites in New Jersey. Aerosol Science and Technology, 17(3), 213–229. https://doi.org/10.1080/02786829208959572.

Komarnicki, G. (2005). Lead and cadmium in indoor air and the urban environment. Environmental Pollution, 136(1), 47–61. https://doi.org/10.1016/j.envpol.2004.12.006.

Kuoppamäki, K., Setälä, H., Rantalainen, A., & Kotze, D. (2014). Urban snow indicates pollution originating from road traffic. *Environmental Pollution*, *195*, 56–63. https://doi.org/10.1016/j.envpol.2014.08.019.

Laden, F., Neas, L.M., Dockery, D.W. and Schwartz, J. (2000). Association of fine particulate matter from different sources with daily mortality in six U.S. cities. Environ. Health Perspect. 108:941–947. doi:10.1289/ehp.00108941

Lancaster, V., & Keller-Mcnulty, S. (1998). A Review of Composite Sampling Methods. Journal of the American Statistical Association, 93(443), 1216–1230. https://doi.org/10.1080/01621459.1998.10473781.

Lawal, A. (2017). Air particulate matter induced oxidative stress and inflammation in cardiovascular disease and atherosclerosis: The role of Nrf2 and AhR-mediated pathways. Toxicology Letters, 270, 88–95. https://doi.org/10.1016/j.toxlet.2017.01.017.

Le, G., Breysse, P., Mcdermott, A., Eftim, S., Geyh, A., Berman, J., & Curriero, F. (2014). Canadian Forest Fires and the Effects of Long-Range Transboundary Air Pollution on Hospitalizations among the Elderly. *ISPRS International Journal of Geo-Information,* *3*(2), 713–731. https://doi.org/10.3390/ijgi3020713.

Le, T. N., Straatman, L. V., Lea, J., & Westerberg, B. (2017). Current insights in noise-induced hearing loss: a literature review of the underlying mechanism, pathophysiology, asymmetry, and management options. Journal of otolaryngology - head & neck surgery = Le Journal d'oto-rhino-laryngologie et de chirurgie cervico-faciale, 46(1):41. https://doi:10.1186/s40463-017-0219-x.

Lercher, P., Evans, G., & Meis, M. (2003). Ambient Noise and Cognitive Processes among Primary Schoolchildren. Environment and Behavior, 35(6): 725–735. https://doi.org/10.1177/0013916503256260.

Li, K., Liang, T., & Wang, L. (2016). Risk assessment of atmospheric heavy metals exposure in Baotou, a typical industrial city in northern China. *Environmental Geochemistry and Health*, *38*(3), 843–853. https://doi.org/10.1007/s10653-015-9765-1.

Lippmann, M., Ito, K., Hwang, J., Maciejczyk, P., & Chen, L. (2006). Cardiovascular effects of nickel in ambient air.(Research). Environmental Health Perspectives, 114(11):1662–1669. https://doi.org/10.1289/ehp.9150.

Liu, Z., Xie, M., Tian, K., & Gao, P. (2017). GIS-based analysis of population exposure to $PM_{2.5}$ air pollution—A case study of Beijing. *Journal of Environmental Sciences*, *59*:48–53. https://doi.org/10.1016/j.jes.2017.02.013.

Loranger, S., Tétrault, M., Kennedy, G. and Zayed, J. (1996). Manganese and other trace elements in urban snow near an expressway. Environmental Pollution. 1996;92:203–211. doi: 10.1016/0269-7491(95)00082-8.

Mackenzie, D., & Galbrun, L. (2007). Noise levels and noise sources in acute care hospital wards. Building Services Engineering Research & Technology, 28(2), 117–131. .

Mackenzie, D., & Galbrun, L. (2007). Noise levels and noise sources in acute care hospital wards. Building Services Engineering Research & Technology, 28(2), 117–131. .

Mann, E., Ranft, U., Eberwein, G., Gladtke, D., Sugiri, D., Behrendt, H., … Wilhelm, M. (2010). Does airborne nickel exposure induce nickel sensitization? Contact Dermatitis, 62(6), 355–362. https://doi.org/10.1111/j.1600-0536.2010.01725.x

Mäntysalo, S., & Vuori, J. (1984). Effects of impulse noise and continuous steady state noise on hearing. *British journal of industrial medicine*, *41*(1)122–132. doi:10.1136/oem.41.1.122.

Masindi, V. and Muedi, K.L. (2018). Environmental Contamination by Heavy Metals, Heavy Metals, Hosam El-Din M. Saleh and Refaat F. Aglan, IntechOpen, DOI: 10.5772/intechopen.76082. Available from: https://www.intechopen.com/books/heavy-metals/environmental-contamination-by-heavy-metals

Mcgrath, D., Zhang, C., & Carton, O. (2004). Geostatistical analyses and hazard assessment on soil lead in silvermines area, Ireland. *127*(2):239–248. Journal of Environmental Pollution, https://doi.org/10.1016/j.envpol.2003.07.002.

Morecambe Metals (2017). What are Ferrous and Non-Ferrous Metals? Available Online at: https://www.morecambemetals.co.uk/what-are-ferrous-metals-and-non-ferrous-metals/. Date Accessed: 1 January 2020.

Münzel, T., Gori, T., Babisch, W., & Basner, M. (2014). Cardiovascular effects of environmental noise exposure. European heart journal, 35(13):829–836. https://doi:10.1093/eurheartj/ehu030.

Muzet, A. (2007). Environmental noise, sleep and health. Sleep Medicine Reviews, 11(2), 135–142. https://doi.org/10.1016/j.smrv.2006.09.001.

National Cancer Institute (NCI) (2019). Nickel Compounds: Which cancers are associated with exposure to nickel and nickel compounds?

National Institute for Occupational Safety and Health (NIOSH). Report to Congress on Workers' Home Contamination Study Conducted Under The Workers' Family Protection Act (29 U.S.C. 671a) DHHS (NIOSH) Publication No. 95-123 [https://www.cdc.gov/niosh/docs/95-123/pdfs/95-123.pdfCdc-pdf(PDF 10.2 MB, 308 pages)] (1995).

Nazarenko, Y., Kurien, U., Nepotchatykh, O., Rangel-Alvarado, R., & Ariya, P. (2016). Role of snow and cold environment in the fate and effects of nanoparticles and select organic pollutants from gasoline engine exhaust. *Journal of Environmental Monitoring*, *18*(2), 190–199. https://doi.org/10.1039/c5em00616c.

NCM. (2003). Cadmium Review. Report No. 1, Issue No. 4. Nordic Council of Ministers, Copenhagen. 26 pp. Available at: http://www.who.int/ifcs/documents/forums/forum5/nmr_cadmium.pdf. Date Accessed: 4 July 5, 2019.

Noble, C., Vanderpool, R., Peters, T., Mcelroy, F., Gemmill, D., Wiener, R., & Noble, C. (2001). Federal Reference and Equivalent Methods for Measuring Fine Particulate Matter. Aerosol Science & Technology, 34(5), 457–464. Retrieved from http://search.proquest.com/docview/18573638/.

Nriagu, J. O.(1979). Global inventory of natural and anthropogenic emissions of trace metals to the atmosphere. Nature 279:409–411 (1979).

Nummi, E. (2015). Is Your Scrap Metal Contaminated with Mercury? Available online: https://www.thermofisher.com/blog/metals/is-your-scrap-metal-contaminated-with-mercury/. Date Accessed: 10 November, 2019.

Occupational Safety and Health Administration (2008). Guidance for the Identification and Control of Safety and Health Hazards in Metal Scrap Recycling. Available online: https://www.osha.gov/Publications/OSHA3348-metal-scrap-recycling.pdf.

Orellano, P., Quaranta, N., Reynoso, J., Balbi, B., Vasquez, J., & Orellano, P. (2017). Effect of outdoor air pollution on asthma exacerbations in children and adults: Systematic review and multilevel meta-analysis. PloS One, 12(3), e0174050–e0174050. https://doi.org/10.1371/journal.pone.0174050.

Ovadnevaite, J.; Kvietkus, K.; Marsalka, A. (2006). 2002 summer fires in Lithuania: Impact on the Vilnius city air quality and the inhabitants health. Sci. Total Environ. 356:11–21.

Oyedepo, S.O., Adeyemi, G.A., Olawole, O.C., Ohijeagbon, O.I., Fagbemi, O.K. et al., (2019). A GIS–based method for assessment and mapping of noise pollution in Ota metropolis, Nigeria. MethodsX, 6:447-457. https://doi.org/10.1016/j.mex.2019.02.027.

Passchier-Vermeer, W., Passchier, W., Gezondheidsrisico Analyse en Toxicologie, & RS: NUTRIM School of Nutrition and Translational Research in Metabolism. (2000). Noise exposure and public health. Environmental Health Perspectives, 108(s1), 123–131. https://doi.org/10.1289/ehp.00108s1123.

Pei, Y., Jiang, R., Zou, Y., Wang, Y., Zhang, S., Wang, G., … Song, W. (2016). Effects of Fine Particulate Matter (PM2.5) on Systemic Oxidative Stress and Cardiac Function in ApoE(-/-) Mice. *International journal of environmental research and public health*, *13*(5), 484. doi:10.3390/ijerph13050484.

Pobi, K., Satpati, S., Dutta, S., Nayek, S., Saha, R., & Gupta, S. (2019). Sources evaluation and ecological risk assessment of heavy metals accumulated within a natural stream of Durgapur industrial zone, India, by using multivariate analysis and pollution indices. *Applied Water Science*, *9*(3):1–16. https://doi.org/10.1007/s13201-019-0946-4.

Ragettli, M.S., Goudreau, S., Plante, C., Perron, S., Fournier, M., and Smargiassi, A. (2016). Annoyance from road traffic, trains, airplanes and from total environmental noise levels. International Journal of Environmental Research Public Health, 13:90.

Rani, A., Kumar, A., Lal, A. and Pant, M. (2014). Cellular mechanisms of cadmium-induced toxicity: a review. International Journal of Environmental Health Research 24: 378-399.

Recio, A., Linares, C., Banegas, J., & Díaz, J. (2016). The short-term association of road traffic noise with cardiovascular, respiratory, and diabetes-related mortality. Environmental Research, 150, 383–390. https://doi.org/10.1016/j.envres.2016.06.014.

Ridgway, J., & Shimmield, G. (2002). Estuaries as Repositories of Historical Contamination and their Impact on Shelf Seas. *Estuarine, Coastal and Shelf Science*, *55*(6):903–928. https://doi.org/10.1006/ecss.2002.1035.

Rückerl, R.; Schneider, A.; Breitner, S.; Cyrys, J.; Peters, A. Health effects of particulate air pollution: A review of epidemiological evidence. Inhal. Toxicol. 2011, 23, 555–592.

Ryu, H., Park, I.K., Chun, BS, and Chang SI (2017). Spatial statistical analysis of the effects of urban form indicators on road-traffic noise exposure of a city in South Korea. Applied Acoustic, 115:93–100.

Sapkota, A., Symons, J., Kleissl, J., Wang, L., Parlange, M., Ondov, J., … Sapkota, A. (2005). Impact of the 2002 Canadian forest fires on particulate matter air quality in Baltimore city. *Environmental Science & Technology*, *39*(1), 24–32. https://doi.org/10.1021/es035311z.

Saxelby, L.A. (2012). Noise Control for a Metal Shredder and Recycling System. j.c. brennan & associates, Inc., Auburn, California. Available Online: http://sandv.com/downloads/1208saxe.pdf Date Accessed: 24 September 2019.

Scientific Opinion on the risks to public health related to the presence of chromium in food and drinking water. (2014). EFSA Journal, 12(3), n/a–n/a. https://doi.org/10.2903/j.efsa.2014.3595.

Seidler, A., Wagner, M., Schubert, M., Dröge, P., Pons-Kühnemann, J., Swart, E., … Seidler, A. (2016). Myocardial Infarction Risk Due to Aircraft, Road, and Rail Traffic Noise. Deutsches Arzteblatt International, 113(24):407–414. https://doi.org/10.3238/arztebl.2016.0407.

Seidman, M. D., & Standring, R. T. (2010). Noise and quality of life. International journal of environmental research and public health, 7(10):3730–3738. https://doi:10.3390/ijerph7103730.

Sharp, D. (2010). Noisy Days, Noisy Nights. Journal of Urban Health: Bulletin of the New York Academy of Medicine.

Shevchenko, V., Pokrovsky, O., Vorobyev, S., Krickov, I., Manasypov, R., Politova, N., … Kirpotin, S. (2017). Impact of snow deposition on major and trace element concentrations and elementary fluxes in surface waters of the Western Siberian Lowland across a 1700 km latitudinal gradient.(Report)(Author abstract). *Hydrology and Earth System Sciences*, *21*(11), 5725–5746. https://doi.org/10.5194/hess-21-5725-2017.

Singh, J., & Lee, B. (2016). Kinetics and extraction of heavy metals resources from automobile shredder residue. *Process Safety and Environmental Protection*, *99*, 69–79. https://doi.org/10.1016/j.psep.2015.10.010.

Smolders, E., & Degryse, F. (2002). Fate and effect of zinc from tire debris in soil. Environmental Science & Technology, 36, 3706–3710.O'Dell, K., Ford, B., Fischer, E., & Pierce, J. (2019). Contribution of Wildland-Fire Smoke to US PM and Its Influence on Recent Trends. *Environmental Science & Technology*, *53*(4), 1797–1804. https://doi.org/10.1021/acs.est.8b05430.

Sofowote, U., & Dempsey, F. (2015). Impacts of forest fires on ambient near–real–time $PM_{2.5}$ in Ontario, Canada: Meteorological analyses and source apportionment of the July 2011–2013 episodes. *Atmospheric Pollution Research*, *6*(1), 1–10. https://doi.org/10.5094/APR.2015.001.

Sørensen, M., Hvidberg, M., Andersen, Z., Nordsborg, R., Lillelund, K., Jakobsen, J., … Raaschou-Nielsen, O. (2011). Road traffic noise and stroke: a prospective cohort study. European Heart Journal, 32(6):737–744. https://doi.org/10.1093/eurheartj/ehq466.

Siudek, P., Frankowski, M., & Siepak, J. (2015). Trace element distribution in the snow cover from an urban area in central Poland. *Environmental monitoring and assessment*, *187*(5), 225. doi:10.1007/s10661-015-4446-1.

Sutherland, E.; Make, B.; Vedal, S.; Zhang, L.; Dutton, S.; Murphy, J.; Silkoff, P.E. Wildfire smoke and respiratory symptoms in patients with chronic obstructive pulmonary disease. J. Allergy Clin. Immunol. 2005, 115, 420–422.

Suttie, E., & Wolff, E. (1993). The local deposition of heavy metal emissions from point sources in Antarctica. *Atmospheric Environment Part A, General Topics*, *27*(12), 1833–1841. https://doi.org/10.1016/0960-1686(93)90288-A.

Szalma, J., & Hancock, P. (2011). Noise Effects on Human Performance: A Meta-Analytic Synthesis. Psychological Bulletin, 137(4):682–707. https://doi.org/10.1037/a0023987.

Tchepel, O., Costa, A., Martins, H., Ferreira, J., Monteiro, A., Miranda, A., & Borrego, C. (2010). Determination of background concentrations for air quality models using spectral analysis and filtering of monitoring data. Atmospheric Environment, 44(1), 106–114. https://doi.org/10.1016/j.atmosenv.2009.08.038

Telloli, C., & Telloli, C. (2014). Metal Concentrations in Snow Samples in an Urban Area in the Po Valley. *International Journal of Geosciences*, *5*(10):1116–1116. https://doi.org/10.4236/ijg.2014.510095.

Terre, L. (2014). Clinical Implications of Impaired Sleep. American Journal of Lifestyle Medicine, 8(6):352–370. https://doi.org/10.1177/1559827614521955.

Tian, H., Cheng, K., Wang, Y., Zhao, D., Lu, L., Jia, W., & Hao, J. (2012). Temporal and spatial variation characteristics of atmospheric emissions of Cd, Cr, and Pb from coal in China. Atmospheric Environment, 50(C):157–163. https://doi.org/10.1016/j.atmosenv.2011.12.045.

Tirez, K., Vanhoof, C., Peters, J., Geerts, L., Bleux, N., Adriaenssens, E., … Berghmans, P. (2015). Speciation of inorganic arsenic in particulate matter by combining HPLC/ICP-MS and XANES analyses. Journal of Analytical Atomic Spectrometry, 30(10):2074–2088. https://doi.org/10.1039/c5ja00105f.

Tomlinson, D., Wilson, J., Harris, C., & Jeffrey, D. (1980). Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. *Helgoländer Meeresuntersuchungen*, *33*(1-4):566–575. https://doi.org/10.1007/BF02414780.

Toronto Public Health, (2015). Pollution Prevention Program for Metal Finishing. Prepared for Toronto Public Health by Rubidium Environmental. Available online at https://www.toronto.ca/wp-content/uploads/2018/04/863f-P2-Program-Coating-Engraving_Final-Public.pdf. Date Accessed: 23 July 2019.

U.S. Department of Health and Human Services [2007] Toxicological profile for Lead (update) [http://www.atsdr.cdc.gov/toxprofiles/tp13.pdfCdc-pdf(PDF 4901KB, 582 pages)] Public Health Service Agency for Toxic Substances and Disease Registry.

U.S. Environmental Protection Agency (US EPA). 1997. Guidance for Network Design and Optimum Site Exposure for PM2.5 and PM10. Office of Air Quality Planning and Standards, December 1997. www.epa.gov/ttnamti1/files/ambient/pm25/network/r-99-022.pdf. Date Accessed: 20 May 2019.

United State Environmental Protection Agency (2018). Particulate Matter Pollution: What is PM and how does it get into the air? Available online at: https://www.epa.gov/pm-pollution/particulate-matter-pm-basics. Date Accessed: 14 February 2019.

United State Environmental Protection Agency, (1984). Locating and Estimating Air Emissions from Sources of Chromium. Office of Air and Radiation Office of Air Quality Planning and Standards Research Triangle Park, North Carolina, NC 27711. Available online https://www3.epa.gov/ttn/chief/le/chromium.pdf. Date Accessed: 17 June 2019.

Urman, R., Habre, R., Fruin, S., Gauderman, J., Lurmann, F., Gilliland, F., and Mcconnell, R. (2016). B15 HEALTH EFFECTS OF INDOOR/OUTDOOR POLLUTION IN CHILDHOOD: Exposure To Transition Metals In Particulate Matter Air Pollution And Children's Lung Function In The Southern California Children's Health Study. American Journal of Respiratory and Critical Care Medicine, 193, 1. Retrieved from http://search.proquest.com/docview/1862907483/.

USEPA (2009). Assessing the Management of Lead in Scrap Metal and Electric Arc Furnace Dust. U.S. Environmental Protection Agency Office of Resource Conservation and Recovery. Available online: https://archive.epa.gov/epawaste/hazard/wastemin/web/pdf/lead-2.pdf. Date Accessed: 2 November 2019.

Vasić, M.V., Mihailović, A., Kozmidis-Luburić, U., Nemes, T., Ninkov, J., Zeremski-Škorić, T. and Antić B. (2012). Metal contamination of short-term snow cover near urban crossroad: correlation analysis of metal content and fine particles distribution. Chemosphere. 86:585–592. https://doi:10.1016/j.chemosphere.2011.10.023.

Wang, Y., Li, J., Jing, H., Zhang, Q., Jiang, J., & Biswas, P. (2015). Laboratory Evaluation and Calibration of Three Low-Cost Particle Sensors for Particulate Matter Measurement. Aerosol Science and Technology, 49(11), 1063–1077. https://doi.org/10.1080/02786826.2015.1100710.

Watson, J., Chow, J., Chen, L., Wang, X., Merrifield, T., Fine, P., & Barker, K. (2011). Measurement system evaluation for upwind/downwind sampling of fugitive dust emissions. Aerosol and Air Quality Research, 11(4), 331–350. https://doi.org/10.4209/aaqr.2011.03.0028.

Werner, M.L., Nico, P.S., Marcus, M.A. & Anastasio, C. (2007). Use of micro-XANES to speciate chromium in airborne fine particles in the Sacramento Valley. Environmental Science and Technology, 41(14), 4919–4924. https://doi.org/10.1021/es070430q.

WHO (2007). Nickel in Drinking Water. WHO/SDE/WSH/07.08/55. Geneva: World Health Organization. Available on https://www.who.int/water_sanitation_health/dwq/chemicals/Nickel110805.pdf. Date Accessed: 30 June 2019.

WHO. World Health Organization (2000). Air quality guidelines for Europe. European series. 91:2nd edition. WHO Regional Publications. http://www.euro.who.int/__data/assets/pdf_file/0005/74732/E71922.pdf. Date Accessed: 24 May 2019.

Wiseman, C.L. and Zereini, F. (2009). Airborne particulate matter, platinum group elements and human health: a review of recent evidence. The Science of the total environment, 407(8):2493-500.

Witham, C. (2005). Volcanic disasters and incidents: A new database. Journal of Volcanology and Geothermal Research, 148(3-4), 191–233. https://doi.org/10.1016/j.jvolgeores.2005.04.017.

Wolff, E.W. and Peel, D.A. (1988). CONCENTRATIONS OF CADMIUM. COPPER. LEAD AND ZINC IN SNOW FROM NEAR DYE 3 IN SOUTH GREENLAND. Annals of Glaciology 7: 61-69. https://doi.org/10.3189/S0260305500004420.

Wong, S., Coates, A., & To, T. (2016). Exposure to industrial air pollutant emissions and lung function in children: Canadian Health Measures Survey, 2007 to 2011.(Research Article)(Report). Health Reports, 27(2):3–9.

World Health Organization (2011). Burden of disease from environmental noise. WHO Regional Office of Europe. Available online at: http://www.euro.who.int/__data/assets/pdf_file/0008/136466/e94888.pdf. Date Accessed: 9 August 2019.

World Health Organization (2019). Lead Poisoning and Health. Available online: https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health, Date Accessed: 2 November 2019.

World Health Organization (WHO) Europe (2018). ENVIRONMENTAL NOISE GUIDELINES for the European Region. http://www.euro.who.int/__data/assets/pdf_file/0008/383921/noise-guidelines-eng.pdf?ua=1. Date Accessed: 22 September 2019

World Health Organization. (2017). Cardiovascular diseases (CVDs). Retrieved from http://www.who.int/mediacentre/factsheets/fs317/en/. Date Accessed: 9 August 2019.

Yao, C., Ma, A., Cushing, S., & Lin, V. (2017). Noise exposure while commuting in Toronto - a study of personal and public transportation in Toronto. *Journal of Otolaryngology - Head & Neck Surgery*, *46*(1), 1–8. https://doi.org/10.1186/s40463-017-0239-6.

Yong Yang, Yang Mei, Chutian Zhang, Ruoxi Zhang, Xiangshen Liao & Yinyin Liu (2016) Heavy metal contamination in surface soils of the industrial district of Wuhan, China, Human and Ecological Risk Assessment: An International Journal, 22:1, 126-140, DOI: 10.1080/10807039.2015.1056291.

Yu, C. H., Huang, L., Shin, J. Y., Artigas, F., & Fan, Z. H. (2014). Characterization of concentration, particle size distribution, and contributing factors to ambient hexavalent chromium in an area with multiple emission sources. Atmospheric environment (Oxford, England : 1994), 94:701–708. https://doi:10.1016/j.atmosenv.2014.06.004.

Zamani, A. A., Yaftian, M. R., & Parizanganeh, A. (2012). Multivariate statistical assessment of heavy metal pollution sources of groundwater around a lead and zinc plant. *Iranian journal of environmental health science & engineering*, *9*(1),29. https://doi:10.1186/1735-2746-9-29.

Ziegel, E. (2001). Geostatistics for Environmental Scientists. *Technometrics*, 499. Retrieved from http://search.proquest.com/docview/213690505/.

Appendix A:

Primary data of respirable particulate matter ($PM_{2.5}$), images of data collection procedure and mass concentration reading.

Figure 1: Dylos DC 1700 Air Quality Monitor for Particulate Matter Measuring Downwind PM2.5 Emissions During Scrap Metal Shredding.

Figure 2: Residential Monitoring of Ambient $PM_{2.5}$ Levels in Dufresne Avenue, South St. Boniface.

Date	**Time**	**Longitude**	**Latitude**	**PM2.5 ug/m3**	**Location**
15-Jun-18	09:00 - 10:00	-97.1034	49.8855	1.813525334	Residential
15-Jun-18	10:00 - 11:00	-97.10437	49.88522	1.845259828	Residential
15-Jun-18	11:01 - 12:00	-97.10265	49.88561	4.285786433	Residential
15-Jun-18	12:01 - 1:00	-97.10177	49.88506	3.921866243	Residential
15-Jun-18	1:01 - 2:00	-97.10304	49.88567	4.102473695	Residential

15-Jun-18	2:01 - 3:00	-97.10356	49.88544	3.85931898	Residential
15-Jun-18	3:01 - 4:00	-97.10481	49.88509	4.095124049	Residential
18-Jun-18	10:34 - 11:31	-97.10346	49.88403	6.088125057	Residential
18-Jun-18	11:39 - 12:38	-97.10299	49.88366	4.73468101	Residential
18-Jun-18	12:43 - 1:41	-97.10307	49.88403	4.351102956	Residential
18-Jun-18	1:47 - 2:46	-97.10249	49.88402	3.937209299	Residential
18-Jun-18	2:51 - 3:59	-97.10132	49.88403	3.369764663	Residential
27-Jun-18	9:17 - 10:15	-97.10162	49.88429	2.885808268	Residential
27-Jun-18	10:21 - 11:20	-97.09938	49.88478	3.712544228	Residential
27-Jun-18	11:26 - 12:24	-97.10347	49.88483	4.239063504	Residential
27-Jun-18	12:39 - 1:34	-97.10135	49.88427	3.779860443	Residential

27-Jun-18	1:52 - 2:51	-97.10173	49.88427	3.395540487	Residential
27-Jun-18	3:07 - 4:08	-97.1033	49.88482	3.668484342	Residential
13-Jun-18	10:27 -11:26	-97.09777	49.88942	10.0134552	Industrial
13-Jun-18	11:27 - 12:26	-97.09777	49.88942	9.585658644	Industrial
13-Jun-18	12:27 - 1:26	-97.09801	49.88999	10.23833252	Industrial
13-Jun-18	1:27 - 2:26	-97.09801	49.88999	10.72963191	Industrial
13-Jun-18	2:27 - 3:26	-97.09706	49.88917	13.20508358	Industrial
14-Jun-18	10:22 - 11:21	-97.0991	49.8909	7.31438645	Industrial
14-Jun-18	11:22 - 12:21	-97.0991	49.8909	4.487478976	Industrial
14-Jun-18	12:22 - 1:21	-97.09902	49.89088	3.998662511	Industrial
14-Jun-18	1:22 - 2:21	-97.0991	49.8909	5.200039343	Industrial

14-Jun-18	2:22 - 3:21	-97.09826	49.89107	5.507500316	Industrial
21-Jun-18	10:32 - 11:31	-97.09898	49.89058	8.272485703	Industrial
21-Jun-18	11:32 -12:31	-97.09898	49.89058	7.310107405	Industrial
21-Jun-18	12:32 - 1:31	-97.09991	49.8904	25.00147001	Industrial
21-Jun-18	1:32 - 2:31	-97.09971	49.89059	16.63693141	Industrial
21-Jun-18	2:32 - 3:30	-97.10045	49.89025	10.96488049	Industrial
26-Jun-18	10:34 - 11:33	-97.09898	49.89058	14.41632455	Industrial
26-Jun-18	11:34 - 12:33	-97.097163	49.889195	7.606519425	Industrial
26-Jun-18	12:34 - 1:33	-97.098985	49.890553	13.82283892	Industrial
26-Jun-18	1:34 - 2:33	-97.09991	49.8904	25.58589166	Industrial
26-Jun-18	2:34 - 3:38	-97.09971	49.89059	11.25843967	Industrial

28-Jun-18	9:36 - 10:35	-97.09626	49.8875	4.26672676	Industrial
28-Jun-18	10:36 - 11:35	-97.09735	49.88835	3.342543238	Industrial
28-Jun-18	11:36 - 12:35	-97.09706	49.88795	8.364232127	Industrial
28-Jun-18	12:36 - 1:35	-97.09705	49.88763	3.950515895	Industrial
28-Jun-18	1:36 - 2:06	-97.09711	49.88604	5.95689603	Industrial

Date	**Time**	**Longitude**	**Latitude**	**PM2.5ug/m3**	**Location**
03-Jul-18	10:13 - 11:12	-97.09991	49.88748	10.15035852	Industrial
03-Jul-18	11:13 - 12:12	-97.09991	49.88748	14.27907102	Industrial
03-Jul-18	12:13 - 1:12	-97.09991	49.88748	9.699722122	Industrial
03-Jul-18	1:13 - 2:12	-97.09991	49.88748	10.46974914	Industrial
03-Jul-18	2:13 - 3:12	-97.09991	49.88748	6.829212702	Industrial
03-Jul-18	3:13 - 3:55	-97.09991	49.88748	3.862573099	Industrial

16-Jul-18	08:55 - 09:55	-97.097	49.88779	14.63287234	Industrial
16-Jul-18	09:56 - 10:55	-97.097	49.88779	19.0191803	Industrial
16-Jul-18	10:56 - 11:55	-97.097	49.88779	8.549665395	Industrial
16-Jul-18	11:56 - 12:55	-97.097	49.88779	11.28240467	Industrial
16-Jul-18	12:56 - 01:55	-97.097	49.88779	16.64248968	Industrial
16-Jul-18	01:56 - 02:55	-97.097	49.88779	32.03633226	Industrial
16-Jul-18	02:56 - 03:55	-97.097	49.88779	14.54693735	Industrial
17-Jul-18	9:00 - 9:59	-97.099671	49.886959	1.269584054	Industrial
17-Jul-18	10:00 - 10:59	-97.099671	49.886959	1.185691077	Industrial
17-Jul-18	11:00 - 11:59	-97.099671	49.886959	1.941959268	Industrial
17-Jul-18	12:00 - 12:59	-97.099671	49.886959	1.645917734	Industrial
17-Jul-18	1:00 - 1:59	-97.099671	49.886959	1.634226533	Industrial
17-Jul-18	2:00 - 2:42	-97.099671	49.886959	3.51204142	Industrial

23-Jul-18	9:56-10:55	-97.09744	49.88854	12.72918793	Industrial
23-Jul-18	10:56-11:55	-97.09744	49.88854	25.77638732	Industrial
23-Jul-18	11:56-12:55	-97.09744	49.88854	32.49402765	Industrial
23-Jul-18	12:56-1:55	-97.09744	49.88854	36.01305873	Industrial
23-Jul-18	1:56-2:55	-97.09744	49.88854	30.82069549	Industrial
23-Jul-18	2:56-4:11	-97.09744	49.88854	14.49996462	Industrial
24-Jul-18	8:48-9:47	-97.096879	49.887706	16.71280554	Industrial
24-Jul-18	9:48-10:47	-97.096879	49.887706	14.46970667	Industrial
24-Jul-18	10:48-11:47	-97.096879	49.887706	1.090849217	Industrial
24-Jul-18	11:48-12:47	-97.096879	49.887706	17.56031398	Industrial
24-Jul-18	12:48-1:47	-97.096879	49.887706	26.863996	Industrial
24-Jul-18	1:48-2:47	-97.096879	49.887706	33.06184977	Industrial
24-Jul-18	2:48-3:47	-97.096879	49.887706	32.63342219	Industrial
24-Jul-18	3:48-4:27	-97.096879	49.887706	20.5671322	Industrial
30-Jul-18	9:06 - 10:05	-97.097811	49.889217	18.528494	Industrial
30-Jul-18	10:06-11:05	-97.097811	49.889217	14.31142403	Industrial
30-Jul-18	11:06 - 12:05	-97.097811	49.889217	21.7203762	Industrial
30-Jul-18	12:06 - 01:05	-97.097811	49.889217	14.65328489	Industrial
30-Jul-18	01:06 - 02:05	-97.097811	49.889217	13.68080581	Industrial

30-Jul-18	02:06 - 03:05	-97.097811	49.889217	10.95375784	Industrial
30-Jul-18	03:06 - 04:05	-97.097811	49.889217	7.183418576	Industrial
05-Jul-18	09:00 - 10:00	-97.10346	49.88403	3.780710052	Residential
05-Jul-18	10:00 - 11:00	-97.10299	49.88366	2.966201902	Residential
05-Jul-18	11:00 - 12:00	-97.10307	49.88403	3.344200684	Residential
05-Jul-18	12:00 - 01:00	-97.10249	49.88402	2.835985896	Residential
05-Jul-18	01:00 - 02:00	-97.10132	49.88403	2.622149863	Residential
05-Jul-18	02:00 - 03:00	-97.10126	49.88368	2.646039641	Residential
06-Jul-18	9:06 - 10:05	-97.1034	49.8855	1.475699572	Residential
06-Jul-18	10:06 - 11:05	-97.10437	49.88522	1.039878442	Residential
06-Jul-18	11:06 - 12:05	-97.10265	49.88561	0.96306588	Residential
06-Jul-18	12:06 - 1:05	-97.10177	49.88506	1.048568524	Residential
06-Jul-18	1:06 - 2:08	-97.10304	49.88567	1.171319034	Residential

11-Jul-18	10:24 - 11:23	-97.10232	49.88322	2.900169943	Residential
11-Jul-18	11:24 - 12:23	-97.1015	49.88282	3.265267118	Residential
11-Jul-18	12:24 - 1:23	-97.10119	49.88266	5.080541445	Residential
11-Jul-18	1:24 - 2:23	-97.10119	49.88266	6.255203187	Residential
11-Jul-18	2:24 - 3:26	-97.1007	49.88274	4.411041616	Residential
12-Jul-18	9:30 - 10:27	-97.10162	49.88429	4.085125913	Residential
12-Jul-18	10:31 - 11:26	-97.09938	49.88478	3.119602766	Residential
12-Jul-18	11:39 - 12:36	-97.10347	49.88483	3.890632483	Residential
12-Jul-18	12:49 - 1:46	-97.10381	49.88153	2.678913813	Residential
12-Jul-18	1:50 - 2:45	-97.10173	49.88427	3.508539156	Residential
12-Jul-18	2:53 - 4:06	-97.1033	49.88482	2.674366386	Residential
13-Jul-18	9:20 - 10:18	-97.1034	49.8855	4.35361614	Residential
13-Jul-18	10:23 - 11:19	-97.1044	49.8852	3.269120827	Residential
13-Jul-18	11:27 - 12:22	-97.1027	49.8856	3.21222662	Residential
13-Jul-18	12:27 - 1:24	-97.1018	49.8851	2.899060938	Residential
13-Jul-18	1:29 - 2:25	-97.103	49.8857	2.410152882	Residential
13-Jul-18	2:32 - 3:44	-97.1036	49.8854	1.873083048	Residential

18-Jul-18	8:51 - 9:52	-97.1044	49.8852	5.678604024	Residential
18-Jul-18	9:55 - 10:53	-97.1016	49.8851	4.38517584	Residential
18-Jul-18	10:59 - 11:57	-97.1036	49.8856	4.002218953	Residential
18-Jul-18	12:04 - 1:01	-97.1027	49.8856	3.04207143	Residential
18-Jul-18	1:05 - 2:04	-97.1018	49.8851	3.251722958	Residential
18-Jul-18	2:05 - 3:01	-97.1033	49.8855	4.306099022	Residential
18-Jul-18	3:10 - 4:04	-97.10161	49.88566	3.621471473	Residential
19-Jul-18	8:51-9:49	-97.10346	49.88403	4.339663828	Residential
19-Jul-18	9:53-10:50	-97.10299	49.88366	4.783904465	Residential
19-Jul-18	10:54-11:49	-97.10307	49.88403	3.978840441	Residential
19-Jul-18	12:05-1:04	-97.10249	49.88402	4.645817008	Residential
19-Jul-18	1:05-1:59	-97.10132	49.88403	4.449577834	Residential
19-Jul-18	2:12-3:11	-97.10126	49.88368	4.745680888	Residential
19-Jul-18	3:12-4:02	-97.10073	49.88402	4.804379998	Residential

Date	Time	Site Name	Longitude	Latitude	PM2.5ug/m3	Location
03-Aug-18	10:00 - 11:00	Doucet	-97.1023	49.88322	1.755229849	Residential
03-Aug-18	11:00 - 12:00	Doucet	-97.1015	49.88282	3.0958439	Residential
03-Aug-18	12:00 - 01:00	Doucet	-97.1012	49.88266	3.395830342	Residential
03-Aug-18	01:00 - 02:00	Doucet	-97.1012	49.88266	3.425260099	Residential
03-Aug-18	02:00 - 03:00	Doucet	-97.1007	49.88274	3.447095861	Residential
03-Aug-18	03:00 - 04:00	Doucet	-97.1025	49.88327	4.020619416	Residential

09-Aug-18	09:00 - 10:00	Giroux	-97.1016	49.88429	4.970773692	Residential
09-Aug-18	10:00 - 11:00	Giroux	-97.0994	49.88478	5.171755334	Residential
09-Aug-18	11:00 - 12:00	Giroux	-97.1035	49.88483	4.457634209	Residential
09-Aug-18	12:00 - 01:00	Giroux	-97.1038	49.88153	6.441252298	Residential
09-Aug-18	01:00 - 02:00	Giroux	-97.1017	49.88427	8.948464504	Residential
09-Aug-18	02:00 - 03:00	Giroux	-97.1033	49.88482	9.101333679	Residential
09-Aug-18	03:00 - 04:00	Giroux	-97.1009	49.88424	9.696377396	Residential
10-Aug-18	09:00 - 10:00	Kavanagh	-97.1034	49.8855	23.09311249	Residential
10-Aug-18	10:00 - 11:00	Kavanagh	-97.1044	49.88522	22.82835516	Residential
10-Aug-18	11:00 - 12:00	Kavanagh	-97.1027	49.88561	21.17143545	Residential
10-Aug-18	12:00 - 01:00	Kavanagh	-97.1018	49.88506	22.84458512	Residential
10-Aug-18	01:00 - 02:00	Kavanagh	-97.103	49.88567	20.95822915	Residential
10-Aug-18	02:00 - 03:00	Kavanagh	-97.1019	49.8856	22.3480908	Residential
10-Aug-18	03:00 - 04:00	Kavanagh	-97.1045	49.88524	20.37480339	Residential
13-Aug-18	09:00 - 10:00	Cherrier	-97.1035	49.88403	5.812883412	Residential
13-Aug-18	10:00 - 11:00	Cherrier	-97.103	49.88366	6.52638872	Residential
13-Aug-18	11:00 - 12:00	Cherrier	-97.1031	49.88403	7.775716084	Residential
13-Aug-18	12:00 - 01:00	Cherrier	-97.1025	49.88402	10.19357043	Residential
13-Aug-18	01:00 - 02:00	Cherrier	-97.1013	49.88403	5.343117131	Residential
13-Aug-18	02:00 - 03:00	Cherrier	-97.1013	49.88368	0.829457566	Residential
15-Aug-18	09:00 - 10:00	Doucet	-97.1023	49.88322	6.230682293	Residential
15-Aug-18	10:00 - 11:00	Doucet	-97.1015	49.88282	5.049392847	Residential
15-Aug-18	11:00 - 12:00	Doucet	-97.1012	49.88266	4.834926058	Residential

15-Aug-18	12:00 - 01:00	Doucet	-97.1012	49.88266	5.235829105	Residential
15-Aug-18	01:00 - 02:00	Doucet	-97.1007	49.88274	4.918084933	Residential
15-Aug-18	02:00 - 03:00	Doucet	-97.1025	49.88327	5.665063134	Residential
15-Aug-18	03:05 - 04:10	Doucet	-97.0987	49.88325	6.192747104	Residential
16-Aug-18	09:00 - 10:00	Giroux	-97.1016	49.88429	16.07278041	Residential
16-Aug-18	10:00 - 11:00	Giroux	-97.0994	49.88478	33.62599292	Residential
16-Aug-18	11:00 - 12:00	Giroux	-97.1035	49.88483	35.00829351	Residential
16-Aug-18	12:00 - 01:00	Giroux	-97.1038	49.88153	30.24444735	Residential
16-Aug-18	01:00 - 02:00	Giroux	-97.1017	49.88427	23.46215884	Residential
16-Aug-18	02:00 - 03:00	Giroux	-97.1033	49.88482	28.01822868	Residential
16-Aug-18	03:05 - 04:10	Giroux	-97.1009	49.88424	29.10257643	Residential
21-Aug-18	09:00 - 10:00	Doucet	-97.1012	49.88266	10.25540289	Residential
21-Aug-18	10:00 - 11:00	Doucet	-97.1012	49.88266	8.277502612	Residential
21-Aug-18	11:00 - 12:00	Doucet	-97.1007	49.88274	3.128084578	Residential
21-Aug-18	12:00 - 01:00	Doucet	-97.1035	49.88404	2.970713043	Residential
21-Aug-18	01:00 - 02:00	Doucet	-97.1016	49.88162	3.798273944	Residential
21-Aug-18	02:00 - 03:00	Doucet	-97.1031	49.88176	2.415835496	Residential
28-Aug-18	09:00 - 10:00	Kavanagh	-97.1034	49.8855	34.51487329	Residential
28-Aug-18	10:00 - 11:00	Kavanagh	-97.1044	49.88522	27.30803727	Residential
28-Aug-18	11:00 - 12:00	Kavanagh	-97.1027	49.88561	26.26669771	Residential
28-Aug-18	12:00 - 01:00	Kavanagh	-97.1018	49.88506	26.04544218	Residential
28-Aug-18	01:00 - 02:00	Kavanagh	-97.103	49.88567	28.7847635	Residential
28-Aug-18	02:00 - 03:00	Kavanagh	-97.1019	49.8856	16.70893216	Residential

28-Aug-18	03:00 - 04:00	Kavanagh	-97.1045	49.88524	19.86808154	Residential
01-Aug-18	09:00 - 10:00	NE	-97.0999	49.88748	4.686057168	Industrial
01-Aug-18	10:00 - 11:00	NE	-97.0999	49.88748	14.77126728	Industrial
01-Aug-18	11:00 - 12:00	NE	-97.0999	49.88748	12.5837978	Industrial
01-Aug-18	12:00 - 01:00	NE	-97.0999	49.88748	10.2995644	Industrial
01-Aug-18	01:00 - 02:00	NE	-97.0999	49.88748	4.370695776	Industrial
01-Aug-18	02:00 - 03:00	NE	-97.0999	49.88748	5.120334214	Industrial
01-Aug-18	03:00 - 04:00	NE	-97.0999	49.88748	6.163368125	Industrial
02-Aug-18	09:46- 10:45	SE	-97.1006	49.89036	10.76694042	Industrial
02-Aug-18	10:46- 11:45	S	-97.1006	49.89036	12.21373992	Industrial
02-Aug-18	11:46- 12:45	SE	-97.1006	49.89036	14.87314798	Industrial
02-Aug-18	12:46 - 01:45	S	-97.1006	49.89036	14.28622147	Industrial
02-Aug-18	01:46 - 02:45	SE	-97.1006	49.89036	11.81667694	Industrial
02-Aug-18	02:46 - 03:45	S	-97.1006	49.89036	6.701413411	Industrial
02-Aug-18	03:46 - 04:31	SE	-97.1006	49.89036	19.1720319	Industrial
07-Aug-18	09:00 - 10:00	SW	-97.0977	49.88932	16.08188905	Industrial
07-Aug-18	10:00 - 11:00	WSW	-97.0977	49.88932	16.15159603	Industrial
07-Aug-18	11:00 - 12:00	SW	-97.0977	49.88932	16.23395773	Industrial
07-Aug-18	12:00 - 01:00	WSW	-97.0977	49.88932	15.04620539	Industrial
07-Aug-18	01:00 - 02:00	SW	-97.0977	49.88932	8.755300154	Industrial
07-Aug-18	02:00 - 03:00	WSW	-97.0977	49.88932	7.546165521	Industrial
07-Aug-18	03:00 - 04:00	SW	-97.0977	49.88932	7.18434371	Industrial
08-Aug-18	09:00 - 10:00	SW	-97.0968	49.88738	32.51010078	Industrial

08-Aug-18	10:00 - 11:00	SW	-97.0968	49.88738	39.79609448	Industrial
08-Aug-18	11:00 - 12:00	SW	-97.0968	49.88738	31.40225984	Industrial
08-Aug-18	12:00 - 01:00	SW	-97.0968	49.88738	26.32868024	Industrial
08-Aug-18	01:00 - 02:00	SW	-97.0968	49.88738	24.70028138	Industrial
08-Aug-18	02:00 - 03:00	SW	-97.0968	49.88738	17.55189687	Industrial
08-Aug-18	03:00 - 04:00	SW	-97.0968	49.88738	18.663867	Industrial
14-Aug-18	09:00 - 10:00	Vers	-97.0965	49.88744	1.504728425	Industrial
14-Aug-18	10:00 - 11:00	Vers	-97.0965	49.88744	1.970127249	Industrial
14-Aug-18	11:00 - 12:00	Vers	-97.0965	49.88744	2.33524625	Industrial
14-Aug-18	12:00 - 01:00	Vers	-97.0965	49.88744	2.3343234	Industrial
14-Aug-18	01:00 - 02:00	Vers	-97.0965	49.88744	2.798753585	Industrial
14-Aug-18	02:00 - 03:00	Vers	-97.0965	49.88744	2.8161619	Industrial
14-Aug-18	03:00 - 04:00	Vers	-97.0965	49.88744	4.09762358	Industrial
17-Aug-18	09:00 - 10:00	Nelson SE	-97.1001	49.89047	13.83649705	Industrial
17-Aug-18	10:00 - 11:00	Nelson SE	-97.1001	49.89047	9.05514736	Industrial
17-Aug-18	11:00 - 12:00	Nelson SE	-97.1001	49.89047	4.512657805	Industrial
17-Aug-18	12:00 - 01:00	Nelson SE	-97.1001	49.89047	13.62973223	Industrial
17-Aug-18	01:00 - 02:00	Nelson SE	-97.1001	49.89047	19.04772482	Industrial
17-Aug-18	02:00 - 03:00	Nelson SE	-97.1001	49.89047	25.36606232	Industrial
17-Aug-18	03:00 - 04:00	Nelson SE	-97.1001	49.89047	23.31278756	Industrial
20-Aug-18	09:16 - 10:00	Nicolas NE	-97.0997	49.88723	17.15260477	Industrial
20-Aug-18	10:00 - 11:00	Nicolas NE	-97.0997	49.88723	17.86973962	Industrial
20-Aug-18	11:00 - 12:00	Nicolas NE	-97.0997	49.88723	17.75744204	Industrial

20-Aug-18	12:00 - 01:00	Nicolas NE	-97.0997	49.88723	14.42569797	Industrial
20-Aug-18	01:00 - 02:00	Nicolas NE	-97.0997	49.88723	13.99744598	Industrial
20-Aug-18	02:00 - 03:00	Nicolas NE	-97.0997	49.88723	12.06539536	Industrial
20-Aug-18	03:00 - 04:00	Nicolas NE	-97.0997	49.88723	9.021854795	Industrial
23-Aug-18	09:00 - 10:00	Vers	-97.0972	49.888	19.13137933	Industrial
23-Aug-18	10:00 - 11:00	Vers	-97.0972	49.888	15.89527546	Industrial
23-Aug-18	11:00 - 12:00	Vers	-97.0972	49.888	14.74823245	Industrial
23-Aug-18	12:00 - 01:00	Vers	-97.0972	49.888	11.1415578	Industrial
23-Aug-18	01:00 - 02:00	Vers	-97.0972	49.888	11.58780408	Industrial
23-Aug-18	02:00 - 03:00	Vers	-97.0972	49.888	10.54947806	Industrial
23-Aug-18	03:00 - 04:00	Vers	-97.0972	49.888	14.65796104	Industrial
27-Aug-18	08:20 - 09:00	Nicolas NE	-97.1001	49.89047	17.67675381	Industrial
27-Aug-18	09:00 - 10:00	Nicolas NE	-97.0997	49.88723	22.77128516	Industrial
27-Aug-18	10:00 - 11:00	Nicolas NE	-97.0997	49.88723	19.58125626	Industrial
27-Aug-18	11:00 - 12:00	Nicolas NE	-97.0997	49.88723	27.54472521	Industrial
27-Aug-18	12:00 - 01:00	Nicolas NE	-97.0997	49.88723	17.11768756	Industrial
27-Aug-18	01:00 - 02:00	Nicolas NE	-97.0997	49.88723	28.63627124	Industrial
27-Aug-18	02:00 - 03:00	Nicolas NE	-97.0997	49.88723	13.94956038	Industrial
27-Aug-18	03:00 - 04:00	Nicolas NE	-97.0997	49.88723	26.58453371	Industrial
29-Aug-18	09:00 - 10:00	Vers	-97.0977	49.88932	60.24107475	Industrial
29-Aug-18	10:00 - 11:00	Vers	-97.0977	49.88932	34.10415228	Industrial
29-Aug-18	11:00 - 12:00	Vers	-97.0977	49.88932	32.51149534	Industrial
29-Aug-18	12:00 - 01:00	Vers	-97.0968	49.88738	17.40858636	Industrial

29-Aug-18	01:00 - 02:00	Vers	-97.0968	49.88738	19.12923723	Industrial
29-Aug-18	02:00 - 03:00	Vers	-97.0968	49.88738	18.40195952	Industrial
29-Aug-18	03:00 - 04:00	Vers	-97.0968	49.88738	20.48392839	Industrial
30-Aug-18	09:00 - 10:00	Nelson S	-97.0991	49.89058	6.15	Industrial
30-Aug-18	10:00 - 11:00	Nelson S	-97.0991	49.89058	11.1	Industrial
30-Aug-18	11:00 - 12:00	Nelson S	-97.0991	49.89058	9.99	Industrial
30-Aug-18	12:00 - 01:00	Nelson S	-97.0991	49.89058	9.38	Industrial
30-Aug-18	01:00 - 02:00	Nelson S	-97.0991	49.89058	27.93	Industrial
30-Aug-18	02:00 - 03:00	Nelson S	-97.0991	49.89058	15.01	Industrial

Date	**Time**	**Site**	**Longitude**	**Latitude**	**PM2.5ug/m3**	**Location**
04-Sep-18	09:00 - 10:00	NW	-97.0977	49.88932	18.05135574	Industrial
04-Sep-18	10:00 - 11:00	NW	-97.0977	49.88932	16.87983306	Industrial
04-Sep-18	11:00 - 12:00	NW	-97.0977	49.88932	15.05195278	Industrial

04-Sep-18	12:00 - 01:00	NW	-97.0968	49.88738	14.56347623	Industrial
04-Sep-18	01:00 - 02:00	NW	-97.0968	49.88738	14.09353264	Industrial
10-Sep-18	09:00 - 10:00	WSW	-97.0977	49.88932	42.18014563	Industrial
10-Sep-18	10:00 - 11:00	W	-97.0977	49.88932	26.60477726	Industrial
10-Sep-18	11:00 - 12:00	W	-97.0977	49.88932	41.1044041	Industrial
10-Sep-18	12:00 - 01:00	SW	-97.0977	49.88932	28.88007329	Industrial
10-Sep-18	01:00 - 02:00	SW	-97.0977	49.88932	22.33617036	Industrial
10-Sep-18	02:00 - 03:00	W	-97.0977	49.88932	18.15508509	Industrial
10-Sep-18	03:00 - 04:00	W	-97.0977	49.88932	17.44100856	Industrial
11-Sep-18	09:00 - 10:00	ESE	-97.1006	49.89036	5.307277176	Industrial
11-Sep-18	10:00 - 11:00	SSE	-97.1006	49.89036	3.494029923	Industrial

11-Sep-18	11:00 - 12:00	SSW	-97.1006	49.89036	16.21448258	Industrial
11-Sep-18	12:00 - 01:00	SSW	-97.1006	49.89036	14.91796569	Industrial
11-Sep-18	01:00 - 02:00	SW	-97.0977	49.88932	9.064889897	Industrial
11-Sep-18	02:00 - 03:00	W	-97.0977	49.88932	42.73185878	Industrial
11-Sep-18	03:00 - 04:00	W	-97.0977	49.88932	32.21929332	Industrial
18-Sep-18	08:00 - 09:00	N	-97.0977	49.88932	40.46269832	Industrial
18-Sep-18	09:00 - 10:00	NW	-97.0977	49.88932	9.577147955	Industrial
18-Sep-18	10:00 - 11:00	N	-97.0977	49.88932	2.157391543	Industrial
18-Sep-18	11:00 - 12:00	N	-97.0968	49.88738	7.385599421	Industrial
18-Sep-18	12:00 - 01:00	NW	-97.0968	49.88738	12.34813892	Industrial
18-Sep-18	01:00 - 02:00	NW	-97.0968	49.88738	6.273149978	Industrial

18-Sep-18	02:00 - 03:00	NW	-97.0968	49.88738	10.69287383	Industrial
25-Sep-18	10:16 - 11:00	W	-97.097	49.88772	36.91648946	Industrial
25-Sep-18	11:00 - 12:00	WNW	-97.097	49.88772	16.63333502	Industrial
25-Sep-18	12:00 - 01:00	WNW	-97.097	49.88772	30.12456913	Industrial
25-Sep-18	01:00 - 02:00	WNW	-97.097	49.88772	22.85499275	Industrial
25-Sep-18	02:00 - 03:00	WNW	-97.097	49.88772	56.45608659	Industrial
25-Sep-18	03:00 - 04:00	W	-97.097	49.88772	55.03269127	Industrial
26-Sep-18	09:00 - 10:00	SSW	-97.0982	49.8901	25.43251778	Industrial
26-Sep-18	10:00 - 11:00	S	-97.0982	49.8901	63.36555702	Industrial
26-Sep-18	11:00 - 12:00	S	-97.0982	49.8901	12.60581895	Industrial
26-Sep-18	12:00 - 01:00	S	-97.0982	49.8901	29.36460496	Industrial

05-Sep-18	10:00 - 11:00	Street - Giroux	-97.1016	49.88429	2.512710419	Residential
05-Sep-18	11:00 - 12:00	Street - Giroux	-97.0994	49.88478	1.551198845	Residential
05-Sep-18	12:00 - 01:00	Street - Giroux	-97.1035	49.88483	1.476094513	Residential
05-Sep-18	01:00 - 02:00	Street - Giroux	-97.1038	49.88153	1.239932415	Residential
05-Sep-18	02:00 - 03:00	Street - Giroux	-97.1017	49.88427	1.08170253	Residential
05-Sep-18	03:00 - 04:00	Street - Giroux	-97.1033	49.88482	1.16085441	Residential
07-Sep-18	09:00 - 10:00	Street - Doucet	-97.1023	49.88322	13.1627628	Residential
07-Sep-18	10:00 - 11:00	Street - Doucet	-97.1015	49.88282	11.33604058	Residential
07-Sep-18	11:00 - 12:00	Street- Doucet	-97.1012	49.88266	16.1734448	Residential
07-Sep-18	12:00 - 01:00	Street - Doucet	-97.1002	49.88322	6.224246141	Residential
07-Sep-18	01:00 - 02:00	Street - Happyland Park	-97.1007	49.88274	8.759467445	Residential

07-Sep-18	02:00 - 03:00	Street- Doucet	-97.1025	49.88327	6.810543877	Residential
07-Sep-18	03:00 - 04:00	Street - Doucet	-97.1012	49.88272	6.213354366	Residential
08-Sep-18	10:00 - 11:00	Street - Giroux	-97.1016	49.88429	2.512710419	Residential
08-Sep-18	11:00 - 12:00	Street - Giroux	-97.0994	49.88478	1.551198845	Residential
08-Sep-18	12:00 - 01:00	Street - Giroux	-97.1035	49.88483	1.476094513	Residential
08-Sep-18	01:00 - 02:00	Street - Giroux	-97.1038	49.88153	1.239932415	Residential
08-Sep-18	02:00 - 03:00	Street - Giroux	-97.1017	49.88427	1.08170253	Residential
08-Sep-18	03:00 - 04:00	Street - Giroux	-97.1033	49.88482	1.16085441	Residential
12-Sep-18	09:00 - 10:00	Street - Happyland Park	-97.1029	49.88153	2.965338979	Residential
12-Sep-18	10:00 - 11:00	Cherrier	-97.103	49.88366	3.279151383	Residential
12-Sep-18	11:00 - 12:00	Street- Cherrier	-97.1031	49.88403	7.150289233	Residential

12-Sep-18	12:00 - 01:00	Street- Cherrier	-97.1025	49.88402	1.233130717	Residential
12-Sep-18	01:00 - 02:00	Street- Cherrier	-97.1013	49.88403	2.351169233	Residential
12-Sep-18	02:00 - 03:00	Street- Cherrier	-97.1013	49.88368	3.055680565	Residential
12-Sep-18	03:00 - 04:00	Street - Cherrier Street	-97.1035	49.88403	3.362839827	Residential
13-Sep-18	11:00 - 12:00	Street- Doucet	-97.1015	49.88282	8.790317316	Residential
13-Sep-18	12:00 - 01:00	Street - Doucet	-97.1012	49.88266	3.130970512	Residential
13-Sep-18	01:00 - 02:00	Street - Doucet	-97.1002	49.88322	1.29747876	Residential
13-Sep-18	02:00 - 03:00	Street- Happylnad Park	-97.1006	49.88148	1.644690001	Residential
13-Sep-18	03:00 - 04:00	Street - Doucet	-97.1012	49.88266	2.914506483	Residential
17-Sep-18	11:00 - 12:00	Doucet Street	-97.1002	49.88322	8.907451002	Residential
17-Sep-18	12:00 - 01:00	Doucet Street	-97.1007	49.88274	3.165730213	Residential

17-Sep-18	01:00 - 02:00	Happyland Park	-97.1037	49.88143	1.335979362	Residential
17-Sep-18	02:00 - 03:00	Doucet Street	-97.1012	49.88272	1.635210287	Residential
17-Sep-18	03:00 - 04:00	Doucet Street	-97.1015	49.88282	2.868738089	Residential
20-Sep-18	09:00 - 10:00	Street - Kavanagh	-97.1034	49.8855	5.055088919	Residential
20-Sep-18	10:00 - 11:00	Street - Kavanagh	-97.1044	49.88522	3.363780943	Residential
20-Sep-18	11:00 - 12:00	Street- Kavanagh	-97.1027	49.88561	2.691014507	Residential
20-Sep-18	12:00 - 01:00	Street - Kavanagh Park	-97.1018	49.88506	4.014381946	Residential
20-Sep-18	01:00 - 02:00	Street - Happyland Park	-97.1037	49.88143	7.753691637	Residential
20-Sep-18	02:00 - 03:00	Street- Kavanagh	-97.103	49.88567	8.159914594	Residential
20-Sep-18	03:00 - 04:00	Street - Kavanagh	-97.1019	49.8856	5.451274796	Residential

Date	**Time**	**Site Location**	**Longitude**	**Latitude**	**PM2.5 ug/m3**	**Location**
01-Oct-18	09:00 - 10:00	Street-Cherrier	-97.10307	49.88403	2.322034617	Residential
01-Oct-18	10:00 - 11:00	Street-Cherrier	-97.10249	49.88402	2.077645145	Residential
01-Oct-18	11:00 - 12:00	Kavanagh Park	-97.10177	49.88506	1.641179341	Residential
01-Oct-18	12:00 - 01:00	Kavanagh Park	-97.103098	49.88549	1.773453614	Residential
01-Oct-18	01:00 - 02:00	Cherrier	-97.10132	49.88403	2.323619713	Residential
01-Oct-18	02:00 - 03:00	Street-Cherrier	-97.10126	49.88368	2.235039696	Residential
01-Oct-18	03:00 - 04:00	Street-Cherrier	-97.10132	49.88403	2.267731816	Residential
06-Oct-18	09:18 - 10:17	Street-Cherrier	-97.10126	49.88368	8.485249902	Residential
06-Oct-18	10:18 - 11:17	Kavanagh Park	-97.10357	49.885651	5.4079154	Residential
06-Oct-18	11:18 - 12:00	Kavanagh Street	-97.101901	49.885409	5.235078719	Residential

06-Oct-18	12:00 - 01:00	Kavanagh Park	-97.103459	49.885617	5.348801167	Residential
06-Oct-18	01:00 - 02:00	Cherrier	-97.10299	49.88366	7.443581774	Residential
06-Oct-18	02:00 - 03:00	Street-Cherrier	-97.10307	49.88403	5.012404068	Residential
06-Oct-18	03:00 - 04:00	Street-Cherrier	-97.10249	49.88402	7.612454996	Residential
09-Oct-18	09:11-10:10	Street- Doucet	-97.10119	49.88266	1.486957081	Residential
09-Oct-18	10:11-11:10	Street- Doucet	-97.100168	49.883215	2.320122355	Residential
09-Oct-18	11:11-12:10	Street- Doucet	-97.1007	49.88274	2.03843995	Residential
09-Oct-18	12:11-01:10	Street- Doucet	-97.103683	49.881433	1.90472111	Residential
09-Oct-18	01:11-02:10	Street- Doucet	-97.101188	49.88272	2.955481976	Residential
09-Oct-18	02:11-03:10	Street-Doucet	-97.1015	49.88282	2.707813473	Residential
09-Oct-18	03:11-04:10	Street- Doucet	-97.10119	49.88266	4.212898758	Residential

10-Oct-18	09:00 - 10:00	Kavanagh Street	-97.1034	49.8855	2.234523473	Residential
10-Oct-18	10:00 - 11:00	Kavanagh Street	-97.10437	49.88522	3.138877173	Residential
10-Oct-18	11:00 - 12:00	Kavanagh Street	-97.10265	49.88561	3.156038257	Residential
10-Oct-18	12:00 - 01:00	Kavanagh Street	-97.10177	49.88506	2.190497927	Residential
10-Oct-18	01:00 - 02:00	Kavanagh Street	-97.103683	49.881433	2.331717786	Residential
10-Oct-18	02:00 - 03:00	Kavanagh Street	-97.10304	49.88567	2.239239994	Residential
10-Oct-18	03:00 - 04:00	Kavanagh Street	-97.10188	49.885604	2.537722818	Residential
18-Oct-18	09:00 - 10:00	Kavanagh Street	-97.1034	49.8855	4.498797951	Residential
18-Oct-18	10:00 - 11:00	Kavanagh Street	-97.10437	49.88522	4.077062657	Residential
18-Oct-18	11:00 - 12:00	Kavanagh Street	-97.10265	49.88561	3.869301861	Residential
18-Oct-18	12:00 - 01:00	Kavanagh Street	-97.10177	49.88506	2.705998711	Residential

18-Oct-18	01:00 - 02:00	Kavanagh Street	-97.10304	49.88567	2.476813998	Residential
18-Oct-18	02:00 - 03:00	Kavanagh Street	-97.10188	49.885604	2.952830309	Residential
18-Oct-18	03:00 - 04:00	Kavanagh Street	-97.10447	49.885239	3.122122365	Residential
22-Oct-18	09:00 - 10:00	Doucet Street	-97.10119	49.88266	1.043543876	Residential
22-Oct-18	10:00 - 11:00	Doucet Street	-97.10119	49.88266	0.65808958	Residential
22-Oct-18	11:00 - 12:00	Doucet Street	-97.1007	49.88274	0.817456692	Residential
22-Oct-18	12:00 - 01:00	Doucet Street	-97.10345	49.88404	0.625826043	Residential
22-Oct-18	01:00 - 02:00	Doucet Street	-97.101567	49.881623	0.737860845	Residential
22-Oct-18	02:00 - 03:00	Doucet Street	-97.103076	49.881761	0.796692558	Residential
22-Oct-18	03:00 - 04:00	Doucet Street	-97.1015	49.88282	0.837475382	Residential
24-Oct-18	09:00 - 10:00	Cherrier Street	-97.10346	49.88403	3.888045457	Residential

24-Oct-18	10:00 - 11:00	Cherrier Street	-97.10299	49.88366	4.24237473	Residential
24-Oct-18	11:00 - 12:00	Cherrier Street	-97.10307	49.88403	3.736395865	Residential
24-Oct-18	12:00 - 01:00	Cherrier Street	-97.10249	49.88402	4.459726226	Residential
24-Oct-18	01:00 - 02:00	Cherrier Street	-97.10132	49.88403	4.023759493	Residential
24-Oct-18	02:00 - 03:00	Cherrier Street	-97.10126	49.88368	3.844907038	Residential
24-Oct-18	03:00 - 04:00	Cherrier Street	-97.10311	49.88403	3.276038257	Residential
31-Oct-18	08:00 - 09:00	Giroux Street	-97.10162	49.88429	1.188589165	Residential
31-Oct-18	09:00 - 10:00	Giroux Street	-97.09938	49.88478	0.906696397	Residential
31-Oct-18	10:00 - 11:00	Giroux Street	-97.10347	49.88483	0.677773473	Residential
31-Oct-18	11:00 - 12:00	Giroux Street	-97.10381	49.88153	0.582360046	Residential
31-Oct-18	12:00 - 01:00	Giroux Street	-97.10173	49.88427	0.82126435	Residential

31-Oct-18	01:00 - 02:00	Giroux Street	-97.1033	49.88482	0.808916166	Residential
31-Oct-18	02:00 - 03:00	Giroux Street	-97.10085	49.884252	0.90717564	Residential
02-Oct-18	08:20-09:17	NE	-97.09991	49.88748	7.301336968	Industrial
02-Oct-18	09:18 - 10:17	ENE	-97.09991	49.88748	8.485249902	Industrial
02-Oct-18	10:18 - 11:17	ENE	-97.09991	49.88748	5.4079154	Industrial
02-Oct-18	12:00 - 01:00	SE	-97.100568	49.890356	5.348801167	Industrial
02-Oct-18	01:00 - 02:00	NE	-97.100568	49.890356	7.443581774	Industrial
02-Oct-18	02:00 - 03:00	E	-97.100568	49.890356	5.012404068	Industrial
02-Oct-18	03:00 - 04:00	SE	-97.100568	49.890356	7.612454996	Industrial
04-Oct-18	09:00 - 10:00	SW	-97.097735	49.88932	5.360871964	Industrial
04-Oct-18	10:00 - 11:00	WNW	-97.097735	49.88932	3.638846633	Industrial

04-Oct-18	11:00 - 12:00	NW	-97.097735	49.88932	8.399866009	Industrial
04-Oct-18	12:00 - 01:00	WNW	-97.097735	49.88932	7.253804371	Industrial
04-Oct-18	01:00 - 02:00	SW	-97.097735	49.88932	21.93634119	Industrial
04-Oct-18	02:00 - 03:00	SSW	-97.097735	49.88932	11.68424968	Industrial
04-Oct-18	03:00 - 04:00	SW	-97.097735	49.88932	35.68697869	Industrial
16-Oct-18	09:18 - 10:17	NW	-97.096821	49.887379	18.38494067	Industrial
16-Oct-18	10:18 - 11:17	NNW	-97.096821	49.887379	32.51299125	Industrial
16-Oct-18	11:18 - 12:00	NNW	-97.096967	49.887715	16.48572402	Industrial
16-Oct-18	12:00 - 01:00	NW	-97.096967	49.887715	42.48689441	Industrial
16-Oct-18	01:00 - 02:00	NW	-97.096967	49.887715	25.66297674	Industrial
16-Oct-18	02:00 - 03:00	NW	-97.096967	49.887715	63.46608823	Industrial

16-Oct-18	03:00 - 04:00	NW	-97.096967	49.887715	67.35237333	Industrial
17-Oct-18	09:18 - 10:17	NNW	-97.097735	49.88932	24.33907001	Industrial
17-Oct-18	10:18 - 11:17	N	-97.097735	49.88932	14.35316858	Industrial
17-Oct-18	11:18 - 12:00	S	-97.097735	49.88932	6.801031846	Industrial
17-Oct-18	12:01 - 01:00	SW	-97.097735	49.88932	12.64783083	Industrial
17-Oct-18	01:01 - 02:00	SSW	-97.097735	49.88932	34.26707697	Industrial
17-Oct-18	02:01 - 03:00	SSW	-97.097735	49.88932	29.85978672	Industrial
17-Oct-18	03:00 - 04:01	S	-97.097735	49.88932	34.36021025	Industrial
25-Oct-18	09:18 - 10:17	SE	-97.100568	49.890356	22.37702055	Industrial
25-Oct-18	10:18 - 11:17	S	-97.100568	49.890356	5.614358204	Industrial
25-Oct-18	12:00 - 01:00	SSE	-97.100568	49.890356	5.936893272	Industrial

29-Oct-18	09:18 - 10:17	SE	-97.100568	49.890356	2.339407217	Industrial
29-Oct-18	10:18 - 11:17	SE	-97.100568	49.890356	1.001239576	Industrial
29-Oct-18	12:00 - 01:00	SE	-97.100568	49.890356	11.91852559	Industrial
29-Oct-18	01:00 - 02:00	S	-97.100568	49.890356	10.16651733	Industrial
29-Oct-18	02:00 - 03:00	SE	-97.100568	49.890356	16.13368069	Industrial
29-Oct-18	03:00 - 04:00	SE	-97.100568	49.890356	22.20954764	Industrial
30-Oct-18	09:18 - 10:17	SW	-97.097735	49.88932	3.212960969	Industrial
30-Oct-18	10:18 - 11:17	WSW	-97.097735	49.88932	2.747493267	Industrial
30-Oct-18	11:18 - 12:00	WSW	-97.097735	49.88932	2.360583922	Industrial
30-Oct-18	12:05 - 01:00	WSW	-97.097735	49.88932	3.099248774	Industrial

Date	Time	PM 2.5ug/m3	Site	Longitude	Latitude	Location
01-Nov-18	09:21 - 10:00	11.44938528	Nelson	-97.099949	49.890492	Industrial
01-Nov-18	10:01-11:00	17.49030146	Nelson	-97.100179	49.890651	Industrial
01-Nov-18	11:01-12:00	12.4686766	Nelson	-97.099365	49.89064	Industrial
01-Nov-18	12:03 - 01:00	10.91555603	Nelson	-97.099949	49.890492	Industrial
01-Nov-18	01:01 - 02:00	14.80522033	Nelson	-97.100179	49.890651	Industrial
01-Nov-18	02:00 - 03:00	13.31907049	Nelson	-97.099365	49.89064	Industrial
01-Nov-18	03:00 - 03:45	20.51896688	Nelson	-97.100214	49.890321	Industrial
05-Nov-18	09:29 - 10:00	4.746266076	Nelson	-97.097735	49.88932	Industrial
05-Nov-18	10:01-11:00	7.967159292	Nelson	-97.100568	49.890356	Industrial
05-Nov-18	11:01-12:00	20.50001537	Nelson	-97.100568	49.890356	Industrial

05-Nov-18	12:03 - 01:00	9.689604221	Nelson	-97.100568	49.890356	Industrial
05-Nov-18	01:01 - 02:00	15.24835714	Nelson	-97.100568	49.890356	Industrial
05-Nov-18	02:00 - 03:00	15.78321785	Nelson	-97.100568	49.890356	Industrial
05-Nov-18	03:00 - 03:45	16.87067981	Nelson	-97.100568	49.890356	Industrial
06-Nov-18	09:24 - 10:00	2.542834729	Kavanagh Park	-97.10177	49.88506	Residential
06-Nov-18	10:00 - 11:00	2.217638349	Kavanagh Park	-97.103098	49.88549	Residential
06-Nov-18	11:00 - 12:00	2.399499823	Cherrier	-97.10132	49.88403	Residential
06-Nov-18	12:00 - 01:00	4.567389374	Street-Cherrier	-97.10126	49.88368	Residential
06-Nov-18	01:00 - 02:00	2.093874342	Street-Cherrier	-97.10132	49.88403	Residential
06-Nov-18	02:00 - 03:00	2.119372774	Street-Cherrier	-97.10126	49.88368	Residential
08-Nov-18	09:19 - 10:00	0.978374813	Kavanagh Park	-97.10357	49.885651	Residential

08-Nov-18	10:00 - 11:00	3.839482025	Kavanagh Street	-97.101901	49.885409	Residential
08-Nov-18	11:00 - 12:00	5.292345134	Kavanagh Park	-97.103459	49.885617	Residential
08-Nov-18	12:00 - 01:00	4.538293023	Cherrier	-97.10299	49.88366	Residential
01-Dec-18	10:00 - 11:00	1.281758434	Street-Cherrier	-97.10346	49.88403	Residential
01-Dec-18	11:00 - 12:00	5.988459702	Street-Cherrier	-97.10299	49.88366	Residential
01-Dec-18	12:00 - 01:00	6.083847821	Street-Cherrier	-97.10307	49.88403	Residential
01-Dec-18	01:00 - 02:00	6.234455311	Street-Cherrier	-97.10249	49.88402	Residential
01-Dec-18	02:00 - 03:00	6.373200629	Street-Cherrier	-97.10132	49.88403	Residential
01-Dec-18	03:00 - 03:22	6.216431922	Street-Cherrier	-97.10126	49.88368	Residential
04-Dec-18	10:04 - 11:00	9.073839298	Giroux Street	-97.10162	49.88429	Residential
04-Dec-18	11:00 - 12:00	2.148753943	Giroux Street	-97.09938	49.88478	Residential

04-Dec-18	12:00 - 01:00	8.934830392	Giroux Street	-97.10347	49.88483	Residential
04-Dec-18	01:00 - 02:00	9.119827322	Giroux Street	-97.10381	49.88153	Residential
04-Dec-18	02:00 - 03:00	8.620982832	Giroux Street	-97.10173	49.88427	Residential
10-Dec-18	09:27 - 10:00	1.873632924	Street-Doucet	-97.10119	49.88266	Residential
10-Dec-18	10:00 - 11:00	1.087344291	Street-Doucet	-97.100168	49.883215	Residential
10-Dec-18	11:00 - 12:00	2.168293927	Street-Doucet	-97.1007	49.88274	Residential
10-Dec-18	12:00 - 01:00	2.629733291	Street-Doucet	-97.103683	49.881433	Residential
10-Dec-18	01:00 - 02:00	3.239023202	Street-Doucet	-97.101188	49.88272	Residential
10-Dec-18	02:00 - 03:00	4.435623349	Street-Doucet	-97.1015	49.88282	Residential
10-Dec-18	03:00 - 04:00	7.543862343	Street-Doucet	-97.10119	49.88266	Residential
11-Dec-18	09:28 - 10:00	1.184109267	Kavanagh Street	-97.1034	49.8855	Residential

11-Dec-18	10:00 - 11:00	2.420892191	Kavanagh Street	-97.10437	49.88522	Residential
11-Dec-18	11:00 - 12:00	2.612937365	Kavanagh Street	-97.10265	49.88561	Residential
11-Dec-18	12:00 - 01:00	5.319645211	Kavanagh Street	-97.10177	49.88506	Residential
11-Dec-18	01:00 - 02:00	2.541720292	Kavanagh Street	-97.103683	49.881433	Residential
11-Dec-18	02:00 - 03:00	2.052189012	Kavanagh Street	-97.10304	49.88567	Residential
12-Dec-18	09:19 - 10:00	2.640926716	Cherrier	-97.10299	49.88366	Residential
12-Dec-18	10:00 - 11:00	2.982932029	Street-Cherrier	-97.10346	49.88403	Residential
12-Dec-18	11:00 - 12:00	4.382304567	Street-Cherrier	-97.10299	49.88366	Residential
12-Dec-18	12:00 - 01:00	8.665109346	Street-Cherrier	-97.10307	49.88403	Residential
12-Dec-18	01:00 - 02:00	5.135976882	Street-Cherrier	-97.10249	49.88402	Residential
12-Dec-18	02:00 - 03:00	4.021842381	Street-Cherrier	-97.10132	49.88403	Residential

12-Dec-18	03:00 - 04:12	3.141229348	Street-Cherrier	-97.10126	49.88368	Residential
13-Dec-18	09:22 - 10:00	2.345596429	Kavanagh Park	-97.103098	49.88549	Residential
13-Dec-18	10:00 - 11:00	4.268923325	Cherrier	-97.10132	49.88403	Residential
13-Dec-18	11:00 - 12:00	6.217652242	Street-Cherrier	-97.10126	49.88368	Residential
13-Dec-18	12:00 - 01:00	6.451623398	Street-Cherrier	-97.10132	49.88403	Residential
13-Dec-18	01:00 - 02:00	6.321165732	Street-Cherrier	-97.10126	49.88368	Residential
13-Dec-18	02:00 - 03:00	6.294562235	Kavanagh Park	-97.10357	49.885651	Residential
13-Dec-18	03:00 - 04:00	6.087623824	Kavanagh Street	-97.101901	49.885409	Residential
06-Dec-18	09:19 - 10:00	14.12478422	WSW	-97.097735	49.88932	Industrial
06-Dec-18	10:00 - 11:00	15.08223456	W	-97.097735	49.88932	Industrial
06-Dec-18	11:00 - 12:00	16.43123492	W	-97.097735	49.88932	Industrial

06-Dec-18	12:00 - 01:00	15.27296238	SW	-97.097735	49.88932	Industrial
14-Dec-18	10:00 - 11:00	12.12451762	SSW	-97.100568	49.890356	Industrial
14-Dec-18	11:00 - 12:00	14.22347825	SSW	-97.100568	49.890356	Industrial
14-Dec-18	12:00 - 01:00	11.32649176	SW	-97.097735	49.88932	Industrial
18-Dec-18	09:31 - 10:00	9.756539321	W	-97.097735	49.88932	Industrial
18-Dec-18	10:00 - 11:00	8.522334877	WNW	-97.096967	49.887715	Industrial
18-Dec-18	11:00 - 12:00	7.872983925	WNW	-97.096967	49.887715	Industrial
18-Dec-18	12:00 - 01:00	7.813445692	W	-97.096967	49.887715	Industrial

Appendix B:

This section provides the primary data of total metals and total mercury analysis of snowpack for the 8 heavy metals of interest in this study. Also, pictures of snow sampling procedure were also included.

Figure 3: Labelling of sample bottles at one of the community member's house in South St. Boniface.

Figure 3.1: Residential sampling of undisturbed accumulated snowpack.

Figure 3.3: Community member participation in snow sampling, 13 March 2019.

Figure 3.4: Snow pack sampling beyond the property line of scrap metal shredding in Mission Industrial Area, Winnipeg, Manitoba. 13 March 2019.

Group of Carcinogens IARC Monograph (Group 1: Carcinogenic to humans; Group 2A: Probably carcinogenic to humans; Group 2B: Possibly carcinogenic to humans; Group 3: Non-carcinogenic)			Commercial Area Sampling Points					
Parameter								
Total Metals (Water)	**Lowest Detection Limit**	**Units** µg/L = mg/L*1000	**Lawrence Auto (CA 1)**	**Jan San (CA2)**	**Sikh Temple (CA3)**	**Kid City (CA4)**	**Fort Richmond BACKGROUND 1 (A+B)**	**Fort Richmomd BACKGROUND 2 [A+B]**
Arsenic (As)-Total	0.00010	µg/L	0.23	0.32	0.22	0.41	<0.00010	0.00010
Beryllium (Be)-Total	0.00010	mg/L	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Cadmium (Cd)-Total	0.00001	µg/L	0.0413	0.0834	0.0679	0.0464	0.0081000	0.0124000
Nickel (Ni)-Total	0.00050	µg/L	0.91	1.08	0.79	0.65	<0.00050	0.74000
Chromium (Cr)-Total	0.000050	µg/L	0.74	1.31	0.8	1.05	0.00017	0.00026
Lead (Pb)-Total	0.000050	µg/L	8.07	4.87	2.89	3.23	0.000200	0.000199
Mercury (Hg)-Total	0.0000050	µg/L	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Cobalt (Co)-Total	0.00010	mg/L	0.00019	0.00018	0.00013	0.00012	<0.00010	<0.00010
Antimony (Sb)-Total	0.00010	mg/L	0.00044	0.00051	0.00036	0.00032	0.00010	0.00013
Vanadium (V)-Total	0.00050	mg/L	0.00088	0.0007	<0.00050	<0.00050	<0.00050	<0.00050
Copper (Cu)-Total	0.00050	mg/L	0.00884	0.0126	0.00634	0.00593	0.00138	0.00182
Iron (Fe)-Total	0.0100	mg/L	0.277	0.367	0.243	0.224	0.032	0.067
Aluminum (Al)-Total	0.0030	mg/L	0.194	0.255	0.135	0.0968	0.0262	0.0403
Manganese (Mn)-Total	0.00010	µg/L	11.5000	12.8000	10.6000	9.94000	2.90000	4.36000
Molybdenum (Mo)-Total	0.00005	mg/L	0.000375	0.000348	0.000263	0.000257	0.000133	0.000114
Phosphorus (P)-Total	0.030000	mg/L	0.036	0.045	0.032	0.034	<0.030	<0.030
Potassium (K)-Total	0.05	mg/L	1.12	0.523	0.431	0.425	0.301	0.348
Selenium (Se)-Total	0.0001	mg/L	0.000066	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050
Strontium (Sr)-Total	0.0002000	mg/L	0.00950	0.0194	0.00741	0.00761	0.00137	0.00226
Sulfur (S)-Total	0.50000	mg/L	<0.50	0.60	<0.50	<0.50	<0.50	<0.50

Tin (Sn)-Total	0.00010	mg/L	0.00018	0.00032	0.00018	0.00022	<0.00010	<0.00010
Titanium (Ti)-Total	0.00100	mg/L	0.00654	0.00669	0.00490	0.00287	0.00128	0.00171
Uranium (U)-Total	0.000010	mg/L	0.000037	0.000033	0.000022	0.000023	<0.000010	<0.000010
Zinc (Zn)-Total	0.003000	μg/L	28.5000	80.2000	50.8000	53.9000	7.5000	9.0000

Group of Carcinogens IARC Monograph (Group 1: Carcinogenic to humans; Group 2A: Probably carcinogenic to humans; Group 2B: Possibly carcinogenic to humans; Group 3: Non-carcinogenic)			Roadside Snow Sampling Points					
Parameter	Lowest Detection Limit	Units µg/L = mg/L*1000	Archibald Road A (Rd 1A)	Archibald Road B (Rd 1B)	Marion Road A (Rd 2A)	Marion Road B (Rd 2B)	Fort Richmond BACKGROUND 1 (A+B)	Fort Richmomd BACKGROUND 2 [A+B]
Total Metals (Water)								
Arsenic (As)-Total	0.00010	µg/L	0.2	1.04	0.14	0.52	<0.00010	0.0001
Beryllium (Be)-Total	0.00010	mg/L	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Cadmium (Cd)-Total	0.00010	µg/L	0.0697	0.177	0.0129	0.0746	0.0000081	0.0000124
Nickel (Ni)-Total	0.00050	µg/L	1.05	4.37	<0.00050	1.85	<0.00050	0.00074
Chromium (Cr)-Total	0.000050	µg/L	0.89	5.21	0.43	2.25	0.00017	0.00026
Lead (Pb)-Total	0.000050	µg/L	3.72	13.2	0.693	4.58	0.0002	0.000199
Mercury (Hg)-Total	0.0000050	µg/L	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Cobalt (Co)-Total	0.00010	mg/L	0.00023	0.00098	0.00013	0.00041	<0.00010	<0.00010
Antimony (Sb)-Total	0.00010	mg/L	0.00052	0.00172	0.00031	0.001	0.0001	0.00013
Vanadium (V)-Total	0.00050	mg/L	0.00088	0.00349	0.00067	0.00151	<0.00050	<0.00050
Copper (Cu)-Total	0.00050	mg/L	0.00631	0.0195	0.00248	0.0129	0.00138	0.00182
Iron (Fe)-Total	0.0100	mg/L	0.383	2.4	0.192	0.873	0.032	0.067
Aluminum (Al)-Total	0.0030	mg/L	0.238	1.33	0.176	0.475	0.0262	0.0403
Manganese (Mn)-Total	0.00010	µg/L	18.2000	67.8	9.52	27.9	2.9	4.36
Molybdenum (Mo)-Total	0.00005	mg/L	0.000314	0.000837	0.000223	0.000553	0.000133	0.000114
Phosphorus (P)-Total	0.030000	mg/L	0.043	0.106	<0.030	0.054	<0.030	<0.030
Potassium (K)-Total	0.05	mg/L	1.09	2.40	0.872	1.26	0.301	0.348
Selenium (Se)-Total	0.0001	mg/L	<0.000050	0.000077	0.000054	<0.000050	<0.000050	<0.000050
Strontium (Sr)-Total	0.0002000	mg/L	0.0125	0.0275	0.00666	0.0131	0.00137	0.00226
Sulfur (S)-Total	0.50000	mg/L	0.57	0.58	<0.50	<0.50	<0.50	<0.50
Tin (Sn)-Total	0.00010	mg/L	0.0002	0.00177	0.0001	0.00078	<0.00010	<0.00010
Titanium (Ti)-Total	0.00100	mg/L	0.00934	0.0667	0.00618	0.0199	0.00128	0.00171
Uranium (U)-Total	0.000010	mg/L	0.000039	0.000137	0.000026	0.000055	<0.000010	<0.000010
Zinc (Zn)-Total	0.003000	mg/L	52.3	166	18.6000	77.1000	7.5000	9.0000

Group of Carcinogens IARC Monograph (Group 1: Carcinogenic to humans; Group 2A: Probably carcinogenic to humans; Group 2B: Possibly carcinogenic to humans; Group 3: Non-carcinogenic)				Scrap metal Recycling Property line sampling points					
Parameter									
Total Metals (Water)	**Lowest Detection Limit**	**Units** µg/L = mg/L*1000	**Industrial Metals (North Nicolas Av.) IM1**	**Industrial Metals (East Gateway)IM2**	**Industrial Metals (Nelson South) IM 3**	**Industrial Metals (SW Borland) IM4**	**Industrial Metals (Versacold W) IM 5**	**Fort Richmond BACKGROUND 1 (A+B)**	**Fort Richmomd BACKGROUND 2 [A+B]**
Arsenic (As)-Total	0.00010	µg/L	0.15	0.27	0.3	0.72	0.23	<0.00010	0.00010
Cadmium (Cd)-Total	0.00010	µg/L	0.213000	0.398000	0.369000	1.53000	0.614000	0.0000081	0.0000124
Nickel (Ni)-Total	0.00050	µg/L	1.63	0.99	3.21	10.2	2.52	<0.00050	0.00074
Chromium (Cr)-Total	0.000050	µg/L	1.23	1.13	5.19	10.8	3.09	0.17000	0.26000
Lead (Pb)-Total	0.000050	µg/L	10.2	15	21.2	85.8	18.5	0.200000	0.199000
Mercury (Hg)-Total	0.0000050	µg/L	<0.0000050	<0.0000050	0.082	0.2	0.03	<0.0000050	<0.0000050
Copper (Cu)-Total	0.00050	mg/L	0.00894	0.00889	0.0261	0.0586	0.0179	0.00138	0.00182
Iron (Fe)-Total	0.0100	mg/L	0.248	0.252	0.959	3.66	0.749	0.032	0.067
Aluminum (Al)-Total	0.0030	mg/L	0.0882	0.148	0.24	0.432	0.145	0.0262	0.0403
Magnesium (Mg)-Total	0.005000	mg/L	0.391	0.926	0.856	1.2	0.471	0.226	0.386
Manganese (Mn)-Total	0.00010	mg/L	12.7000	11.7000	28.0000	72.2000	25.4000	2.90000	4.36000
Molybdenum (Mo)-Total	0.00005	mg/L	0.000426	0.000287	0.00145	0.0026	0.00138	0.000133	0.000114
Phosphorus (P)-Total	0.030000	mg/L	<0.030	0.041	0.062	0.094	0.031	<0.030	<0.030
Potassium (K)-Total	0.05	mg/L	0.264	0.53	0.339	0.287	0.217	0.301	0.348
Selenium (Se)-Total	0.0001	mg/L	<0.000050	<0.000050	0.000059	<0.000050	<0.000050	<0.000050	<0.000050
Strontium (Sr)-Total	0.0002000	mg/L	0.00806	0.00943	0.014	0.0246	0.012	0.00137	0.00226
Sulfur (S)-Total	0.50000	mg/L	<0.50	0.62	<0.50	<0.50	<0.50	<0.50	<0.50
Tin (Sn)-Total	0.00010	mg/L	0.00023	0.00018	0.00083	0.00272	0.00076	<0.00010	<0.00010
Titanium (Ti)-Total	0.00100	mg/L	0.00193	0.00454	0.00564	0.0102	0.00392	0.00128	0.00171

Uranium (U)-Total	0.000010	mg/L	0.000012	0.000028	0.00003	0.000048	0.000013	<0.000010	<0.000010
Zinc (Zn)-Total	0.003000	mg/L	124.000	39.9000	410.000	1660.00	493.000	7.5000	9.0000

Group of Carcinogens IARC Monograph (Group 1: Carcinogenic to humans; Group 2A: Probably carcinogenic to humans; Group 2B: Possibly carcinogenic to humans; Group 3: Non-carcinogenic)				Residential/Parkland Snow Sampling Points				
Parameter								
Total Metals (Water)	**Lowest Detection Limit**	**Units**	**Cherrier St. Point A (SSB1)**	**Cherrier St. Point B (SSB2)**	**Kavanagh Point A (SSB3)**	**Kavanagh Point B (SSB4)**	**Giroux Point A (SSB5)**	**Giroux Point B (SSB6)**
Arsenic (As)-Total	0.10000	µg/L	<0.10	0.21000	0.12000	0.15000	<0.00010	<0.00010
Beryllium (Be)-Total	0.00010	mg/L	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Cadmium (Cd)-Total	0.00010	mg/L	0.0201000	0.0592000	0.0233000	0.0517000	0.0403000	0.0233000
Nickel (Ni)-Total	0.00050	mg/L	<0.00050	0.83000	<0.00050	4.82000	<0.00050	<0.00050
Chromium (Cr)-Total	0.000050	mg/L	0.14000	0.74000	0.27000	0.49000	0.23000	0.24000
Lead (Pb)-Total	0.000050	mg/L	0.510000	3.80000	0.679000	5.04000	0.940000	1.05000
Mercury (Hg)-Total	0.0000050	mg/L	<0.0000050	<0.0000050	<0.0000050	<0.0000050	0.0000120	<0.0000050
Cobalt (Co)-Total	0.00010	mg/L	0.00018	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Antimony (Sb)-Total	0.00010	mg/L	0.00012	0.00029	0.00016	0.00023	0.00016	0.00021
Vanadium (V)-Total	0.00050	mg/L	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Copper (Cu)-Total	0.00050	mg/L	0.00141	0.00443	0.00177	0.00297	0.00180	0.00212
Iron (Fe)-Total	0.0100	mg/L	0.034	0.214	0.06	0.137	0.039	0.04
Aluminum (Al)-Total	0.0030	mg/L	0.0281	0.100	0.0318	0.0611	0.0259	0.0297
Manganese (Mn)-Total	0.00010	mg/L	4.33000	10.2000	4.89000	7.90000	4.62000	5.73000
Molybdenum (Mo)-Total	0.00005	mg/L	0.000082	0.000140	0.000113	0.000156	0.000102	0.000122

Phosphorus (P)-Total	0.030000	mg/L	<0.030	0.033	<0.030	0.036	<0.030	<0.030
Potassium (K)-Total	0.05	mg/L	0.106	0.138	0.103	0.176	0.114	0.174
Selenium (Se)-Total	0.0001	mg/L	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050
Strontium (Sr)-Total	0.0002000	mg/L	0.00208	0.00317	0.00236	0.00367	0.00260	0.00302
Sulfur (S)-Total	0.50000	mg/L	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Tin (Sn)-Total	0.00010	mg/L	<0.00010	0.00021	<0.00010	0.00096	<0.00010	<0.00010
Titanium (Ti)-Total	0.00100	mg/L	0.00111	0.00355	0.00112	0.0102	0.00106	0.00119
Uranium (U)-Total	0.000010	mg/L	<0.000010	0.000016	<0.000010	0.000010	<0.000010	<0.000010
Zinc (Zn)-Total	0.003000	mg/L	12.0000	43.4000	14.6000	35.6000	16.2000	18.0000

Group of Carcinogens IARC Monograph (Group 1: Carcinogenic to humans; Group 2A: Probably carcinogenic to humans; Group 2B: Possibly carcinogenic to humans; Group 3: Non-carcinogenic)								
Parameter								
Total Metals (Water)	**Lowest Detection Limit**	**Units**	**Doucet Point A (SSB7)**	**Doucet Point B(SSB8)**	**Kavanagh Park (SSB 9)**	**Happyland Park (SSB10)**	**Fort Richmond BACKGROUND 1 (A+B)**	**Fort Richmomd BACKGROUND 2 [A+B]**
Arsenic (As)-Total	0.10000	µg/L	0.17000	<0.00010	<0.00010	<0.00010	<0.00010	0.00010
Beryllium (Be)-Total	0.00010	mg/L	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010
Cadmium (Cd)-Total	0.00010	mg/L	0.0207000	0.0144000	0.0338000	0.0097000	0.0081000	0.0124000
Nickel (Ni)-Total	0.00050	mg/L	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	0.00074
Chromium (Cr)-Total	0.000050	mg/L	0.35000	0.33000	0.17000	0.24000	0.00017	0.00026
Lead (Pb)-Total	0.000050	mg/L	1.03000	1.08000	0.641000	0.667000	0.000200	0.000199
Mercury (Hg)-Total	0.0000050	mg/L	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050	<0.0000050
Cobalt (Co)-Total	0.00010	mg/L	<0.00010	0.00018	0.00021	0.00050	<0.00010	<0.00010
Antimony (Sb)-Total	0.00010	mg/L	0.00026	0.00031	0.00016	0.00021	0.00010	0.00013
Vanadium (V)-Total	0.00050	mg/L	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050
Copper (Cu)-Total	0.00050	mg/L	0.00305	0.00219	0.00172	0.00263	0.00138	0.00182
Iron (Fe)-Total	0.0100	mg/L	0.083	0.105	0.041	0.083	0.032	0.067
Aluminum (Al)-Total	0.0030	mg/L	0.0538	0.0567	0.0255	0.0479	0.0262	0.0403
Manganese (Mn)-Total	0.00010	mg/L	7.28000	6.70000	4.55000	5.98000	0.00290	0.00436
Molybdenum (Mo)-Total	0.00005	mg/L	0.000115	0.000117	0.000092	0.000115	0.000133	0.000114
Phosphorus (P)-Total	0.030000	mg/L	0.046	<0.030	<0.030	<0.030	<0.030	<0.030
Potassium (K)-Total	0.05	mg/L	0.307	0.206	0.102	0.431	0.301	0.348
Selenium (Se)-Total	0.0001	mg/L	<0.000050	<0.000050	0.000050	<0.000050	<0.000050	<0.000050
Strontium (Sr)-Total	0.0002000	mg/L	0.00582	0.00335	0.00228	0.00367	0.00137	0.00226

Sulfur (S)-Total	0.50000	mg/L	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Tin (Sn)-Total	0.00010	mg/L	<0.00010	0.00011	<0.00010	<0.00010	<0.00010	<0.00010
Titanium (Ti)-Total	0.00100	mg/L	0.00219	0.00206	0.00075	0.00174	0.00128	0.00171
Uranium (U)-Total	0.000010	mg/L	0.000012	0.000011	<0.000010	0.000011	<0.000010	<0.000010
Zinc (Zn)-Total	0.003000	mg/L	17.1000	15.8000	16.1000	9.3000	7.5000	9.0000

Table of Natural Logarithm Transformed Means Concentration of Heavy Metals

Site	**Heavy Metals**	**Concentrations (µg/L)**	**Transformed Data**
Industrial	Pb	30.1	3.405
Industrial	As	0.33	-1.109
Industrial	Cd	0.62	-0.478
Industrial	Cr	4.29	1.456
Industrial	Ni	3.71	1.311
Industrial	Hg	0.06	-2.813410717
Industrial	Zn	545	6.300785795
Industrial	Mn	30	3.401197382
Roadside	Pb	5.55	1.713797928
Roadside	As	0.48	-0.733969175
Roadside	Cd	0.08	-2.525728644
Roadside	Cr	2.2	0.78845736
Roadside	Ni	1.82	0.598836501
Roadside	Hg	0	#NUM!
Roadside	Zn	78.5	4.363098625
Roadside	Mn	30.9	3.430756184
Commercial	Pb	4.75	1.558144618
Commercial	As	0.3	-1.203972804
Commercial	Cd	0.06	-2.813410717
Commercial	Cr	0.99	-0.010050336

Commercial	Ni	0.86	-0.15082289
Commercial	Hg	0	#NUM!
Commercial	Zn	53.4	3.977810746
Commercial	Mn	11.2	2.415913778
Residential	Pb	1.42	0.350656872
Residential	As	0.09	-2.407945609
Residential	Cd	0.03	-3.506557897
Residential	Cr	0.3	-1.203972804
Residential	Ni	0.94	-0.061875404
Residential	Hg	0	#NUM!
Residential	Zn	9.3	2.2300144
Residential	Mn	6.07	1.803358605

Appendix C:

This section of the appendix provides the daytime hourly noise levels recorded on Digital Sound Level Meter in Mission Industrial Area and South St. Boniface between July and December 2018.

Fig. 3.4 Roadside air and noise monitoring on Marion and Archibald Roads in South St. Boniface, Winnipeg, Manitoba (June, 2018).

Figure 3.4: Industrial Metals Inc. Noise Monitoring Using Digital Sound Level Meter

Date	Location	Location	Daily Average LAeq (dBA)	Longitude	Latitude
12-Jul-18	Giroux	Residential	70.1	-97.1003	49.8846
12-Jul-18	Giroux	Residential	47.83	-97.1039	49.8849
12-Jul-18	Giroux	Residential	44.3	-97.1032	49.8849
12-Jul-18	Giroux	Residential	49.6	-97.0997	49.8842
12-Jul-18	Giroux	Residential	50.3	-97.1032	49.8848
12-Jul-18	Giroux	Residential	43.7	-97.1039	49.8848
12-Jul-18	Giroux	Residential	44.6	-97.1031	49.8844
12-Jul-18	Giroux	Residential	45.6	-97.1022	49.8849
12-Jul-18	Giroux	Residential	74.7	-97.1	49.8845
13-Jul-18	Kavanagh	Residential	73.4	-97.1006	49.8854
13-Jul-18	Kavanagh	Residential	43.5	-97.102	49.8856
13-Jul-18	Kavanagh	Residential	44.1	-97.0994	49.8849
13-Jul-18	Kavanagh	Residential	45.2	-97.1043	49.8851
13-Jul-18	Kavanagh	Residential	44.2	-97.1031	49.8856
13-Jul-18	Kavanagh	Residential	44.7	-97.1036	49.8855
13-Jul-18	Kavanagh	Residential	45.3	-97.1031	49.8856
13-Jul-18	Kavanagh	Residential	50.1	-97.1011	49.885
13-Jul-18	Kavanagh	Residential	78.1	-97.1006	49.8853
18-Jul-18	Kavanagh	Residential	68.1	-97.1006	49.8854
18-Jul-18	Kavanagh	Residential	50.5	-97.102	49.8856
18-Jul-18	Kavanagh	Residential	46.3	-97.1027	49.8856
18-Jul-18	Kavanagh	Residential	44.8	-97.1043	49.8851
18-Jul-18	Kavanagh	Residential	45.4	-97.1031	49.8856
18-Jul-18	Kavanagh	Residential	47.1	-97.1036	49.8855
18-Jul-18	Kavanagh	Residential	49.5	-97.1031	49.8856
18-Jul-18	Kavanagh	Residential	51.1	-97.1011	49.885
18-Jul-18	Kavanagh	Residential	70.3	-97.1006	49.8853
19-Jul-18	Doucet	Residential	69.8	-97.1021	49.8822
19-Jul-18	Doucet	Residential	51.2	-97.1015	49.8826
19-Jul-18	Doucet	Residential	48.7	-97.1023	49.8831
19-Jul-18	Doucet	Residential	46.4	-97.1002	49.8824
19-Jul-18	Doucet	Residential	52.3	-97.1011	49.8832
19-Jul-18	Doucet	Residential	48.9	-97.1019	49.8816
19-Jul-18	Doucet	Residential	47.2	-97.1012	49.8827
19-Jul-18	Doucet	Residential	50.7	-97.1012	49.8827
19-Jul-18	Doucet	Residential	76.9	-97.1018	49.8819
27-Jul-18	Cherrier	Residential	65.5	-97.0999	49.8838
27-Jul-18	Cherrier	Residential	53.4	-97.1009	49.884
27-Jul-18	Cherrier	Residential	46.8	-97.0987	49.8834

27-Jul-18	Cherrier	Residential	45.1	-97.1026	49.884
27-Jul-18	Cherrier	Residential	47.5	-97.1031	49.8836
27-Jul-18	Cherrier	Residential	52.6	-97.1034	49.884
27-Jul-18	Cherrier	Residential	51.5	-97.1036	49.8855
27-Jul-18	Cherrier	Residential	51.9	-97.1014	49.8834
27-Jul-18	Cherrier	Residential	62.6	-97.0998	49.8837
16-Jul-18	East Downwind	Industrial	66.2	-97.1016	49.8881
16-Jul-18	East Downwind	Industrial	62.8	-97.1016	49.8881
16-Jul-18	East Downwind	Industrial	63.5	-97.1016	49.8881
16-Jul-18	East Downwind	Industrial	67.1	-97.1016	49.8881
16-Jul-18	East Downwind	Industrial	65.5	-97.1016	49.8881
16-Jul-18	East Downwind	Industrial	60.8	-97.1016	49.8881
23-Jul-18	West Downwind	Industrial	78.5	-97.097	49.8876
23-Jul-18	West Downwind	Industrial	77.1	-97.097	49.8876
23-Jul-18	West Downwind	Industrial	74.7	-97.097	49.8876
23-Jul-18	West Downwind	Industrial	77.8	-97.097	49.8876
23-Jul-18	West Downwind	Industrial	79.3	-97.097	49.8876
23-Jul-18	West Downwind	Industrial	81.9	-97.097	49.8876
23-Jul-18	West Downwind	Industrial	79.5	-97.097	49.8876
24-Jul-18	West Downwind	Industrial	82.4	-97.0972	49.8879
24-Jul-18	West Downwind	Industrial	78.2	-97.0972	49.8879
24-Jul-18	West Downwind	Industrial	76.4	-97.0972	49.8879
24-Jul-18	West Downwind	Industrial	79.6	-97.0972	49.8879
24-Jul-18	West Downwind	Industrial	81.3	-97.0972	49.8879
24-Jul-18	West Downwind	Industrial	82.4	-97.0972	49.8879
24-Jul-18	West Downwind	Industrial	79.1	-97.0972	49.8879
26-Jul-18	North Downwind	Industrial	60.3	-97.0983	49.8865
26-Jul-18	North Downwind	Industrial	58.9	-97.0983	49.8865
26-Jul-18	North Downwind	Industrial	59.2	-97.0983	49.8865
26-Jul-18	North Downwind	Industrial	63.2	-97.0983	49.8865
26-Jul-18	North Downwind	Industrial	57.6	-97.0983	49.8865
26-Jul-18	North Downwind	Industrial	59.5	-97.0983	49.8865
26-Jul-18	North Downwind	Industrial	57.1	-97.0983	49.8865
30-Jul-18	Southwest Downwind	Industrial	77.5	-97.098	49.8895
30-Jul-18	Southwest Downwind	Industrial	82.8	-97.098	49.8895
30-Jul-18	Southwest Downwind	Industrial	76.1	-97.098	49.8895
30-Jul-18	Southwest Downwind	Industrial	80.6	-97.098	49.8895

30-Jul-18	Southwest Downwind	Industrial	79.3	-97.098	49.8895
30-Jul-18	Southwest Downwind	Industrial	82.5	-97.098	49.8895
30-Jul-18	Southwest Downwind	Industrial	65.7	-97.098	49.8895

Date	Location	Location	LAeq (dBA)	Longitude	Latitude
03-Aug-18	Doucet	Residential	77.7	-97.0995	49.8829
03-Aug-18	Doucet	Residential	52.8	-97.1019	49.8816
03-Aug-18	Doucet	Residential	49.5	-97.1012	49.8827
03-Aug-18	Doucet	Residential	50.2	-97.1012	49.8827
03-Aug-18	Doucet	Residential	47.4	-97.1018	49.8819
03-Aug-18	Doucet	Residential	48.4	-97.1011	49.8832
03-Aug-18	Doucet	Residential	50.7	-97.1019	49.8816
03-Aug-18	Doucet	Residential	51.2	-97.1012	49.8827
03-Aug-18	Doucet	Residential	78.2	-97.1018	49.8819
09-Aug-18	Giroux	Residential	71.8	-97.1003	49.8846
09-Aug-18	Giroux	Residential	48.3	-97.1039	49.8849
09-Aug-18	Giroux	Residential	51.9	-97.1032	49.8849
09-Aug-18	Giroux	Residential	47.8	-97.0997	49.8842
09-Aug-18	Giroux	Residential	46.2	-97.1032	49.8848
09-Aug-18	Giroux	Residential	54.6	-97.1039	49.8848
09-Aug-18	Giroux	Residential	47.1	-97.1031	49.8844
09-Aug-18	Giroux	Residential	45.4	-97.1022	49.8849
09-Aug-18	Giroux	Residential	69.6	-97.1	49.8845
10-Aug-18	Kavanagh	Residential	70.2	-97.1006	49.8854
10-Aug-18	Kavanagh	Residential	51.5	-97.102	49.8856
10-Aug-18	Kavanagh	Residential	46.8	-97.0994	49.8849
10-Aug-18	Kavanagh	Residential	44.2	-97.1043	49.8851
10-Aug-18	Kavanagh	Residential	42.6	-97.1031	49.8856
10-Aug-18	Kavanagh	Residential	44.9	-97.1036	49.8855
10-Aug-18	Kavanagh	Residential	47.3	-97.1031	49.8856
10-Aug-18	Kavanagh	Residential	49.7	-97.1011	49.885
10-Aug-18	Kavanagh	Residential	75.9	-97.1006	49.8853
15-Aug-18	Doucet	Residential	69.7	-97.1021	49.8822
15-Aug-18	Doucet	Residential	46.3	-97.1015	49.8826
15-Aug-18	Doucet	Residential	49.5	-97.1023	49.8831
15-Aug-18	Doucet	Residential	52.1	-97.1002	49.8824
15-Aug-18	Doucet	Residential	45.8	-97.1011	49.8832
15-Aug-18	Doucet	Residential	45.2	-97.1019	49.8816

15-Aug-18	Doucet	Residential	46	-97.1012	49.8827
15-Aug-18	Doucet	Residential	45.8	-97.1019	49.8816
15-Aug-18	Doucet	Residential	71.3	-97.1018	49.8819
16-Aug-18	Giroux	Residential	70.4	-97.1003	49.8846
16-Aug-18	Giroux	Residential	50.2	-97.1039	49.8849
16-Aug-18	Giroux	Residential	48.3	-97.1032	49.8849
16-Aug-18	Giroux	Residential	46.1	-97.0997	49.8842
16-Aug-18	Giroux	Residential	46.7	-97.1032	49.8848
16-Aug-18	Giroux	Residential	47.5	-97.1039	49.8848
16-Aug-18	Giroux	Residential	51.3	-97.1031	49.8844
16-Aug-18	Giroux	Residential	48.7	-97.1022	49.8849
16-Aug-18	Giroux	Residential	63.1	-97.1	49.8845
21-Aug-18	Doucet	Residential	72.6	-97.1021	49.8822
21-Aug-18	Doucet	Residential	52.9	-97.1015	49.8826
21-Aug-18	Doucet	Residential	47.3	-97.1023	49.8831
21-Aug-18	Doucet	Residential	48.6	-97.1002	49.8824
21-Aug-18	Doucet	Residential	46.4	-97.1011	49.8832
21-Aug-18	Doucet	Residential	50.8	-97.1019	49.8816
21-Aug-18	Doucet	Residential	49.6	-97.1012	49.8827
21-Aug-18	Doucet	Residential	53.1	-97.1002	49.8824
21-Aug-18	Doucet	Residential	77.5	-97.1018	49.8819
24-Aug-18	Cherrier	Residential	65.8	-97.0999	49.8838
24-Aug-18	Cherrier	Residential	48.2	-97.1009	49.884
24-Aug-18	Cherrier	Residential	46.4	-97.0987	49.8834
24-Aug-18	Cherrier	Residential	51.3	-97.1026	49.884
24-Aug-18	Cherrier	Residential	45.1	-97.1031	49.8836
24-Aug-18	Cherrier	Residential	45.4	-97.1034	49.884
24-Aug-18	Cherrier	Residential	47	-97.1036	49.8855
24-Aug-18	Cherrier	Residential	54.2	-97.1014	49.8834
24-Aug-18	Cherrier	Residential	73.4	-97.0998	49.8837
01-Aug-18	North	Industrial	65.2	-97.0989	49.8867
01-Aug-18	North	Industrial	63.6	-97.0989	49.8867
01-Aug-18	North	Industrial	69.4	-97.0989	49.8867
01-Aug-18	North	Industrial	70.7	-97.0989	49.8867
01-Aug-18	North	Industrial	70.9	-97.0989	49.8867
01-Aug-18	North	Industrial	67.3	-97.0989	49.8867
01-Aug-18	North	Industrial	66.8	-97.0989	49.8867
02-Aug-18	Southwest	Industrial	73.8	-97.0974	49.8891
02-Aug-18	Southwest	Industrial	79.2	-97.0974	49.8891
02-Aug-18	Southwest	Industrial	77.6	-97.0974	49.8891
02-Aug-18	Southwest	Industrial	74.1	-97.0974	49.8891

02-Aug-18	Southwest	Industrial	73.4	-97.0974	49.8891
02-Aug-18	Southwest	Industrial	70.2	-97.0974	49.8891
02-Aug-18	Southwest	Industrial	72.9	-97.0974	49.8891
07-Aug-18	Southwest	Industrial	73.8	-97.0974	49.8891
07-Aug-18	Southwest	Industrial	70.2	-97.0974	49.8891
07-Aug-18	Southwest	Industrial	69.6	-97.0974	49.8891
07-Aug-18	Southwest	Industrial	73.4	-97.0974	49.8891
07-Aug-18	Southwest	Industrial	70.7	-97.0974	49.8891
07-Aug-18	Southwest	Industrial	71.2	-97.0974	49.8891
07-Aug-18	Southwest	Industrial	72.4	-97.0974	49.8891
08-Aug-18	North	Industrial	84.2	-97.0978	49.8864
08-Aug-18	North	Industrial	81.5	-97.0978	49.8864
08-Aug-18	North	Industrial	83.8	-97.0978	49.8864
08-Aug-18	North	Industrial	82.1	-97.0978	49.8864
08-Aug-18	North	Industrial	84.9	-97.0978	49.8864
08-Aug-18	North	Industrial	80.7	-97.0978	49.8864
08-Aug-18	North	Industrial	81.4	-97.0978	49.8864
14-Aug-18	South	Industrial	57.6	-97.0989	49.8867
14-Aug-18	South	Industrial	55.3	-97.0989	49.8867
14-Aug-18	South	Industrial	52.8	-97.0989	49.8867
14-Aug-18	South	Industrial	50.2	-97.0989	49.8867
14-Aug-18	South	Industrial	52.6	-97.0989	49.8867
14-Aug-18	South	Industrial	58.1	-97.0989	49.8867
14-Aug-18	South	Industrial	56	-97.0989	49.8867
20-Aug-18	Southwest	Industrial	65.8	-97.0977	49.8903
20-Aug-18	Southwest	Industrial	67.2	-97.0977	49.8903
20-Aug-18	Southwest	Industrial	64.1	-97.0977	49.8903
20-Aug-18	Southwest	Industrial	65.6	-97.0977	49.8903
20-Aug-18	Southwest	Industrial	67.9	-97.0977	49.8903
20-Aug-18	Southwest	Industrial	68.3	-97.0977	49.8903
20-Aug-18	Southwest	Industrial	64.6	-97.0977	49.8903
23-Aug-18	North	Industrial	62.2	-97.0984	49.8864
23-Aug-18	North	Industrial	64.8	-97.0984	49.8864
23-Aug-18	North	Industrial	58.4	-97.0984	49.8864
23-Aug-18	North	Industrial	60.6	-97.0984	49.8864
23-Aug-18	North	Industrial	59.1	-97.0984	49.8864
23-Aug-18	North	Industrial	56.5	-97.0984	49.8864
23-Aug-18	North	Industrial	54.8	-97.0984	49.8864
27-Aug-18	North	Industrial	70.6	-97.097	49.8859
27-Aug-18	North	Industrial	67.2	-97.097	49.8859
27-Aug-18	North	Industrial	68.9	-97.097	49.8859

27-Aug-18	North	Industrial	66.4	-97.097	49.8859
27-Aug-18	North	Industrial	68.2	-97.097	49.8859
27-Aug-18	North	Industrial	65.4	-97.097	49.8859
27-Aug-18	North	Industrial	68.1	-97.097	49.8859
29-Aug-18	West	Industrial	79.4	-97.0972	49.888
29-Aug-18	West	Industrial	82.7	-97.0972	49.888
29-Aug-18	West	Industrial	80.2	-97.0972	49.888
29-Aug-18	West	Industrial	78.6	-97.0972	49.888
29-Aug-18	West	Industrial	77.9	-97.0972	49.888
29-Aug-18	West	Industrial	81.7	-97.0972	49.888
29-Aug-18	West	Industrial	82.9	-97.0972	49.888
30-Aug-18	Southwest	Industrial	76.3	-97.0974	49.8891
30-Aug-18	Southwest	Industrial	73.7	-97.0974	49.8891
30-Aug-18	Southwest	Industrial	78.1	-97.0974	49.8891
30-Aug-18	Southwest	Industrial	76.4	-97.0974	49.8891
30-Aug-18	Southwest	Industrial	75.3	-97.0974	49.8891
30-Aug-18	Southwest	Industrial	74.1	-97.0974	49.8891
30-Aug-18	Southwest	Industrial	73.8	-97.0974	49.8891

Date	Location	LAeq (dBA)	Longitude	Latitude
04-Sep-18	Industrial	78.3	-97.0974	49.8891
04-Sep-18	Industrial	77.7	-97.0974	49.8891
04-Sep-18	Industrial	78.1	-97.0974	49.8891
04-Sep-18	Industrial	81.4	-97.0974	49.8891
04-Sep-18	Industrial	79.3	-97.0974	49.8891
04-Sep-18	Industrial	78.1	-97.0974	49.8891
04-Sep-18	Industrial	83.8	-97.0974	49.8891
10-Sep-18	Industrial	80.4	-97.0972	49.888
10-Sep-18	Industrial	78.6	-97.0972	49.888
10-Sep-18	Industrial	77.3	-97.0972	49.888
10-Sep-18	Industrial	80.9	-97.0972	49.888
10-Sep-18	Industrial	81.2	-97.0972	49.888
10-Sep-18	Industrial	78.1	-97.0972	49.888
10-Sep-18	Industrial	77.9	-97.0972	49.888
11-Sep-18	Industrial	82.2	-97.0972	49.888
11-Sep-18	Industrial	83.4	-97.0971	49.8881
11-Sep-18	Industrial	76.9	-97.0971	49.8881
11-Sep-18	Industrial	81.2	-97.0971	49.8881
11-Sep-18	Industrial	80.6	-97.0971	49.8881
11-Sep-18	Industrial	79.2	-97.0971	49.8881
11-Sep-18	Industrial	81.8	-97.0971	49.8881

11-Sep-18	Industrial	74.3	-97.0971	49.8881
18-Sep-18	Industrial	75.8	-97.0975	49.8887
18-Sep-18	Industrial	76.1	-97.0975	49.8887
18-Sep-18	Industrial	75.2	-97.0975	49.8887
18-Sep-18	Industrial	82.7	-97.0975	49.8887
18-Sep-18	Industrial	83.5	-97.0975	49.8887
18-Sep-18	Industrial	84.1	-97.0975	49.8887
18-Sep-18	Industrial	82.8	-97.0975	49.8887
25-Sep-18	Industrial	79.3	-97.0975	49.8887
25-Sep-18	Industrial	79.5	-97.0972	49.888
25-Sep-18	Industrial	78.2	-97.0972	49.888
25-Sep-18	Industrial	73.9	-97.0972	49.888
25-Sep-18	Industrial	80.6	-97.0972	49.888
25-Sep-18	Industrial	81.1	-97.0972	49.888
25-Sep-18	Industrial	84.5	-97.0972	49.888
25-Sep-18	Industrial	81.2	-97.0972	49.888
26-Sep-18	Industrial	79.2	-97.0975	49.8887
26-Sep-18	Industrial	78.6	-97.0975	49.8887
26-Sep-18	Industrial	77.3	-97.0975	49.8887
26-Sep-18	Industrial	80.9	-97.0975	49.8887
26-Sep-18	Industrial	81.2	-97.0975	49.8887
05-Sep-18	Residential	67.5	-97.1021	49.8822
05-Sep-18	Residential	56.4	-97.1015	49.8826
05-Sep-18	Residential	52.7	-97.1023	49.8831
05-Sep-18	Residential	53.6	-97.1002	49.8824
05-Sep-18	Residential	55.2	-97.1011	49.8832
05-Sep-18	Residential	54.8	-97.1019	49.8816
05-Sep-18	Residential	55.6	-97.1012	49.8827
05-Sep-18	Residential	54.3	-97.1023	49.8831
05-Sep-18	Residential	65.2	-97.1018	49.8819
06-Sep-18	Residential	76.8	-97.0983	49.8818
06-Sep-18	Residential	59.4	-97.0994	49.8849
06-Sep-18	Residential	58.2	-97.1043	49.8851
06-Sep-18	Residential	54.3	-97.1031	49.8856
06-Sep-18	Residential	50.1	-97.1036	49.8855
06-Sep-18	Residential	52.5	-97.1031	49.8856
06-Sep-18	Residential	57.6	-97.102	49.8856
06-Sep-18	Residential	62.3	-97.1011	49.885
06-Sep-18	Residential	75.5	-97.0991	49.8822
12-Sep-18	Residential	68.2	-97.0983	49.8818
12-Sep-18	Residential	52.5	-97.0994	49.8849

12-Sep-18	Residential	48.6	-97.1043	49.8851
12-Sep-18	Residential	45.2	-97.1031	49.8856
12-Sep-18	Residential	49.8	-97.1036	49.8855
12-Sep-18	Residential	53.4	-97.1031	49.8856
12-Sep-18	Residential	50.2	-97.102	49.8856
12-Sep-18	Residential	51	-97.1011	49.885
12-Sep-18	Residential	74.9	-97.0991	49.8822
13-Sep-18	Residential	65.7	-97.0999	49.8838
13-Sep-18	Residential	48.7	-97.1009	49.884
13-Sep-18	Residential	49.6	-97.0987	49.8834
13-Sep-18	Residential	50.2	-97.1026	49.884
13-Sep-18	Residential	48.5	-97.1031	49.8836
13-Sep-18	Residential	53.7	-97.1034	49.884
13-Sep-18	Residential	45.4	-97.1036	49.8855
13-Sep-18	Residential	47.9	-97.1014	49.8834
13-Sep-18	Residential	64.8	-97.0998	49.8837
17-Sep-18	Residential	73.2	-97.1021	49.8822
17-Sep-18	Residential	50.4	-97.1015	49.8826
17-Sep-18	Residential	52.1	-97.1023	49.8831
17-Sep-18	Residential	50.5	-97.1002	49.8824
17-Sep-18	Residential	48.6	-97.1011	49.8832
17-Sep-18	Residential	53.5	-97.1019	49.8816
17-Sep-18	Residential	49.2	-97.1012	49.8827
17-Sep-18	Residential	48.8	-97.1011	49.8832
17-Sep-18	Residential	74.1	-97.1018	49.8819
20-Sep-18	Residential	66.5	-97.0999	49.8838
20-Sep-18	Residential	57.4	-97.1009	49.884
20-Sep-18	Residential	55.2	-97.0987	49.8834
20-Sep-18	Residential	49.6	-97.1026	49.884
20-Sep-18	Residential	54.3	-97.1031	49.8836
20-Sep-18	Residential	56.4	-97.1034	49.884
20-Sep-18	Residential	57.5	-97.1036	49.8855
20-Sep-18	Residential	60.1	-97.1014	49.8834
20-Sep-18	Residential	67.5	-97.0998	49.8837

Date	Location	LAeq (dBA)	Longitude	Latitude
01-Oct-18	Residential	64.8	-97.1003	49.8846
01-Oct-18	Residential	44.5	-97.1039	49.8849
01-Oct-18	Residential	49.8	-97.1032	49.8849
01-Oct-18	Residential	50.2	-97.0997	49.8842
01-Oct-18	Residential	49.4	-97.1032	49.8848
01-Oct-18	Residential	51.6	-97.1039	49.8848
01-Oct-18	Residential	50.8	-97.1031	49.8844
01-Oct-18	Residential	48.3	-97.1022	49.8849
01-Oct-18	Residential	68.3	-97.1	49.8845
09-Oct-18	Residential	66.1	-97.0999	49.8838
09-Oct-18	Residential	54.6	-97.1009	49.884
09-Oct-18	Residential	49.3	-97.0987	49.8834
09-Oct-18	Residential	45.9	-97.1026	49.884
09-Oct-18	Residential	48.5	-97.1031	49.8836
09-Oct-18	Residential	50.7	-97.1034	49.884
09-Oct-18	Residential	48.6	-97.1036	49.8855
09-Oct-18	Residential	53.2	-97.1014	49.8834
09-Oct-18	Residential	65.7	-97.0998	49.8837
10-Oct-18	Residential	63.9	-97.1006	49.8854
10-Oct-18	Residential	57.8	-97.102	49.8856
10-Oct-18	Residential	56.5	-97.0994	49.8849
10-Oct-18	Residential	54.9	-97.1043	49.8851
10-Oct-18	Residential	54.4	-97.1031	49.8856
10-Oct-18	Residential	61	-97.1036	49.8855
10-Oct-18	Residential	58.2	-97.1031	49.8856
10-Oct-18	Residential	59.7	-97.1011	49.885
10-Oct-18	Residential	66.4	-97.1006	49.8853
18-Oct-18	Residential	67.2	-97.1006	49.8854
18-Oct-18	Residential	46.6	-97.102	49.8856
18-Oct-18	Residential	47.9	-97.0994	49.8849
18-Oct-18	Residential	46.2	-97.1043	49.8851
18-Oct-18	Residential	49.5	-97.1031	49.8856
18-Oct-18	Residential	46.3	-97.1036	49.8855
18-Oct-18	Residential	45.1	-97.1031	49.8856
18-Oct-18	Residential	45.7	-97.1011	49.885
18-Oct-18	Residential	62.7	-97.1006	49.8853
22-Oct-18	Residential	77.4	-97.1021	49.8822
22-Oct-18	Residential	51.2	-97.1015	49.8826
22-Oct-18	Residential	50.6	-97.1023	49.8831
22-Oct-18	Residential	48.9	-97.1002	49.8824

22-Oct-18	Residential	54.2	-97.1011	49.8832
22-Oct-18	Residential	52.4	-97.1019	49.8816
22-Oct-18	Residential	49.6	-97.1012	49.8827
22-Oct-18	Residential	54.5	-97.1019	49.8816
22-Oct-18	Residential	73.5	-97.1018	49.8819
24-Oct-18	Residential	64.1	-97.0999	49.8838
24-Oct-18	Residential	45.4	-97.1009	49.884
24-Oct-18	Residential	46.7	-97.0987	49.8834
24-Oct-18	Residential	48.5	-97.1026	49.884
24-Oct-18	Residential	50.2	-97.1031	49.8836
24-Oct-18	Residential	49.6	-97.1034	49.884
24-Oct-18	Residential	48.4	-97.1036	49.8855
24-Oct-18	Residential	48.7	-97.1014	49.8834
24-Oct-18	Residential	65.8	-97.0998	49.8837
31-Oct-18	Residential	68.5	-97.1003	49.8846
31-Oct-18	Residential	50.6	-97.1039	49.8849
31-Oct-18	Residential	48.4	-97.1032	49.8849
31-Oct-18	Residential	47.1	-97.0997	49.8842
31-Oct-18	Residential	49.3	-97.1032	49.8848
31-Oct-18	Residential	49.7	-97.1039	49.8848
31-Oct-18	Residential	48.4	-97.1031	49.8844
31-Oct-18	Residential	52.3	-97.1022	49.8849
31-Oct-18	Residential	68.1	-97.1	49.8845
02-Oct-18	Industrial	58.2	-97.0975	49.8887
02-Oct-18	Industrial	57.8	-97.0975	49.8887
02-Oct-18	Industrial	58.2	-97.0972	49.888
02-Oct-18	Industrial	59.6	-97.0972	49.888
02-Oct-18	Industrial	58.1	-97.0972	49.888
02-Oct-18	Industrial	54.9	-97.0972	49.888
02-Oct-18	Industrial	54.8	-97.0972	49.888
04-Oct-18	Industrial	76.2	-97.1016	49.8881
04-Oct-18	Industrial	77.5	-97.1016	49.8881
04-Oct-18	Industrial	74.7	-97.1016	49.8881
04-Oct-18	Industrial	73.2	-97.1016	49.8881
04-Oct-18	Industrial	75.7	-97.1016	49.8881
04-Oct-18	Industrial	77.9	-97.1016	49.8881
04-Oct-18	Industrial	75.2	-97.1016	49.8881
15-Oct-18	Industrial	82.3	-97.0979	49.8895
15-Oct-18	Industrial	81.1	-97.0979	49.8895
15-Oct-18	Industrial	80.6	-97.0979	49.8895
16-Oct-18	Industrial	75.6	-97.0979	49.8895

16-Oct-18	Industrial	77.9	-97.0979	49.8895
16-Oct-18	Industrial	77.3	-97.0979	49.8895
16-Oct-18	Industrial	76.6	-97.0979	49.8895
16-Oct-18	Industrial	78.2	-97.0974	49.8885
16-Oct-18	Industrial	79.5	-97.0974	49.8885
16-Oct-18	Industrial	78.1	-97.0974	49.8885
17-Oct-18	Industrial	81.6	-97.097	49.8875
17-Oct-18	Industrial	82.2	-97.097	49.8875
17-Oct-18	Industrial	84.6	-97.097	49.8875
17-Oct-18	Industrial	81.9	-97.097	49.8875
17-Oct-18	Industrial	81.2	-97.097	49.8875
17-Oct-18	Industrial	82.8	-97.097	49.8875
17-Oct-18	Industrial	78.1	-97.097	49.8875
25-Oct-18	Industrial	55.9	-97.0966	49.8875
25-Oct-18	Industrial	53.8	-97.0966	49.8875
25-Oct-18	Industrial	56.1	-97.0966	49.8875
25-Oct-18	Industrial	52.6	-97.0966	49.8875
25-Oct-18	Industrial	55.8	-97.0966	49.8875
25-Oct-18	Industrial	54.5	-97.0966	49.8875
25-Oct-18	Industrial	53.9	-97.0966	49.8875
29-Oct-18	Industrial	55.5	-97.0989	49.8905
29-Oct-18	Industrial	56.8	-97.0989	49.8905
29-Oct-18	Industrial	56.1	-97.0989	49.8905
29-Oct-18	Industrial	58.6	-97.0989	49.8905
29-Oct-18	Industrial	56.8	-97.0989	49.8905
29-Oct-18	Industrial	57.5	-97.0989	49.8905
29-Oct-18	Industrial	55.9	-97.0989	49.8905
30-Oct-18	Industrial	68.2	-97.0989	49.8905
30-Oct-18	Industrial	67.3	-97.0989	49.8905
30-Oct-18	Industrial	66.6	-97.0989	49.8905
30-Oct-18	Industrial	68.7	-97.0989	49.8905
30-Oct-18	Industrial	69.5	-97.0989	49.8905
30-Oct-18	Industrial	68	-97.0989	49.8905
30-Oct-18	Industrial	68.3	-97.0989	49.8905

November/December 2018

Longitude	Latitude	Location	LAeq (dBA)
-97.0989	49.8905		55.5
-97.0989	49.8905		53.8
-97.0989	49.8905		56.1
-97.0989	49.8905		52.6

-97.0989	49.8905		52.8
-97.0989	49.8905		54.5
-97.0989	49.8905		53.9
-97.0989	49.8905		58.6
-97.0989	49.8905		57.2
-97.0989	49.8905		55.8
-97.0989	49.8905		56.1
-97.0989	49.8905		56.9
-97.0989	49.8905		54.8
-97.0989	49.8905		58.5
-97.0989	49.8905		59.2
-97.0978	49.8903		70.4
-97.0978	49.8903		71.2
-97.0978	49.8903		67.8
-97.0978	49.8903		69.6
-97.0978	49.8903		65.4
-97.0978	49.8903		66
-97.0978	49.8903		66.1
-97.0977	49.8908		62.7
-97.0977	49.8908		58.3
-97.0977	49.8908		57.6
-97.0977	49.8908		56.8
-97.0977	49.8908		59.2
-97.0989	49.8905		56.7
-97.0989	49.8905		58.1
-97.0989	49.8905		57.4
-97.0989	49.8905		56.3
-97.0989	49.8905		58.6
-97.0977	49.8903		65.7
-97.0977	49.8903		63.6
-97.0977	49.8903		64.8
-97.0977	49.8903		65.2
-97.0978	49.8894		62.8
-97.0978	49.8894		67.5
-97.0978	49.8894		69.2
-97.0978	49.8894		66.4
-97.0988	49.8906		65.2
-97.0988	49.8906		66.3
-97.0988	49.8906		64.6
-97.0988	49.8906		64.2
-97.102	49.8856		49.8

-97.0994	49.8849		52.2
-97.1043	49.8851		54.3
-97.1031	49.8856		54.7
-97.1036	49.8855		55.1
-97.102	49.8856		56.6
-97.0994	49.8849		55.5
-97.1043	49.8851		56.8
-97.1015	49.8826		46.8
-97.1023	49.8831		48.4
-97.1002	49.8824		47.5
-97.0987	49.8834		56.9
-97.1026	49.884		58.5
-97.1031	49.8836		57
-97.1034	49.884		57.8
-97.1043	49.8851		53.2
-97.1031	49.8856		51.8
-97.1036	49.8855		50.5
-97.102	49.8856		48.7
-97.0994	49.8849		52.4
-97.1015	49.8826		49.4
-97.1023	49.8831		50.8
-97.1002	49.8824		49.2
-97.1011	49.8832		48.9
-97.1023	49.8831		52.1
-97.1011	49.8832		51.3
-97.102	49.8856		45.2
-97.0994	49.8849		46
-97.1043	49.8851		48.1
-97.1031	49.8856		49.4
-97.1036	49.8855		50.2
-97.1032	49.8849		44.7
-97.0997	49.8842		48.9
-97.1032	49.8848		47.2
-97.1039	49.8848		46.5
-97.1031	49.8844		46
-97.1009	49.884		45.2
-97.0987	49.8834		48.3
-97.1026	49.884		46.5
-97.1031	49.8836		49.7
-97.1034	49.884		51.1