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Spatial Relationships Between Socio-Economic Status And Sources of Hazardous Air Pollution in the City of Toronto, Canada

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SPATIAL RELATIONSHIPS BETWEEN SOCIO-ECONOMIC STATUS AND SOURCES OF HAZARDOUS AIR POLLUTION IN THE CITY OF TORONTO, CANADA

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ABSTRACT

This research paper identifies and characterizes areas in the City of Toronto that may be impacted by facilities that emit air pollutants. The impacted areas were isolated using a combination of K-Means cluster analysis and kernel density estimation to determine whether disparity in socio-economic status can be correlated with the location of these facilities. Dissemination Area (DA) level data from the 2006 Canadian Census were evaluated against pollution data provided by Environment Canada's 2006 National Pollutant Release Inventory (NPRI) database. A total of 67 socio-economic variables from the 2006 Statistics Canada census were analysed. The City of Toronto's 3,577 DAs were assigned to one of two cluster groups: Underprivileged Areas, or Areas of Affluence. The DAs represented by the two cluster groups were then analyzed alongside the NPRI pollution data, which had been developed into generalized concentration ranges using a 5km search radius. Although the Areas of Affluence cluster contains 15% more facilities (141) than the Underprivileged Areas (104), the latter are generally impacted by higher concentrations of a more diverse range of pollution. For example, a larger percent of Toronto residents living in Underprivileged Areas are exposed to the highest concentrations of total emissions, heavy metals, miscellaneous compounds, and non-carcinogenic emissions when compared to the population of DAs designated as Areas of Affluence. Conversely, a larger percent of residents living in Areas of Affluence are generally exposed to the highest concentrations of volatile organic compounds and carcinogenic emissions. The findings suggest an environmental justice concern, with respect to industrial air pollution within the City of Toronto.

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AERMOD – AMS / EPA Regulatory Model

CAC – Criteria Air Contaminant

CALPUFF – California Puff Model

CDC – Centers for Disease Control and Prevention

CSD – Census Subdivision

CT – Census Tract

DA – Dissemination Area / Enumeration Area

HRSDC – Human Resources and Skills Development Canada

ESRI® – Environmental Systems Research Institute

ISC3 – Industrial Source Complex 3 Model

KMO – Kaiser-Meyer-Olkin

LICO – Low Income Cut-offs

LiDAR – Light Detection and Ranging

LIM – Low Income Measures

MBM – Market Basket Measure

NPRI – National Pollutant Release Inventory

PASW® – Predictive Analytics SoftWare

SPSS™ – Statistical Package for the Social Sciences

TEP – Toxic Equivalency Potential

USDA – United States Department of Agriculture

USEPA – United States Environmental Protection Agency

VOC – Volatile Organic Compound

CHAPTER 1. Introduction

1.1. Research Background

The complex relationship between socio-economic status and pollution has been studied in many cities throughout the world by environmental researchers during the past number of decades. Similar to other major urban centres in North America, the human health effects caused by airborne pollution have become a major concern for both public administrators in the City of Toronto, and environmental scientists monitoring the situation. Nevertheless, "[i]n Canada, relatively few studies exist examining the relationship between pollution and social factors" (Pollution Watch, 2008, p.2).

Air pollution in the City of Toronto has been linked in recent years to high morbidity rates that are often associated with this phenomenon (Kantor et al., 2010). A technical report published for Toronto Public Health "estimate[s] that approximately 1,700 premature deaths each year, and between 3,000 and 6,000 hospital admissions are associated with the criteria pollutants O_3, NO_2, SO_2, CO, and PM_{10}" (Pengelly and Sommerfreund, 2004, p.17). In addition to contributing to premature deaths and elevated hospital admissions, Landrigan et al. (2010) suggests that the release of harmful chemical reagents into the atmosphere has been proven to cause a range of health issues including asthma, autoimmune disease, heart and lung disease, physical abnormalities in newborns, sudden infant death syndrome, and neurological impairment. However, additional research is needed to help better understand the intricacies of the social and economic conditions in Toronto and how these variables relate to air pollution.

1.2. Study Area

The research reported in this paper focuses on the City of Toronto, which is located in the Province of Ontario along the northwestern shoreline of Lake Ontario. The City of Toronto (Figure 1), in addition to being Canada's largest urban area, covers a land surface area of 634.15 km^2 and represents a population of approximately 2.5 million people. Furthermore, Toronto is bordered by the municipalities of Mississauga to the west, Vaughan and Markham along the north, and Pickering to the east. The primary study area developed for this research is made up of the 3,577 Dissemination Areas (DAs) located within the borders of the city.

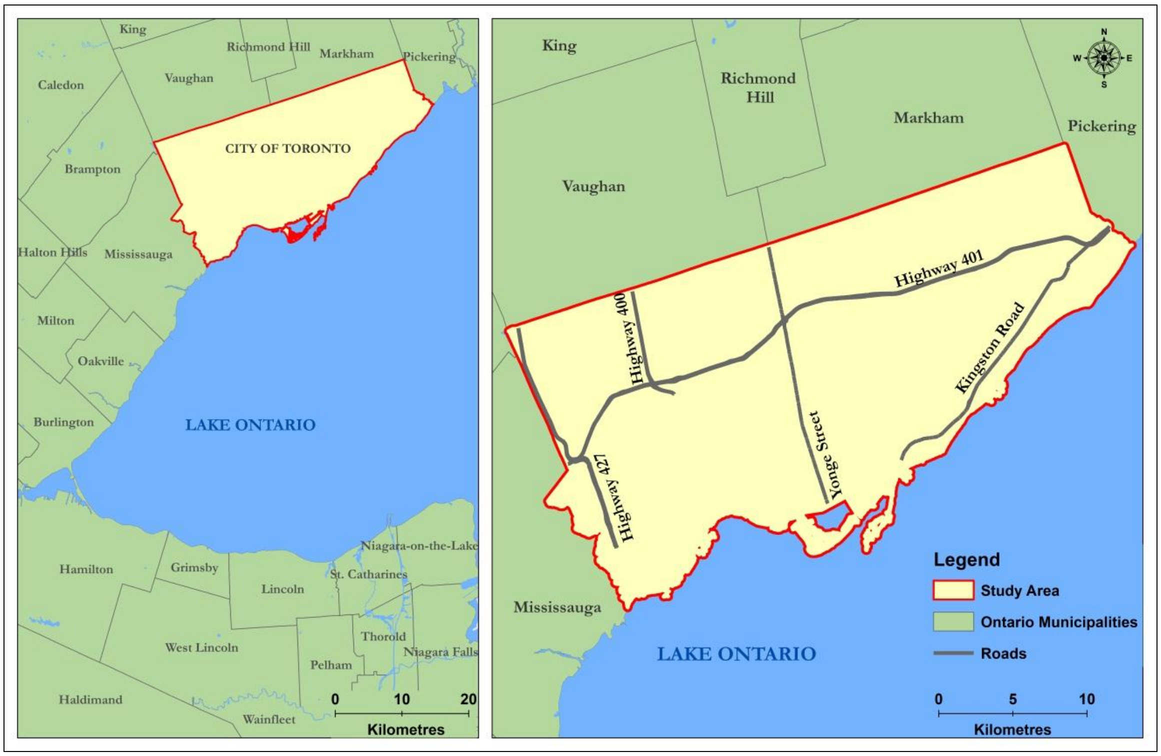

Figure 1: Overview Map of Toronto, Ontario

1.3. Research Objectives and Hypothesis

The objective of this research is to identify whether specific segments of the City of Toronto's population are living near industries that are emitting elevated levels of harmful airborne contaminants. To accomplish this objective, Statistics Canada 2006 census data at the DA level were combined with 2006 NPRI air pollution source data. The 2006 census year and the corresponding 2006 NPRI data were selected for this study, to establish a common point in time to examine both geodemographics and NPRI monitored air pollution output in Toronto. The corresponding 2006 NPRI data tracked the output of 1,068 chemicals from the largest polluting sites in Canada. Specifically, a total of 247 facilities in Toronto (Figure 2) were reported as being the source of 79 measurable types of air pollutants.

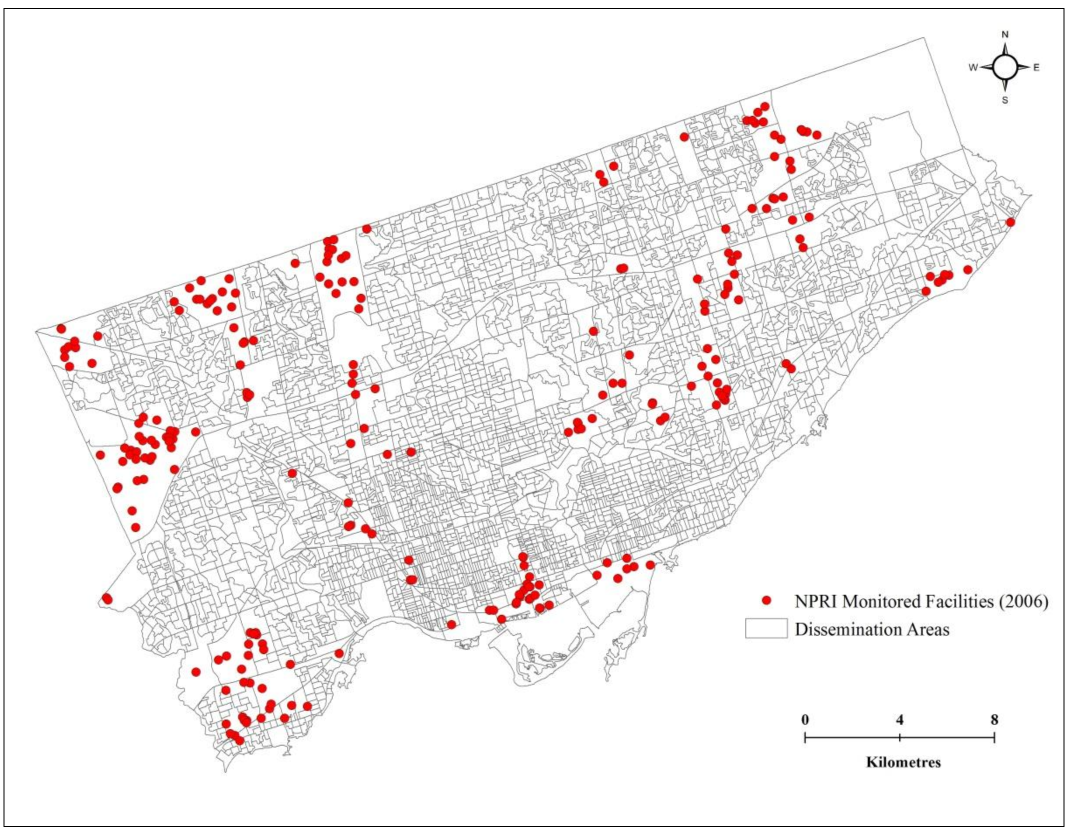

Figure 2: Location of NPRI Monitored Facilities in Toronto

The majority of the chemicals monitored by the NPRI are highly toxic and capable of inflicting serious health disorders if exposed to over a significant period of time. Kernel density estimation was selected as a means of identifying areas of the city that are potentially affected by the release of chemical contaminants from nearby NPRI monitored facilities. In addition to the use of kernel density estimation, specific at-risk demographics of the population were isolated using the census data based on previous pollution research conducted by Landrigan et al. (2010), Day (2010), Su et al. (2011), Konisky and Schario (2010), Gilbert and Chakraborty (2011), Villeneuve et al. (2003), Jerrett et al. (2001), Buzzelli and Jerrett (2007), and Premji et al. (2007).

A total of 67 statistical variables representing age, gender, marital status, citizenship, immigration status, ethnic origin, education, rates of employment, field of employment, after-tax individual income levels, rates of individual and family low income, housing ownership, time period of housing construction, and housing type were aggregated using the 2006 census. Through the application of cluster analysis, the 67 aggregated variables were analyzed in conjunction with the kernel density estimation results, to detect the spatial relationship between socio-economic status and density of air pollution.

The hypothesis of this research paper is that after-tax income levels and ethnic origin of residential population at the DA level share a relationship with annual exposure to emissions released from NPRI monitored facilities. The reasons for environmental disparity in a region are highly complex, as they often relate to the historical, economic, cultural, and demographic influences on settlement patterns of the urban space. This research does not seek to study actual exposure to air pollutants. Rather, the purpose of this study is to examine the social and economic characteristics of Toronto DAs that were affected by the emissions from NPRI monitored facilities in 2006, and determine whether specific demographics are more greatly impacted by specific types of pollutants.

CHAPTER 2. Literature Review

2.1. Pollution Research in the City of Toronto

According to Buzzelli and Jerrett (2007), the City of Toronto has a high rate of social disparity and segregation when compared to other major Canadian urban centres. Toronto exhibits some of the most extreme cases of intra-urban wealth and despair gradients. International pollution research has often concluded that "[i]ncome inequality negatively affects environmental quality, and that environment degradation worsens population health" (Drabo, 2011, p.157). Given the negative health impacts found by Pengelly and Sommerfreund (2004) for Toronto Public Health with regards to air pollution, areas within the City of Toronto may be exposed to above-average concentrations of chemical pollutants based on socio-economic status.

Airborne pollution in itself does not necessarily represent a risk in terms of instigating negative health side-effects. Rather, the potential for chemically induced disease is determined by the concentration, proximity, and relative toxicity of exposure (Premji et al., 2007). Given that a wide range of chemicals are released, both within and in the periphery of large urban areas, "there remains considerable uncertainty as to which population subgroups may be more susceptible to deleterious health effects" (Villeneuve et al., 2003, p.427). Chemical contaminants will not react in the same way when brought into contact with a living organism. While some contaminants such as airborne heavy metals demonstrate a definite risk to an affected population, other chemical emissions such as carbon dioxide are more benign in nature. Research published by Jerrett et al. (2001) reveals that the development of accurate exposure assessments is often difficult.

The myriad of geographical variables that affect the spread of airborne contaminants have hindered past environmental research studying air pollution, in developing precise exposure assessments that can be adopted by government. For instance, Scire et al. (2000) recommends applying geophysical, surface atmospheric, and upper atmospheric input datasets in the formulation of an accurate dispersion model. Geophysical data include surface roughness lengths, land use categories, terrain elevations, and leaf area indices. In addition to the surface geophysical data, the meteorological datasets include wind direction, wind speed, temperature gradients, air density gradients, stability classes, mixing heights, precipitation, short-wave solar radiation, and relative humidity.

2.2. Contemporary Air Pollution Research

Research focusing on the relationship between settlement patterns and air pollution, to date, has primarily dealt with the potential links between pollution and four primary census variables, including age (Landrigan et al., 2010; Day, 2010), racial background (Su et al., 2011; Konisky and Schario, 2010; Gilbert and Chakraborty, 2011), economic and educational status (Villeneuve et al., 2003; Jerrett et al., 2001; Buzzelli and Jerrett, 2007; Premji et al., 2007), and the incidence of pollution related disease (Drabo, 2011). Research conducted in Canadian cities (Kantor et al., 2010; Jerrett et al., 2001; Jerrett et al., 2005; Villeneuve et al., 2003) has focused on ascertaining how vehicle emissions such as nitrogen oxides (NO_X), sulfur oxides (SO_X), volatile organic compounds (VOCs), particulate matter (PM_X), and ground level ozone (O_3) relate to social and health related variables. Among the above studies, Premji et al. (2007) have utilized the Environment Canada NPRI when studying the relationship between socio-economic status and pollution on Montreal Island, Quebec. Furthermore, Cheng et al. (2009) have conducted research on the release of atmospheric mercury reported in the NPRI in Toronto, Ontario.

Published research has not yet developed a general consensus regarding the relationship between socio-economic status and pollution. The research findings published by Premji et al., (2007) suggest that only select census variables have a relationship with pollution data. Census variables such as unemployment, secondary sector employment, the proportion of residents without post-secondary education, children, the elderly, recent immigrants, and minorities were all found to share a proximity relationship with the geographic location of pollution sources. While a person's age can potentially elevate the detrimental effects of pollutants, ethnicity, recent immigrant status, low economic status, and low education status are generally viewed by environmental justice researchers as holding the greatest geographic association with the sources of pollution.

Environmental justice is a broad concept "concerned both analytically and practically with social equality in environmental quality and access to environmental goods; and with ensuring that those already disadvantaged in society are not further disadvantaged in these terms" (Day, 2010, p.2658). Environmental justice research attempts to determine "whether economically and politically disadvantaged communities bear a disproportionate burden of the impacts of exposure to environmental hazards" (Villeneuve et al., 2003, p.427). The reasons for environmental disparity in a region are highly complex as they often relate to the historical, economic, cultural, and demographic influences on settlement patterns of the urban space. Furthermore, "[e]nvironmental justice advocates have often contended that disparities in environmental risks faced by minority and low-income groups are in part due to unequal protection provided by government" (Konisky and Schario, 2010, p.835).

Furthermore, the geographic level of detail to which the socio-economic data were aggregated, also has a significant influence on the results of comparing pollution source data with census data. Prior studies have utilized Statistics Canada data reported for Census Subdivisions (CSDs) (Premji et al., 2007), Census Tracts (CTs) (Jerrett et al., 2005; Buzzelli and Jerrett, 2007), and Census Dissemination Areas (DAs) (Villeneuve et al., 2003). While larger statistical areas such as CSDs can be successfully developed into a socio-economic model, as was demonstrated by Premji et al. (2007), researchers who have utilized the smallest possible areas, such as DAs, had greater success in detecting a relationship between socio-economic status and pollution.

2.3. The National Pollutant Release Inventory (NPRI)

The most comprehensive environmental monitoring database currently available to the Canadian public is Environment Canada's NPRI. The NPRI was developed in 1992, as part of the Canadian federal government's policy of Multi-Stakeholder Consultations (MSCs), which attempts to represent a range of government administrative and business interests to gain a consensus in balancing between economic and environmental concerns (Henriques and Sadorsky, 2008). The NPRI was modeled after its American counterpart, the United States Environmental Protection Agency's (USEPA) Toxic Release Inventory (TRI), enacted six years earlier in 1986, as part of the Emergency Planning and Community Right-to-Know Act (United States Environmental Protection Agency, 2011).

The Canadian Environmental Protection Act, established in 1999, requires under the authority of Sections 46-50 that facilities operating within Canada meet specific reporting criteria (Environment Canada, 2011).

Facilities are required to submit an annual report to Environment Canada summarizing pollutant releases to air, water and land, disposals, and transfers for recycling (Dunn, 2009). Working in conjunction with Environment Canada, facilities that meet the requirements to report to the NPRI must calculate annual emissions rates. A combination of seven reporting methods utilize emissions measurement instruments to calculate the average discharge flow rate, or take into consideration the amount of materials being transformed into emissions during facility operation through mathematical calculations. The seven reporting methods include continuous emission monitoring systems, predictive emission monitoring, source testing, mass balance, site-specific emission factor, published emission factor, and engineering estimates (Environment Canada, 2010). The NPRI currently details the pollutant releases, disposals, and transfers of approximately 8,400 facilities operating across the country and reports on 366 listed chemical substances (Environment Canada, 2011).

2.3.1. NPRI Data Limitations

Although the NPRI is an invaluable tool for the advancement of environmental research, the statistics reported have a number of drawbacks that must be gradually improved upon by Environment Canada. It has been suggested, "[w]hile these reports provide invaluable information on pollution sources in Canada and quantities of pollutants released to the Canadian environment, they nonetheless fall short of the public's desire for meaningful interpretation of the data" (Dunn, 2009, p.580). Premji et al. (2007) stipulate that NPRI typically underestimates pollution values, as it does not reference emissions from facilities too small or exempt from reporting. NPRI data accuracy has also been called into question by Dunn (2009) as current methodologies practiced by the Government of Canada, such as the NPRI, only report a small percentage of potential emissions, and do not consider the relative toxicity of the chemicals.

Landrigan et al. (2010) have reported that a substantial percentage of High Production Volume (HPV) chemical emissions have never been tested for environmental toxicity. Currently, "[i]nformation on potential toxicity is publicly available for only about two-thirds of the 3,000 HPV chemicals. Information on possible developmental toxicity or the potential capacity to cause injury to infants and children is especially lacking. This information is available for less than one-third of HPV chemicals" (Landrigan et al., 2010, p.180). At present, environmental research in Canada must contend with serious study limitations "because of the lack of high quality environmental monitoring data" (Buzzelli and Jerrett, 2007, p.196). Environment Canada has demonstrated its intent to improve the NPRI, by continuing to test for additional chemical releases as the inventory is expanded each year. Despite current methodological issues, "[t]he NPRI remains…a uniquely valuable source of pollution emission data" (Premji et al., 2007, p.142).

2.3.2. Chemical Toxic Equivalency Potential

To overcome the lack of toxicity reporting by the NPRI, researchers such as Dunn (2009), and Cheng et al. (2009) have incorporated risk ranking and scoring systems to augment the methodologies developed as part of their publications. The potential impacts of chemical emissions on the Earth's biosphere are enhanced by examining the respective Toxic Equivalency Potential (TEP) of the emissions. TEPs were first developed in 1994 for the USEPA, which was working in conjunction with the University of Tennessee. The purpose of TEPs was to create a scientifically standardized method whereby every manufactured chemical could be ranked according to the health risk imposed on an individual when exposed to such an emission (Davis et al., 1994). Dunn (2009) suggests that by providing such a ranking system to NPRI data, priority study areas can be more easily identified for the purposes of environmental remediation.

A readily available online database containing the relative toxicity rankings for gaseous, liquid, and solid chemicals has been established in the United States by Environmental Defense. The database, designated as Scorecard, was established on April 22, 1998 as a freely available public-information service under the supervision of toxicologist Dr. William Pease. At present, the Scorecard TEP database contains information on 356 airborne chemicals, which have been researched using approximately 400 chemical databases published through the USEPA, USDA, and CDC (Scorecard, 2011). The Scorecard TEPs are based upon the associated risk a particular chemical has in comparison to a more widely known type of chemical. For chemical contaminants known to contribute to the risk of cancer, benzene-equivalents are used as the basis with which to compare the degree of risk in potential exposure. Additionally, all contaminant releases that cause non-cancer related health ailments are compared to toluene-equivalents. The TEP data provides a specific multiplier value to calculate the relative toxicity of chemical emissions to an airborne environment or a water source. While the

Scorecard references the multiplier values in relation to pounds (lbs) of a specific contaminant, the TEP values are meant to be applied to any unit of measurement.

2.4. Air Pollution Dispersion Models

A key method of air pollution analysis that has been established during this past decade is the use of meteorological data to simulate the flow of emissions across an urban landscape. "Meteorology is well known to be an important factor contributing to air quality [analysis]. It encompasses many atmospheric processes that control or strongly influence the evolution of emissions, chemical species, aerosols and particulate matter" (Seaman, 2000, p.2231). Several recommended pollution dispersion models are available through governmental organizations such as USEPA, including CALPUFF, AERMOD, and ISC3.

When studying the dispersion of air pollutants, the most important factors to consider are "the dispersion, transformation and removal of air pollutants from the ambient atmosphere" (Giri, 2008, p.50). As "pollutants get airborne from the ground surface, their residence in the ambient atmosphere and the formation of secondary pollutants is controlled not only by the rate of source-emission but also by wind speed, turbulence level, air temperature, and precipitation." (Giri, 2008, p.53). Research conducted by Arain et al. (2009), Giri (2008), and Ghim and Hyun (2001) suggests that wind direction and wind speed have the greatest influence on airborne particulate dispersion. The "[w]ind is a key meteorological variable having a major impact on horizontal transport and distribution of air pollutants, as well as vertical mixing and dispersion in a region. Downwind areas from proximate emission sources such as industrial locations and highways may be exposed to significantly higher levels of pollution" (Arain et al., 2007, p.3454). Furthermore, the "lower wind speeds and higher temperatures in urban areas create an environment conducive to the build-up of pollutants" (Arain et al., 2009, p.167).

The successful application of dispersion models requires specific facility, geophysical and meteorological datasets that are not available in every region. For instance, to complete an accurate assessment of pollution dispersion using the USEPA endorsed CALPUFF model, Scire et al., (2000) recommends applying stack height, particulate scale, emission rate, and emission duration for facility input data. Geophysical data includes surface roughness lengths, land use categories, terrain elevations, and leaf area indices. However, without precise surface measurements such as those provided through data collection instruments as LiDAR, data can be difficult to retrieve for urban landscapes that take into consideration building heights. In addition to the facility and geophysical data, the meteorological datasets utilized by CALPUFF require both surface and upper atmospheric measurements. The recommended meteorological datasets include wind direction, wind speed, temperature gradients, air density gradients, stability classes, mixing heights, precipitation, short-wave solar radiation, and relative humidity.

Historic weather data for locations across Canada can be retrieved from Environment Canada's National Climate Data and Information Archive (Environment Canada, 2011). For instance, three weather stations located in close proximity to the City of Toronto during 2006, are noted to provide hourly weather data that can be potentially assembled for a meteorological dispersion analysis. The three weather stations, which operate out of Buttonville Airport, Toronto Island Airport, and Lester B. Pearson International Airport

(Figure 3), record the hourly time intervals, temperature, dew point temperature, relative humidity, wind direction, wind speed, visibility, station pressure, wind chill, and precipitation conditions throughout the year. A total of 8,760 records were reported by Environment Canada for each of the three weather stations during 2006.

Figure 3: Environment Canada Weather Stations

The available surface atmospheric data provides valuable insight into the way wind direction and wind speed potentially carry emissions across the urban landscape. A series of twelve eight-point wind rose diagrams (Figure 4) were prepared for each of the three weather stations located within proximity of Toronto, to illustrate the surface meteorological patterns. The average wind direction and wind speed data was divided into three month increments, based upon the transitions in seasons during the year. The most prevalent average wind direction that was observed from the three weather stations occurred during the Fall months (October, November, and December), and emanated from a westerly direction (270^{o}) for approximately 25-27 percent of the total readings during this time period. The average seasonal wind speeds recorded from the three weather stations range between 0-25.7 km/h.

The meteorological information indicates that emissions dispersion in the City of Toronto will not follow a uniform pattern, and will be distributed outwards from the source facility in all directions at varying rates of speed. Pollutant concentration will therefore not be constant as it is dispersed by wind currents. However, the lack of precise upper atmospheric data, in addition to the current unavailability of high accuracy surface data, seriously limits the results produced by available dispersion models, making the incorporation of this technology impractical at this time. For this reason, the research conducted in this paper will not employ a meteorological dispersion model as part of the methodology and analysis.

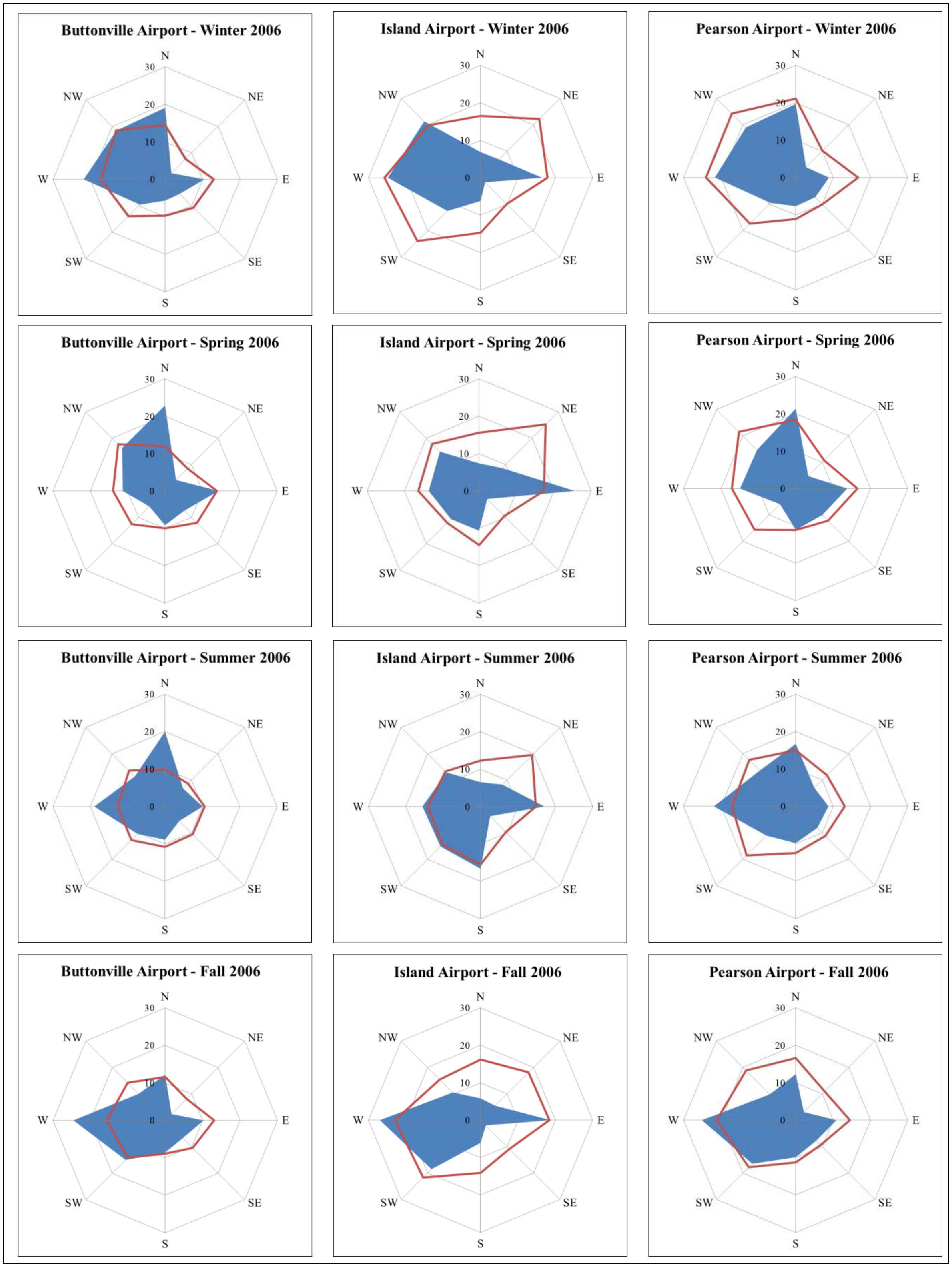

Figure 4: Average 2006 Surface Wind Directions (Percentages (%) as indicated by blue polygons) and Wind Speeds (km/h as indicated by red polygons) for Buttonville Airport, Toronto Island Airport, and Lester B. Pearson International Airport

CHAPTER 3. Data and Methodology

3.1. Organization of Research

Similar to Villeneuve et al. (2003), a DA level of geographic detail was used to aggregate variables for this research. Typically, DAs in Canada are composed of one or more neighbouring blocks with a population between 400-700 people (Statistics Canada, 2003). The 3,577 DAs located in Toronto are generally larger than the standard definition provided by Statistics Canada. The Toronto DAs range in size between 0-12,533 people, with an average population of 699. Statistics Canada reports data for a total of 3,551 of the DAs located in Toronto, thereby providing a data coverage of approximately 99.3 percent.

The research conducted in this paper follows four distinct stages of development. The first stage relates to the selection and pre-processing of the socio-economic data for the City of Toronto. The second stage employs statistical analysis of the selected 67 variables using K-Means cluster analysis to reduce the 3,551 applicable DAs to a smaller number of manageable subgroups. The third stage combined the 2006 NPRI air pollution datasets with the carcinogenic and non-carcinogenic TEP scores provided by Scorecard into a single spatial database. The fourth stage involved developing annual concentration estimates for the each of the 3,577 DAs in the City of Toronto using the aggregated data for total emissions, VOCs, heavy metals, miscellaneous compounds, TEP carcinogens, and TEP non-carcinogens. The concentration estimates were calculated through kernel density estimation. The aggregated pollution data were then combined with the Toronto DAs by creating spatial joins using the polygon centroids for each DA. The relationship between air pollution and the socio-economic characteristics of the K-Means cluster analysis subgroups were then studied.

3.2. Summary of the Census Data

To subdivide the City of Toronto based on census data, a large assortment of census variables were necessary to ensure that the prevailing socio-economic characteristics of the DAs were examined by the cluster analysis algorithm. A broad range of 67 variables from the 2006 Canadian census were used representing age and gender, marital status, primary language, citizenship and immigration status, region of ethnic origin, education, employment, after-tax individual income, after-tax low income, housing ownership, housing era of construction, and housing type. The variables were standardized using percentage formulas to determine the proportion of people living in each DA that were classified according to the variables. The percentage standardization process was necessary because the populations of Toronto DAs differ greatly from one another. The specific variables that were aggregated for the analysis, including the numerator and denominator descriptions used to standardize the data, can be examined in greater detail in Appendix A.1. The percentage standardization function used to standardize the variables is shown below.

$$X = \left(\frac{N}{D}\right) \times 100$$

Where:

$\boldsymbol{X}$ is the standardized percentage value of the variable;

$\boldsymbol{N}$ is the numerator as defined by Appendix A.1.; and

$\boldsymbol{D}$ is the denominator as defined by Appendix A.1.

3.3. K-Means Cluster Analysis

Employing the statistical program SPSS® version 18, K-Means cluster analysis was performed on the 67 census variables. Cluster analysis has been previously demonstrated by Kelderman et al. (2003), Ma et al. (2008), and Sundaraya et al. (2011) to be a useful method of reducing large complex datasets into a smaller number of cluster subgroups. Given that there are 3,551 applicable records for each of the variables, K-Means cluster analysis was selected as the optimal method of calculating cluster groupings. K-Means cluster analysis is different from the hierarchical cluster analysis method because the K-Means method is meant to classify datasets containing thousands of records, whereas the hierarchical method can only process up to 100 records (Predictive Analytics SoftWare, 2009).

The K-Means analysis method assigns cluster groupings based upon statistical commonalities in the variables. The process requires the number k of clusters to be specified. Upon providing this number, the procedure divides the data into an initial set of clusters. Cluster centres represent the average value of the DAs assigned to a specific cluster. The K-Means algorithm then re-allocates cases to the cluster groups based on minimizing the distance from the cluster centres and updates the cluster centres. These steps are iterated until the reassignment of cases minimizes the distance of each case from its cluster centre (Predictive Analytics SoftWare, 2009). Two clusters were selected to subdivide the DAs representing the City of Toronto. Attempts to use more than two clusters failed to adequately subdivide the census data. A disproportionate number of DAs, in one or more of the cluster groups, were provided with cluster centre values of zero, meaning that these cluster groups did not take into account all of the census variables during the analysis. Two cluster groups provided real cluster centre values for each of the census variables, thereby ensuring that the cluster groups could be evaluated against one another during the analysis. A total of 23 iterations were required to compute the data convergence of the two cluster groups.

3.4. NPRI Variables

The NPRI datasets contains air, water and land based pollution records for facilities across Canada. The 2006 NPRI data were stored as a Microsoft® Access™ database and required significant processing to extract the air pollution data. The air pollution data utilized four units of measurement for emissions, including tonnes, kilograms, grams, and grams (TEQ). The chemical contaminants released in Toronto were first converted to kilograms to standardize the data to a single standard unit of measurement. Using spatial joins, the NPRI Access™ pollution data were combined with a facility point shapefile provided by Environment Canada in ArcMap™ detailing all of the monitored facilities across the country.

All of the facilities located within the borders of the City of Toronto were then extracted into a separate point shapefile. A total of 13,724,019 kg of emissions were produced in Toronto during 2006. Specifically for Toronto, a total of 823 chemical releases with a provided unit of measurement were reported from 247 private and publicly operated facilities located across city. The 823 chemical releases were made up of 79 different contaminants as defined by the NPRI, and are detailed in Appendix A-2. The pollution produced in Toronto (Figure 5) can be classified as three types of emissions. Volatile Organic Compounds (VOCs) represent 9,626,520 kg (70%), and

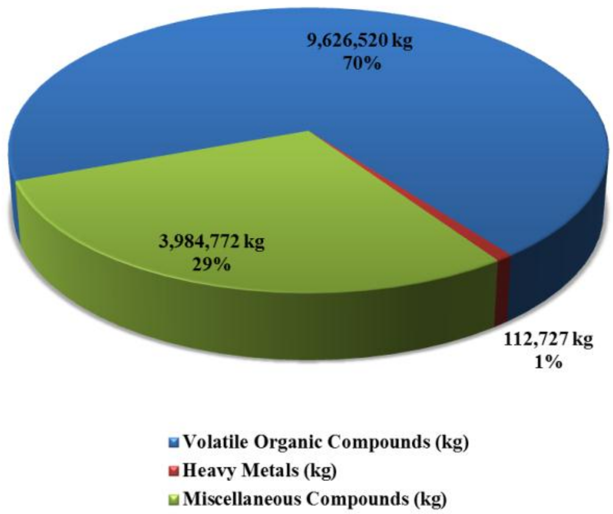

Figure 5: Pollution in Toronto

include all organic chemicals that have a high vapour pressure at room temperature such as paints and solvents; heavy metals, which include such materials as lead, copper, and mercury, represent 112,727 kg (1%); and miscellaneous compounds that include carbon monoxide, dioxins and furans, and all other chemicals not classified as VOCs or heavy metals, account for 3,984,772 kg (29%) of emissions during 2006. The spatial distribution of facilities by total emissions data (Figure 6) is illustrated using the Quantile classification method. The Quantile method divides the pollution data into intervals that place an identical number of values into each class. Facilities that released the largest amount of total emissions predominantly operate along the north-western border of Toronto near Mississauga and Vaughan, and along the eastern parts of the city near Scarborough. The spatial distribution of VOC emissions (Figure 7) followed a similar trend to total emissions. Facilities that released the largest amount of VOCs were predominantly located along the western border of Toronto, but less overall emissions were observed emanating from city's downtown. The emission of heavy metals (Figure 8) are pronounced throughout the city, but are primarily located along the lakeshore. Miscellaneous compounds emissions (Figure 9) were also primarily emitted from facilities located along the lakeshore.

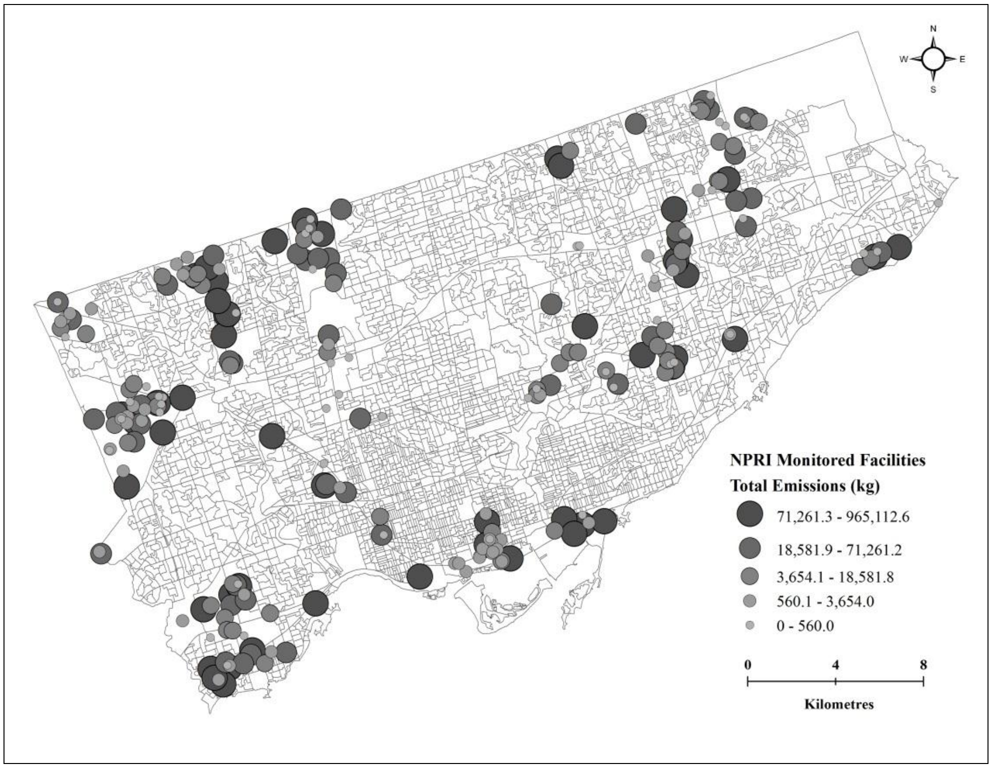

Figure 6: Total Emissions

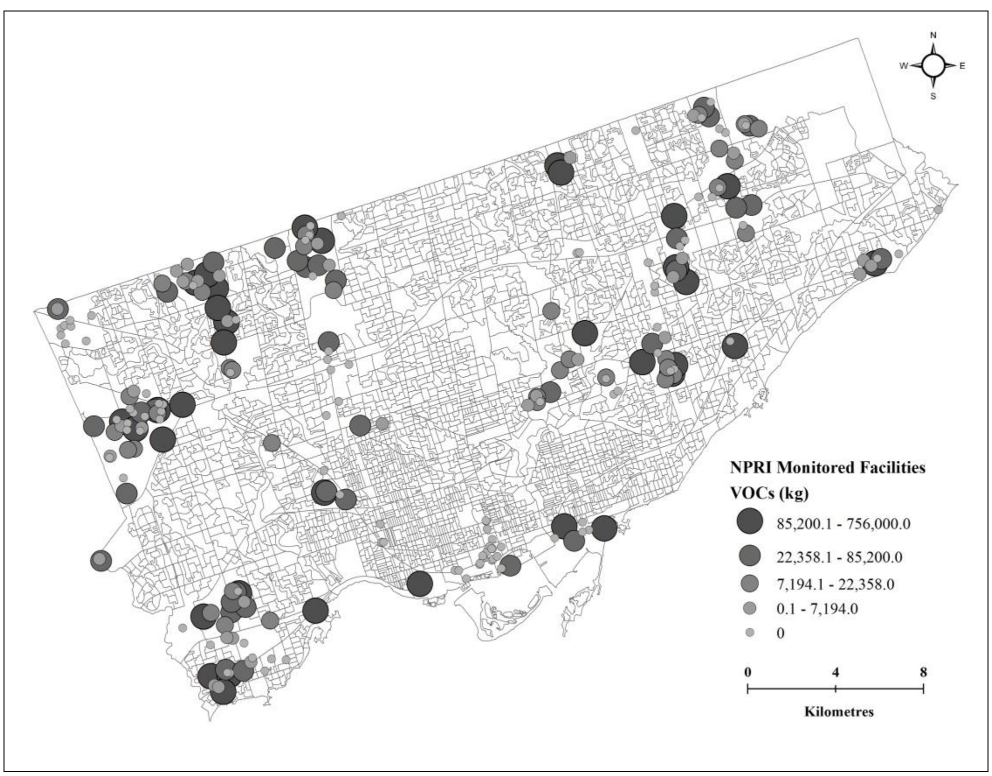

Figure 7: Volatile Organic Compounds

Figure 8: Heavy Metals

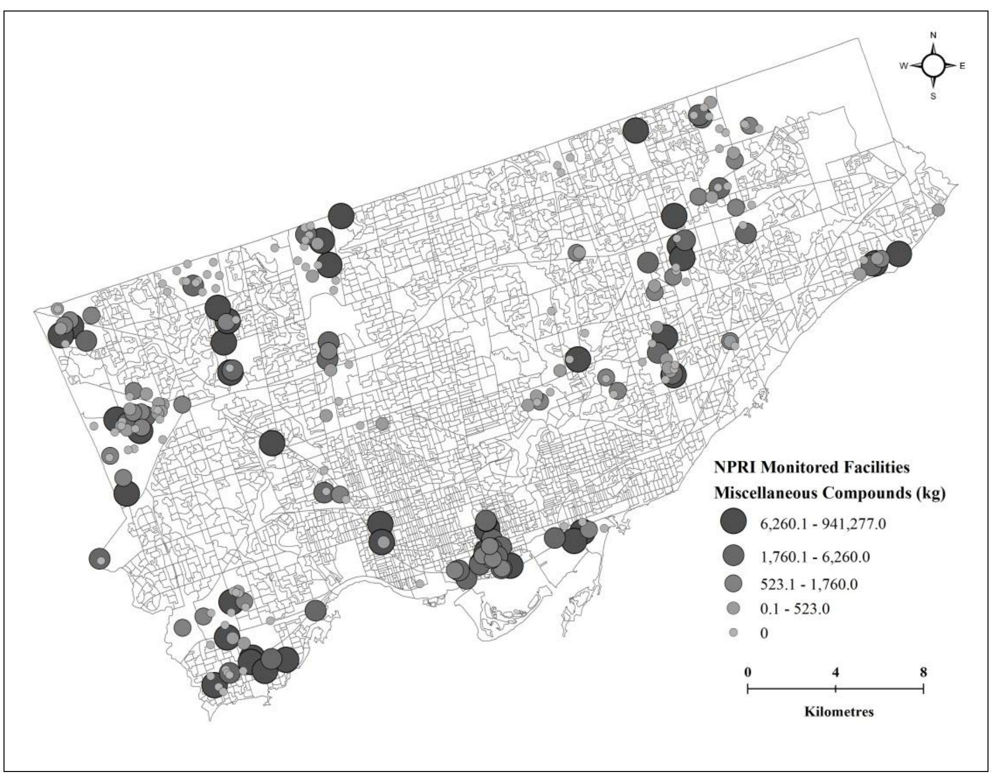

Figure 9: Miscellaneous Compounds

The top 10 facilities that reported the greatest mass of emissions during 2006 are detailed in Appendices A.3. to A.8. The 10 facilities from both the private and public sectors documented by the NPRI in 2006 that are among the most prominent emitters of airborne contaminants, include O-I Canada Corp., Chemtura Canada, Alcan Packaging, Hymopack Ltd., Sapa Canada Inc., Cascades Canada Inc., Kraft Canada, the City of Toronto's Highland Creek Treatment Plant, The Canada Metal Company Ltd., and Enwave District Energy's Walton Street Steam Plant.

3.4.1. Toxic Equivalency Potential

Although calculating the total mass of emissions is a useful measure to determine the scale of pollution from sources across Toronto, the actual relative toxicity of the chemicals must also be taken into account. To develop toxicity rankings for the NPRI data, Scorecard TEP data were imported into ArcMap™ using the Chemical Abstracts Service (CAS) unique identifier number as the common variable to relate the datasets. The Scorecard TEP scores were multiplied to the total amount of each chemical reported by the NPRI in 2006, creating two new values representing the potential toxicity of carcinogenic and non-carcinogenic substances.

While the carcinogenic chemicals are representative of the toxicity of benzene contamination, non-carcinogenic substances are representative of the toxicity of toluene contamination. Of the 79 airborne chemicals emitted in Toronto, 13 did not have a corresponding TEP. The 13 unaccounted airborne chemicals (Table 1) represent 7,912,581 kg, or approximately 57.7 percent of total emissions for 2006.

Table 1: Airborne Chemicals Requiring Toxic Equivalency Potential (TEP) Scores

CAS Number	Chemical Name	Total Emissions (kg)
103-23-1	Bis(2-ethylhexyl) adipate	1,130
111-76-2	2-Butoxyethanol	67,885
1163-19-5	Decabromodiphenyl oxide	1
1717-00-6	HCFC-141b	1,655
26471-62-5	Toluenediisocyanate (mixed isomers)	29
584-84-9	Toluene-2,4-diisocyanate	3
7632-00-0	Sodium nitrite	24,479
7664-93-9	Sulphuric acid	797
872-50-4	N-Methyl-2-pyrrolidone	8,712
NA - 20	Nonylphenol and its ethoxylates	17,796
NA - 22	Phosphorus (total)	119
NA - M08	PM - Total Particulate Matter	461,940
NA - M16	Volatile Organic Compounds (VOCs)	7,328,035

In particular, the CAS listed chemical NA-M16 - Volatile Organic Compounds (Appendix A.2.), which represent 7,328,035 kg, or the equivalent of 53.4% of all emissions in Toronto in 2006, did not have a listed TEP because this particular chemical is actually made up of numerous compounds, each with its own TEP. The NA-M16 chemical is one of 33 chemicals released in Toronto that are classified as VOCs by the NPRI. To ensure that the maximum possible emissions were taken into account for this study, the average carcinogenic and non-carcinogenic TEP scores for the 33 VOCs measured in Toronto during 2006 were used as the numeric weighting for NA-M16. The formula used for NA-M16 to determine carcinogenic and non-carcinogenic TEP is shown below.

$$VOC = X/33$$

Where:

$\boldsymbol{VOC}$ is the average carcinogenic or non-carcinogenic TEP of the 33 VOC designated chemicals monitored in Toronto by the NPRI for 2006; and

$\boldsymbol{X}$ is the total carcinogenic or non-carcinogenic TEP of the 33 VOC designated chemicals.

With the TEP measurements and NPRI data combined, the total carcinogenic emissions for Toronto are equivalent to 149,428,111 kg of benzene, while the non-carcinogenic properties of the emissions would be equivalent to 651,307,718 kg of toluene. Both of the TEP emissions scores are much larger than the 13,724,019 kg recorded for total emissions because the majority of the released chemicals are exceedingly toxic. The distribution of carcinogenic and non-carcinogenic emissions in Toronto is not equally distributed spatially. The location of carcinogenic emissions (Figure 10) are primarily spread along the western sections of the city, near the Mississauga border, and along the eastern parts of the city near Scarborough. Non-carcinogenic emissions (Figure 11) are spread throughout the City of Toronto, with the greatest densities of emissions occurring along the western sections of the city, near the Mississauga border, and along the eastern parts of the city near Scarborough.

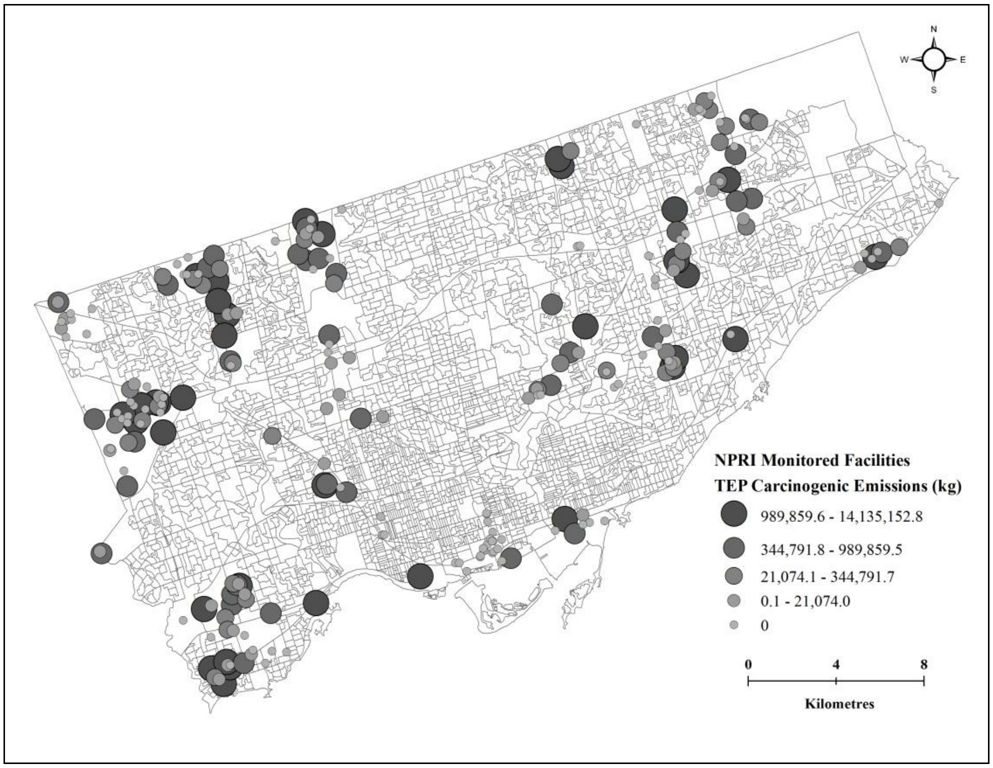

Figure 10: TEP Carcinogenic Emissions

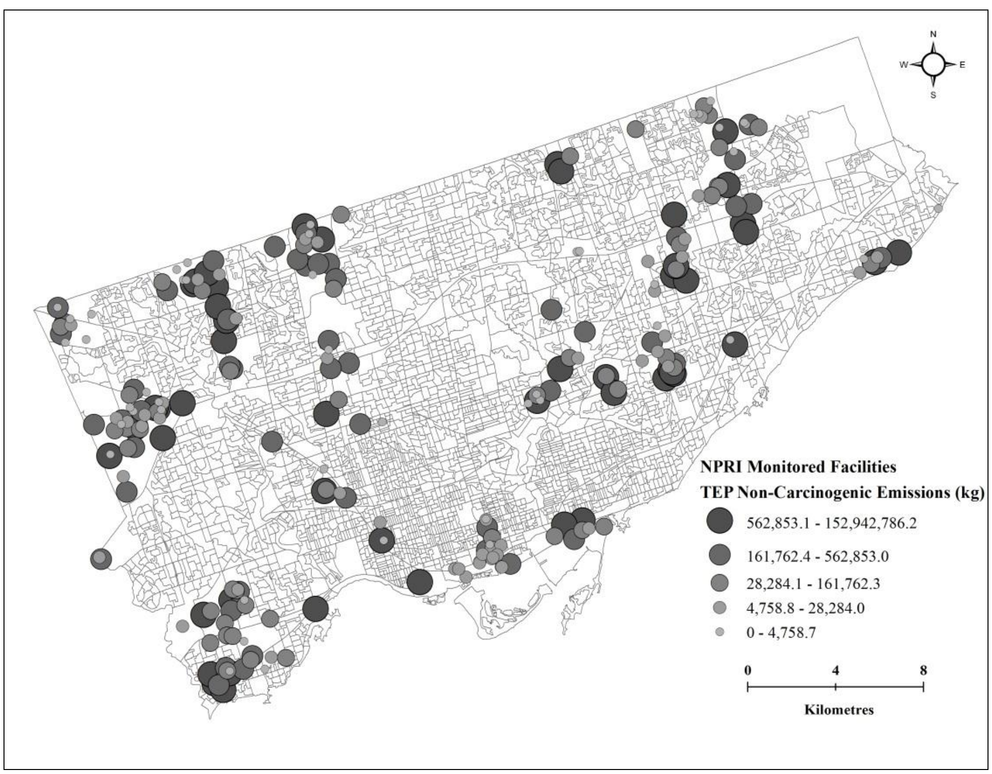

Figure 11: TEP Non-Carcinogenic Emissions

3.4.2. Limitations of Toxic Equivalency Potentials

The primary limitation with the NPRI data relates to the calculation of the TEP for NA-M16 - Volatile Organic Compounds. Although the NA-M16 data represents 53.4% of all emissions in Toronto in 2006, Scorecard does not list a toxic equivalency for this chemical classification because it represents a multitude of VOCs, each with its own TEP. A significant range of multiplier values exist for VOCs based upon the calculations performed by Scorecard, and the accurate TEP ultimately depends upon the type of industry being monitored for NA-M16. The benefit of including the NA-M16 data is that 53.4% of the overall pollution data reported by the NPRI can be included in the final calculation of carcinogenic and non-carcinogenic emissions.

3.5. Kernel Density Estimation

Following the aggregation of the NPRI pollution data, kernel density estimation was selected as a means of creating generalized dispersion maps of the six pollution types including, total emissions, VOCs, heavy metals, miscellaneous compounds, TEP carcinogens, and TEP non-carcinogens. Kernel density estimation has been used in numerous pollution studies (Crouse et al., 2009; Portnov et al., 2009; Criado and Grether, 2011), environmental analysis research (Corcoran et al., 2007), and in combination with K-Means cluster analysis (Anderson, 2009). According to Corcoran et al. (2007), kernel density estimation is a useful technique when there is a large volume of input variables that are spatially clustered. The NPRI 2006 dataset represents an ideal input for kernel density estimation as many facilities that were monitored by Environment Canada throughout the City of Toronto were clustered in tight groupings in the urban landscape.

The kernel density estimation function involves calculating the sum of all the input points that are located within a fixed search radius. The sum of the points is then divided by the overall area of the search window to provide the density values of each output cell. The kernel density estimation typically weighs more heavily those points located near the centre of the search radius than those points located near the edge of the search window. The calculations are then repeated for any subsequent input points (Anderson, 2009; Portnov et al., 2009).

A 5km search radius was employed for the purposes of calculating generalized pollution concentration maps using the NPRI data. Search radiuses of both greater and smaller value than 5km were examined prior to this selection. While smaller ranges benefitted from being very spatially precise in terms of the location of pollutant releases, very few DAs could be examined through these means. Although search radiuses greater than 5km were more generalized in terms of depicting concentration ranges throughout the city, very little spatial dissimilarity was detected between the results of a 5km search radius and the results of calculations using a larger input search radius.

Following the creation of the six kernel density raster images, the quantile classification method was selected using five classes to represent the pollution data. The six raster datasets were then reclassified using the raster reclass operation in ArcMap™ to match the specific quantile ranges of each type of pollutant. To provide an identifiable pollution range for each of the 3,577 DAs in Toronto, a relationship between the raster data and the DA polygon shapefile had to be created. The reclassed raster images were converted into polygon shapefiles and related to the centroids of the DA polygon shapefile using a spatial join operation. This process provided the Toronto DAs with a pollution range for each of the six pollutant types, which could then be compared with the results of the cluster analysis.

3.5.1. Kernel Density Estimation Limitations

The primary limitation of kernel density estimation relates to the limited number of input variables. Although concentration values can be developed using kernel density estimation, this method assumes that no other variables aside from the input points are influencing the spread of pollutants across the urban landscape. Essential meteorological dispersion variables described by the CALPUFF model, such as prevailing winds, surface topography, atmospheric pressure, and precipitation, are not included in the calculation. The kernel density estimation calculation provides a generalized raster output that can serve an approximation regarding the dispersion of pollutants in Toronto.

CHAPTER 4. Results

4.1. K-Means Cluster Analysis

The K-Means cluster analysis classified the Toronto DAs into two distinct clusters based upon the cluster centres defined for each variable. The cluster centres (Table 2) denote the average percentage of the population for each DA that is assigned to a specific cluster group. For instance, the data table indicates that for the English language variable, the DAs assigned to Cluster Group 1 have a 49 percent average proportion of people that list English as their primary language, while Cluster Group 2 have a 56.5 percent average proportion. This indicates that the residents of the DAs assigned to Cluster Group 2 have a significantly higher proportional rate of having English as their primary language. The cluster variables that are at least a 10 percent higher than the counterpart cluster variables have been colour coded dark grey. Cluster centre values that are shaded as dark grey represent variables that have the most prominent cluster centres in order to indicate what variables have the greatest impact in defining the nature of the cluster group.

The first cluster group demonstrates significant differences when compared to the second cluster group. The DAs assigned to this cluster have the highest proportion of population, both male and female, between the ages of 20 and 64, indicating that these areas of the city have a greater working age population. This cluster also has the highest proportion of single, separated, and divorced individuals. Citizenship and immigrants cluster centres establish that these DAs have the highest proportion of non-citizens, recent immigrants, and non-permanent residents. The ethnic origin data also indicate that people of Caribbean, African, Arab, West Asian, and South Asian ethnic origin are more predominant in this cluster group. Economically, Cluster Group 1 has the highest proportion of after-tax low family income, and after-tax non-family low income. Furthermore, a higher proportion of people earn less than $25,000 per year in after-tax income. This cluster group is also noted to have a higher unemployment rate when compared to the second cluster group. Employment statistics suggest that people living in these DAs have a greater incidence of working in the Art, Culture, Recreation and Sports, Sales and Services, as well as in Secondary Industry sectors. Housing in this cluster is principally rented in apartment building type structures, with a significant proportion of dwellings built between 1981 and 2006. The variables with the most prominent cluster centres suggest that this first cluster group can be defined as Underprivileged Areas.

The second cluster group includes DAs that have the highest proportion of population, both male and female, between the ages of 0 and 19, as well as 65 years of age and over. The age ranges indicate that these areas of the city have a higher average proportion of youths and adolescents, and the elderly. This cluster also has the highest proportion of married individuals. Citizenship and immigrants cluster centres establish that these DAs have the highest proportion of Canadian citizens, and people that were born in Canada. The ethnic origin data also indicates that residents of European or North American ancestry are more predominant in this cluster. Economically, this cluster group has the highest proportion of people earning greater than $50,000 per year in after-tax income. Employment statistics also indicate that people living in these DAs have a greater incidence of working in jobs as part of the Management, Health, as well as Social Science, Education, Government Service and Religion sectors. Housing in this cluster is principally owned, and includes semi-detached, single detached, and apartment duplex building type structures. A significant proportion of these dwellings were built prior to 1981. The characteristic cluster centre values suggest that the second cluster group can be defined as Areas of Affluence.

Table 2: K-Means Cluster Analysis Cluster Centres

Variables	Cluster Group 1 Underprivileged Areas (%)	Cluster Group 2 Areas of Affluence (%)
Gender and Age		
Males	48.1	48.7
- Ages 0-19	10.4	11.6
- Ages 20-64	32.0	30.1
- Ages 65 and Over	5.6	6.9
Females	51.9	51.3
- Ages 0-19	9.9	10.9
- Ages 20-64	33.9	31.8
- Ages 65 and Over	8.1	8.6
Marital Status		
Single	41.9	32.6
Married	39.7	53.2
Separated	4.2	2.6
Divorced	8.1	5.6
Widowed	6.1	6.1
Primary Language		
English	49.0	56.5
French	1.4	1.1
Non Official	48.3	42.2
Citizenship and Immigration Status		
Canadian Citizen	80.9	90.6
Non-Citizen	17.7	9.3
Born Canadian	47.8	56.1
Immigrant	49.3	42.8
- Immigrated Prior to 2001	37.2	37.5
- Recent Immigrants (2001 and After)	12.1	5.3
Non-Permanent Resident	2.8	1.1
Region of Ethnic Origin		
British Isles	21.9	28.3
French	4.6	5.0

Variables	Cluster Group 1 Underprivileged Areas (%)	Cluster Group 2 Areas of Affluence (%)
Region of Ethnic Origin continued		
Aboriginal	1.3	1.0
North American	10.9	13.3
Caribbean	7.0	4.6
Central and South American	3.2	2.1
European	34.2	41.0
African	5.2	2.1
Arab	1.6	1.1
West Asian	3.0	1.7
South Asian	10.5	9.1
Southeast Asian	18.9	18.1
Oceania	0.2	0.2
Education		
Certificate	77.4	79.2
No Certificate	21.2	20.7
Employment		
Employment Rate	58.7	61.1
- Management	8.9	12.2
- Natural and Applied Sciences	7.4	7.5
- Business, Finance and Administration	19.5	21.1
- Health	4.3	5.1
- Art, Culture, Recreation and Sports	5.9	5.2
- Social Science, Education, Government Service and Religion	8.9	10.3
- Sales and Services	24.8	21.2
- Trades, Transport and Equipment Operators	10.8	10.4
- Primary Industry	0.6	0.6
- Secondary Industry	7.5	6.1
Unemployment Rate	8.7	6.1
After-Tax Individual Income		
Less than $25,000	59.9	50.3
$25,000 to $49,999	27.4	29.3
$50,000 and Over	10.7	18.7
After-Tax Low Income		
Family Low Income	19.8	8.2
Non-Family Low Income	38.4	23.8
Housing Ownership		
Owned	35.1	83.5
Rented	63.6	16.3
Housing Era of Construction		
Built Prior to 1981	75.3	84.0

Variables	Cluster Group 1 Underprivileged Areas (%)	Cluster Group 2 Areas of Affluence (%)
Housing Era of Construction continued		
Built 1981 and After	23.3	15.9
Housing Type		
Semi-Detached	6.0	11.9
Single Detached	8.4	59.7
Apartment Duplex	2.6	9.1
Row House	7.0	4.9
Apartment, Less than Five Stories	28.3	12.7
Apartment, Five Stories or More	47.1	1.5
Single Attached	0.2	0.1
Movable	0.0	0.0

The cluster analysis partitioned the city-wide DAs unevenly between the two cluster groups. A total of 1,391 DAs (38.9%) were assigned to Underprivileged Areas, 2,160 DAs (60.4%) were assigned to Areas of Affluence, and 26 DAs (0.7%) did not have available census data and were not included as part of the cluster analysis. The spatial cluster characteristics (Table 3) specify that the Underprivileged Areas have fewer DAs and a smaller total land area of 202.56 km^2 (31.9%). However, Underprivileged Areas account for the larger population of 1,324,665 people (53.1%). The DAs classified as Areas of Affluence have the larger land area of 423.98 km^2 (66.9%), but the smaller population of 1,157,835 people (46.9%).

Table 3: Cluster Characteristics

	Underprivileged Areas	Areas of Affluence	No Data
Total Number of DAs	1,391	2,160	26
Total Area (km)	202.56	423.98	7.61
Total Population	1,324,665	1,167,835	N/A
Percent Total Number of DAs (%)	38.9	60.4	0.7
Percent Total Area (%)	31.9	66.9	1.2
Percent Total Population (%)	53.1	46.9	N/A

When the SPSS® cluster results were imported into ArcMap™, the two cluster groups (Figure 12) became clearly identifiable spatially. The urban core along Yonge Street, the lakeshore areas, and the areas along the eastern and western borders of Toronto were primarily designated as Areas of Affluence. The inner wealthy core of the city was bordered by the Underprivileged Areas cluster that forms a ring around the central affluent areas, and includes much of the city's downtown areas.

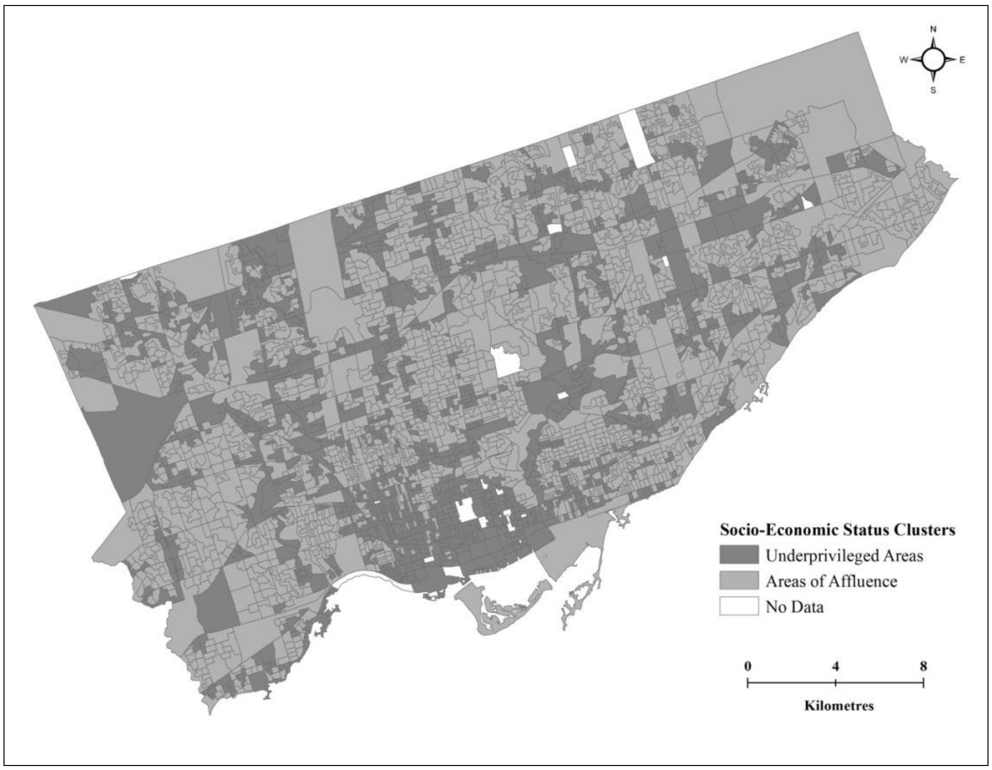

Figure 12: Spatial Distribution of Cluster Groupings

4.2. Kernel Density Estimation

The kernel density estimations, when combined with the DA polygons, demonstrate the presence of significant emissions clustering in specific areas of the city for each of the six pollutant types. In addition to the 5km search radius, the default area units input of square kilometres in the ESRI® kernel density function was used to create pollutant densities that are measured in kg/km^2. Total emissions (Figure 13) are visibly distributed in high concentrations in Toronto's downtown, along the western border near Mississauga, and in the eastern half of the city towards Pickering. Elevated concentrations of VOC emissions (Figure 14) are primarily located along the western border of the city near Mississauga. Less elevated concentrations of VOCs are also observed near the eastern border of Pickering. Heavy metals (Figure 15) are in the highest concentration along the shoreline of Lake Ontario, with the largest cluster positioned over the downtown. Miscellaneous Compounds (Figure 16) share a similar cluster pattern as Total Emissions, with the highest concentration of pollutants located in Toronto's downtown, along the western border near Mississauga, and in the eastern half of the city towards Pickering. TEP Carcinogenic Emissions (Figure 17) share a similar distribution pattern as VOC emissions. The highest concentrations are located along the western border of the city near Mississauga, with less elevated concentrations also observed near the eastern border of Pickering. TEP Non-Carcinogenic Emissions (Figure 18) are spatially clustered along the north-western border of the city near Vaughan and Mississauga, in the city's downtown, and in the eastern half of Toronto near the border with Pickering.

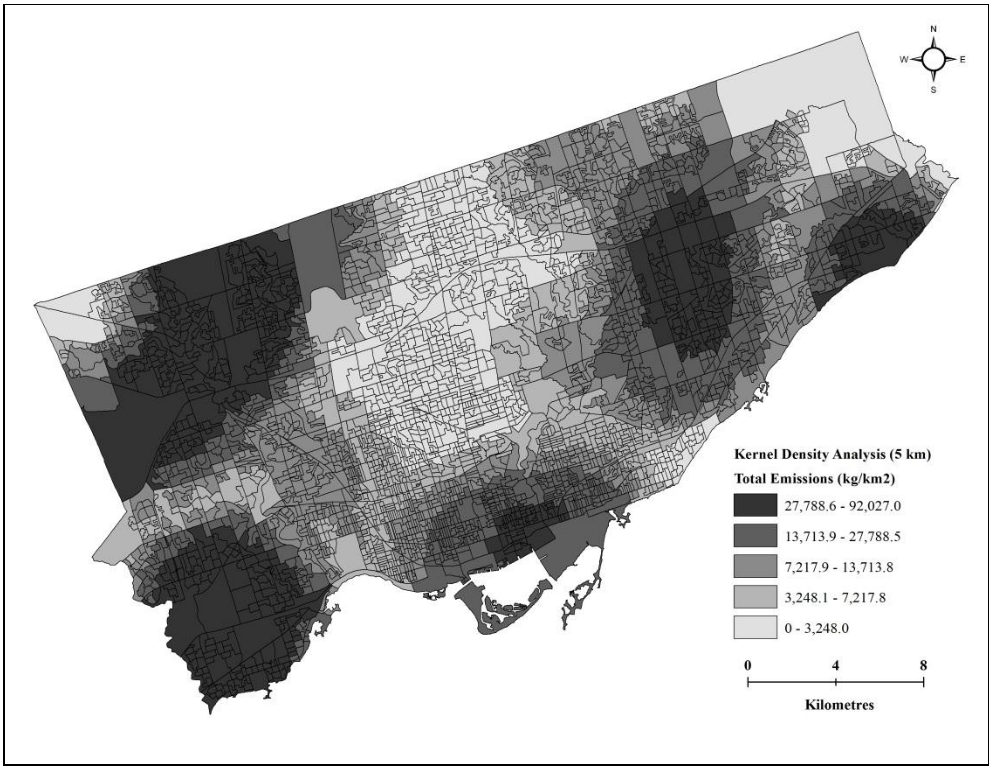

Figure 13: Total Emissions 5km Search Radius

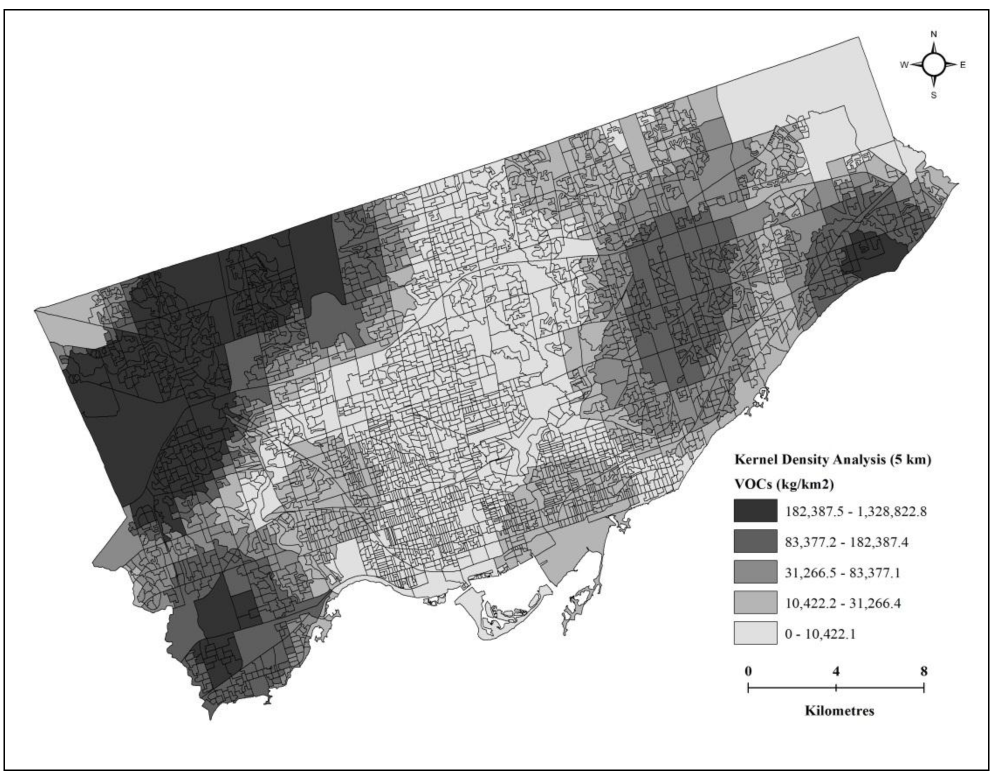

Figure 14: Volatile Organic Compounds 5km Search Radius

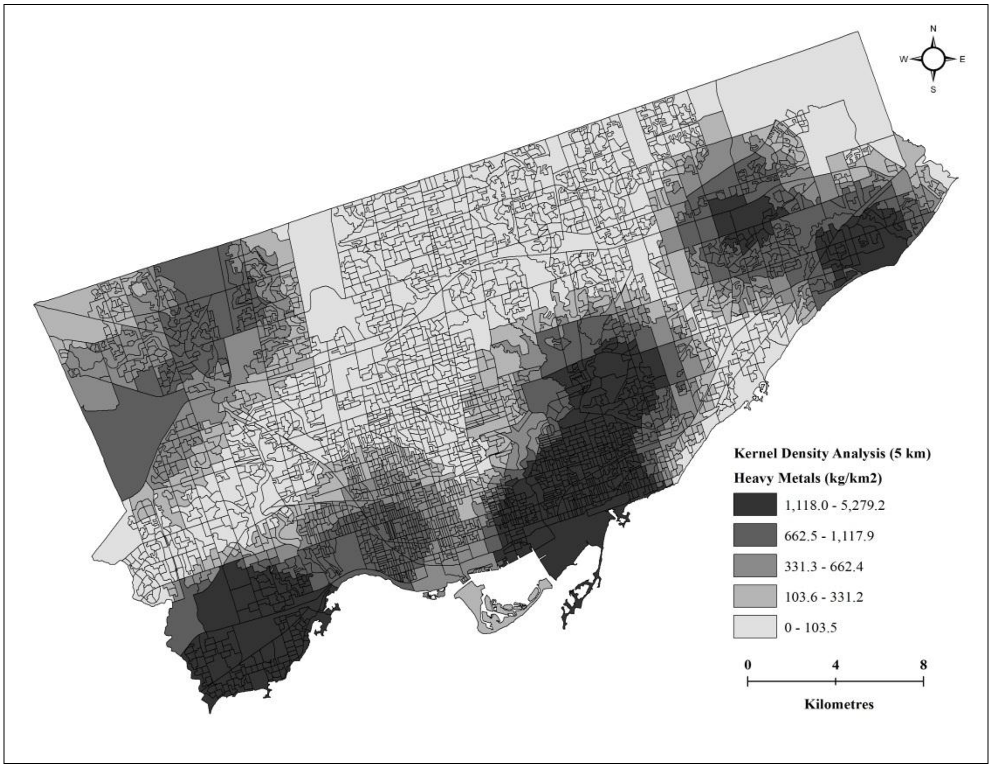

Figure 15: Heavy Metals 5km Search Radius

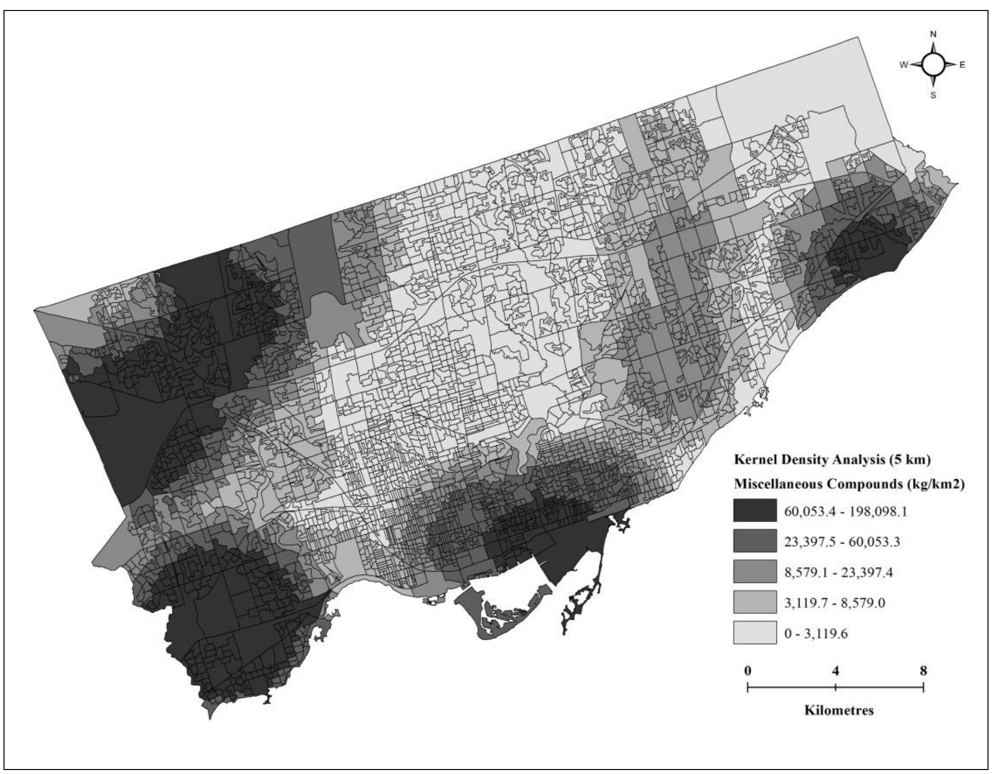

Figure 16: Miscellaneous Compounds 5km Search Radius

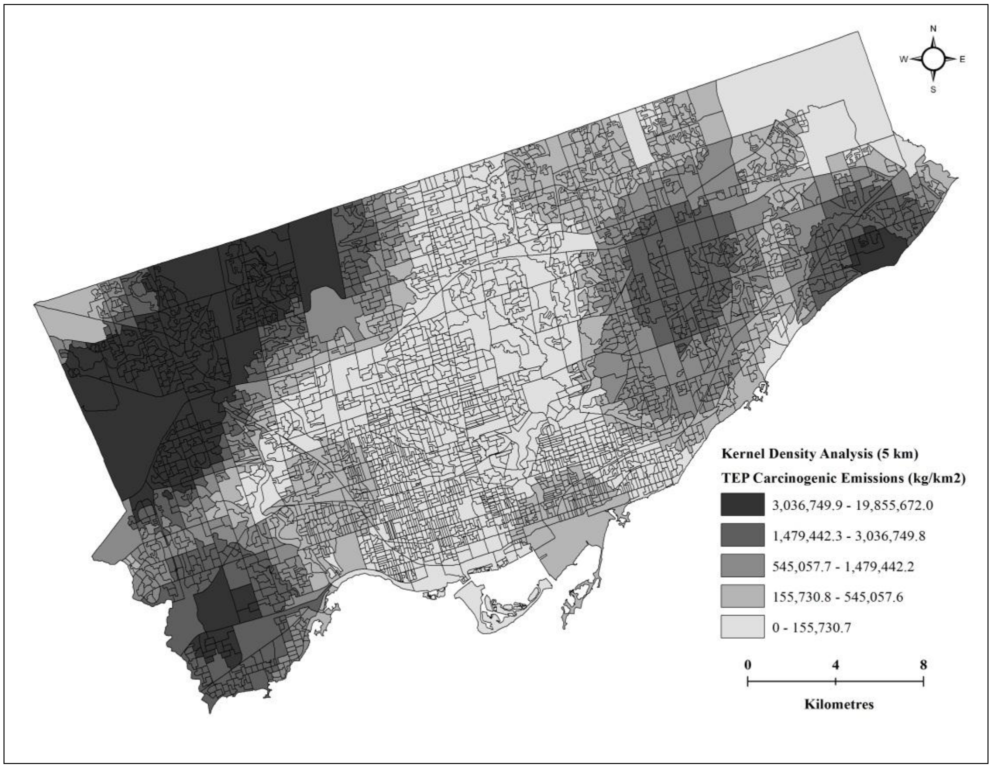

Figure 17: TEP Carcinogenic Emissions 5km Search Radius

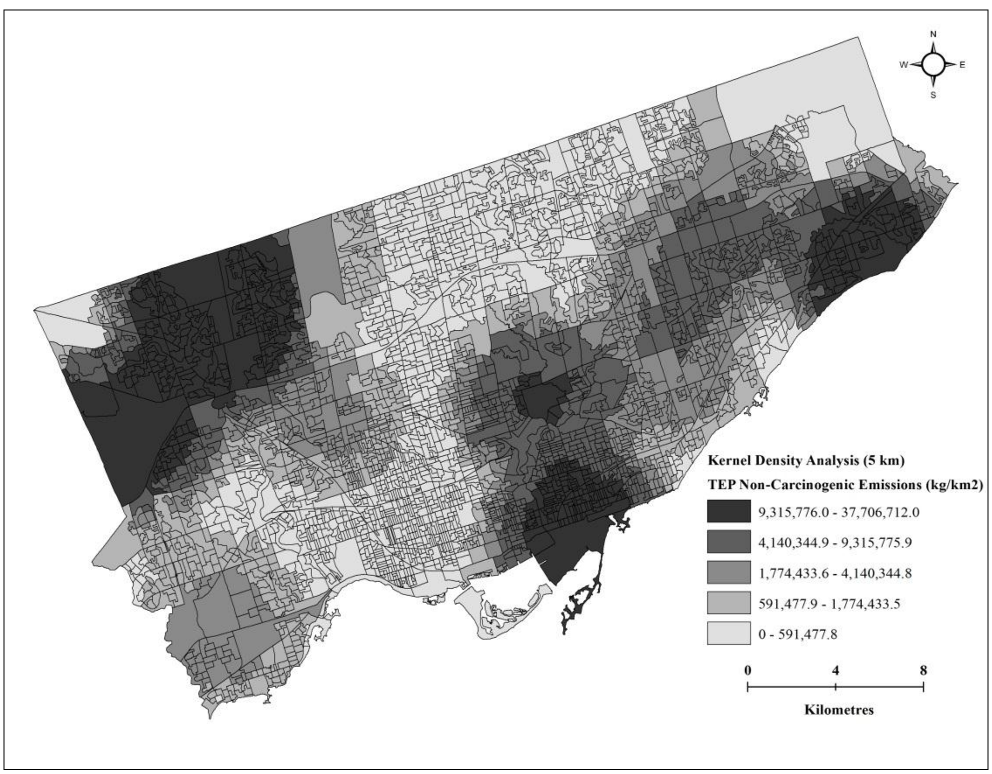

Figure 18: TEP Non-Carcinogenic Emissions 5km Search Radius

CHAPTER 5. Discussion of Results

5.1. Total Emissions

The total emissions data (Table 4) indicate that the residents living in Underprivileged Areas are more likely to be exposed to higher concentrations of emissions than people living in Areas of Affluence. When examining the population characteristics of the Areas of Affluence, a total of 484,400 people (41.5% of the population of the cluster group, representing 19.4% of Toronto's total population) are exposed to the two lowest ranges of total emissions 0-7,217.8 kg/km^2, as compared to 414,720 people (31.3% of the population of the cluster group, representing 16.7% of Toronto's total population) for Underprivileged Areas.

Table 4: Total Emissions 5km Search Radius

	Total Emissions Concentrations (kg/km^2)				
	0 - 3,248.0	**3,248.1 - 7,217.8**	**7,217.9 - 13,713.8**	**13,713.9 - 27,788.5**	**27,788.6 - 92,027.0**
Underprivileged Areas					
Number of DAs	**217**	**244**	**362**	**330**	**238**
Total Population	208,160	206,560	353,225	302,370	254,350
Percent of Total City-wide Population (%)	8.4	8.3	14.2	12.1	10.2
Percent of Total Cluster Group Population (%)	15.7	15.6	26.7	22.8	19.2
Areas of Affluence					
Number of DAs	**424**	**458**	**517**	**385**	**376**
Total Population	239,215	245,185	281,035	202,280	200,120
Percent of Total City-wide Population (%)	9.6	9.8	11.3	8.1	8.0
Percent of Total Cluster Group Population (%)	20.5	21.0	24.1	17.3	17.1
No Data					
Number of DAs	**0**	**6**	**6**	**8**	**6**

This trend then reverses for the three highest concentration ranges of 7,217.9-92,027.0 kg/km^2, which illustrates that the residents of Underprivileged Areas are most greatly affected by total emissions. A total of 909,945 people living in Underprivileged Areas (68.7% of the population of the cluster group, representing 36.5% of Toronto's total population) are exposed to the three highest ranges of total emissions, as compared to 683,435 people (58.5% of the population of the cluster group, representing 27.4% of Toronto's total population) for Areas of Affluence. This means that an excess of 226,510 of Toronto's residents, which are residing in Underprivileged Areas, are exposed annually to medium or high concentrations of total emissions, beyond what would normally be expected based on an even distribution of population.

5.2. Volatile Organic Compounds

The concentration ranges of VOC emissions (Table 5) are split relatively evenly between Underprivileged Areas and Areas of Affluence. The lowest concentration range for VOCs, 0-10,422.1 kg/km^2, primarily affects the 541,935 people (40.9% of the population of the cluster group, representing 21.7% of Toronto's total population) living in Underprivileged Areas. Toronto residents living in Areas of Affluence are also affected by the lowest concentration range, but to a lesser extent, as 384,610 people (32.9% of the population of the cluster group, representing 15.4% of Toronto's total population) are reported living in these affected DAs.

The second VOC concentration range 10,422.2-31,266.4 kg/km^2, is divided between the 342,915 people (25.9% of the population of the cluster group, representing 13.8% of Toronto's total population) living in Underprivileged Areas, and the 327,380 people (28.0% of the population of the cluster group, representing 13.1% of Toronto's total population) living in Areas of Affluence. The third- and fourth-highest concentrations of

VOCs 31,266.5-182,387.4 kg/km^2 directly affect the 353,690 residents of Areas of Affluence (32.9% of the population of the cluster group, representing 15.4% of Toronto's total population) to a greater extent than the 307,735 people (23.2% of the population of the cluster group, representing 12.3% of Toronto's total population) living in Underprivileged Areas.

Table 5: Volatile Organic Compounds 5km Search Radius

	VOCs Concentrations (kg/km^2)				
	0 - 10,422.1	**10,422.2 - 31,266.4**	**31,266.5 - 83,377.1**	**83,377.2 - 182,387.4**	**182,387.5 - 1,328,822.8**
Underprivileged Areas					
Number of DAs	**653**	**359**	**149**	**119**	**111**
Total Population	541,935	342,915	169,800	137,935	132,080
Percent of Total City-wide Population (%)	21.7	13.8	6.8	5.5	5.3
Percent of Total Cluster Group Population (%)	40.9	25.9	12.8	10.4	10.0
Areas of Affluence					
Number of DAs	**700**	**591**	**374**	**299**	**196**
Total Population	384,610	327,380	194,815	158,875	102,155
Percent of Total City-wide Population (%)	15.4	13.1	7.8	6.4	4.1
Percent of Total Cluster Group Population (%)	32.9	28.0	16.7	13.6	8.7
No Data					
Number of DAs	**12**	**11**	**1**	**2**	**0**

The highest concentration range 182,387.5-1,328,822.8 kg/km^2, primarily affects the 132,080 people (10.0% of the population of the cluster group, representing 5.3% of Toronto's total population) living in Underprivileged Areas, as compared to the 102,155 people (8.7% of the population of the cluster group, representing 4.1% of Toronto's total population) residing in Areas of Affluence. An excess of 29,925 of Toronto's residents, who are residing in Underprivileged Areas, are exposed annually to the highest concentration of VOCs, while an excess of 45,955 people in Areas of Affluence are exposed to the second- and third-highest concentration ranges of VOC emissions.

5.3. Heavy Metals

The concentration ranges of heavy metal emissions (Table 6) are similar in many respects to total emissions. A total of 686,020 people living in Areas of Affluence (58.7% of the population of the cluster group, representing 27.5% of Toronto's total population) are exposed to the two lowest ranges of heavy metals emissions 0-331.2 kg/km^2, as compared to 617,805 people (46.7% of the population of the cluster group, representing 16.7% of Toronto's total population) for Underprivileged Areas. This trend then reverses for the three highest concentration ranges of 331.3-5,279.2 kg/km^2, which illustrates that the residents of Underprivileged Areas are most greatly affected by airborne heavy metals. A total of 706,860 people living in Underprivileged Areas (53.4% of the population of the cluster group, representing 28.4% of Toronto's total population) are exposed to the three highest ranges of total emissions, as compared to 481,815 people (41.3% of the population of the cluster group, representing 19.4% of Toronto's total population) for Areas of Affluence. This means that an excess of 225,045 of Toronto's residents, which are residing in Underprivileged Areas, are exposed annually to the top three highest concentrations of heavy metals emissions.

Table 6: Heavy Metals 5km Search Radius

	Heavy Metals Concentrations (kg/km^2)				
	0 - 103.5	**103.6 - 331.2**	**331.3 - 662.4**	**662.5 - 1,117.9**	**1,118.0 - 5,279.2**
Underprivileged Areas					
Number of DAs	**426**	**177**	**272**	**279**	**237**
Total Population	447,080	170,725	240,575	254,930	211,355
Percent of Total City-wide Population (%)	17.9	6.8	9.7	10.2	8.5
Percent of Total Cluster Group Population (%)	33.8	12.9	18.2	19.2	16.0
Areas of Affluence					
Number of DAs	**874**	**367**	**304**	**265**	**350**
Total Population	488,375	197,645	158,710	138,965	184,140
Percent of Total City-wide Population (%)	19.6	7.9	6.4	5.6	7.4
Percent of Total Cluster Group Population (%)	41.8	16.9	13.6	11.9	15.8
No Data					
Number of DAs	**4**	**7**	**5**	**4**	**6**

5.4. Miscellaneous Compounds

The quantile concentration ranges of miscellaneous compounds (Table 7) demonstrate that a total of 444,585 people living in Areas of Affluence (38.1% of the population of the cluster group, representing 17.8% of Toronto's total population) are exposed to the lowest range of miscellaneous compounds emissions 0-3119.6 kg/km^2, as compared to 415,175 people (31.3% of the population of the cluster group, representing 16.7% of Toronto's total population) for Underprivileged Areas. The second and third emission range 3,119.7-23,397.4 kg/km^2, is divided between the 482,260 people (36.4% of the population of the cluster group, representing 19.4% of Toronto's total population) living in Underprivileged Areas, and the 442,815 people (37.9% of the population of the cluster group, representing 17.8% of Toronto's total population) living in Areas of Affluence. The two highest concentration ranges of 23,397.5-198,098.1 kg/km^2, most greatly affect the residents of Underprivileged Areas. A total of 427,230 people living in Underprivileged Areas (32.2% of the population of the cluster group, representing 17.1% of Toronto's total population) are exposed to the three highest ranges of total emissions, as compared to 280,435 people (24.0% of the population of the cluster group, representing 11.2% of Toronto's total population) for Areas of Affluence. This means that an excess of 146,795 of Toronto's residents, which are residing in Underprivileged Areas, are exposed annually to the top two highest concentrations of total miscellaneous compounds.

Table 7: Miscellaneous Compounds 5km Search Radius

	Miscellaneous Compounds Concentrations (kg/km^2)				
	0 - 3,119.6	**3,119.7 - 8,579.0**	**8,579.1 - 23,397.4**	**23,397.5 - 60,053.3**	**60,053.4 - 198,098.1**
Underprivileged Areas					
Number of DAs	**428**	**260**	**215**	**304**	**184**
Total Population	415,175	281,260	201,000	259,705	167,525
Percent of Total City-wide Population (%)	16.7	11.3	8.1	10.4	6.7
Percent of Total Cluster Group Population (%)	31.3	21.2	15.2	19.6	12.6
Areas of Affluence					
Number of DAs	**792**	**480**	**362**	**268**	**258**
Total Population	444,585	253,215	189,600	144,705	135,730
Percent of Total City-wide Population (%)	17.8	10.2	7.6	5.8	5.4
Percent of Total Cluster Group Population (%)	38.1	21.7	16.2	12.4	11.6
No Data					
Number of DAs	**8**	**3**	**3**	**6**	**6**

5.5. TEP Carcinogenic Emissions

The quantile concentration ranges of TEP Carcinogenic Emissions (Table 8) indicate that a total of 598,100 people living in Underprivileged Areas (45.2% of the population of the cluster group, representing 24.0% of Toronto's total population) are exposed to the lowest range of emissions 0-155,730.7 kg/km^2, as compared to 425,170 people (36.4% of the population of the cluster group, representing 17.1% of Toronto's total population) for Areas of Affluence. The second, third, and fourth emissions ranges 155,730.8-3,036,749.8 kg/km^2, predominantly affect the 650,310 people (55.7% of the population of the cluster group, representing 21.6% of Toronto's total population) living in Areas of Affluence. Underprivileged Areas are also affected, but to a lesser extent with 603,335 people (45.5% of the population of the cluster group, representing 24.1% of Toronto's total population).

Table 8: TEP Carcinogenic Emissions 5km Search Radius

	TEP Carcinogenic Emissions Concentrations (kg/km^2)				
	0 - 155,730.7	**155,730.8 - 545,057.6**	**545,057.7 - 1,479,442.2**	**1,479,442.3 - 3,036,749.8**	**3,036,749.9 - 19,855,672.0**
Underprivileged Areas					
Number of DAs	**719**	**307**	**143**	**114**	**108**
Total Population	598,100	307,755	155,085	140,495	123,230
Percent of Total City-wide Population (%)	24.0	12.3	6.2	5.6	4.9
Percent of Total Cluster Group Population (%)	45.2	23.2	11.7	10.6	9.3
Areas of Affluence					
Number of DAs	**778**	**560**	**360**	**281**	**181**
Total Population	425,170	309,180	191,340	149,790	92,355
Percent of Total City-wide Population (%)	17.1	12.4	7.7	6.0	3.7
Percent of Total Cluster Group Population (%)	36.4	26.5	16.4	12.8	7.9
No Data					
Number of DAs	**16**	**7**	**1**	**2**	**0**

The highest concentration range of 3,036,749.9-19,855,672.0 kg/km2, most greatly affect the residents of Underprivileged Areas. A total of 123,230 people living in Underprivileged Areas (9.3% of the population of the cluster group, representing 4.9% of Toronto's total population) are exposed to the highest range of emissions, as compared to

92,355 people (7.9% of the population of the cluster group, representing 3.7% of Toronto's total population) for Areas of Affluence. An excess of 30,875 of Toronto's residents residing in Underprivileged Areas are exposed annually to the highest concentration range of TEP Carcinogens, while 46,975 excess people living in Areas of Affluence are exposed to the second, third, and fourth highest concentration ranges.

5.6. TEP Non-Carcinogenic Emissions

The quantile concentration ranges of TEP Non-Carcinogenic Emissions (Table 9) indicate that a total of 471,615 people living in Underprivileged Areas (35.6% of the population of the cluster group, representing 18.7% of Toronto's total population) are exposed to the lowest range of emissions 0-591,477.8 kg/km^2, as compared to 379,220 people (32.5% of the population of the cluster group, representing 15.2% of Toronto's total population) for Areas of Affluence. The second emissions range 591,477.9-1,774,433.5 kg/km^2, predominantly affects the 251,035 people (21.5% of the population of the cluster group, representing 10.1% of Toronto's total population) living in Areas of Affluence. Underprivileged Areas are also affected, but to a lesser extent with 229,960 people (17.4% of the population of the cluster group, representing 9.1% of Toronto's total population). The third concentration range 1,774,433.6-4,140,344.8 kg/km^2, is divided between the 206,185 people (15.6% of the population of the cluster group, representing 8.2% of Toronto's total population) living in Underprivileged Areas, and the 203,260 people (17.4% of the population of the cluster group, representing 8.2% of Toronto's total population) living in Areas of Affluence.

Table 9: TEP Non-Carcinogenic Emissions 5km Search Radius

	TEP Non-Carcinogenic Emissions Concentrations (kg/km^2)				
	0 - 591,477.8	**591,477.9 - 1,774,433.5**	**1,774,433.6 - 4,140,344.8**	**4,140,344.9 - 9,315,775.9**	**9,315,776.0 - 37,706,712.0**
Underprivileged Areas					
Number of DAs	**580**	**240**	**192**	**195**	**184**
Total Population	471,615	229,960	206,185	235,090	181,815
Percent of Total City-wide Population (%)	18.7	9.1	8.2	9.3	7.2
Percent of Total Cluster Group Population (%)	35.6	17.4	15.6	17.7	13.7
Areas of Affluence					
Number of DAs	**667**	**467**	**389**	**360**	**277**
Total Population	379,220	251,035	203,260	187,695	146,625
Percent of Total City-wide Population (%)	15.2	10.1	8.2	7.5	5.9
Percent of Total Cluster Group Population (%)	32.5	21.5	17.4	16.1	12.6
No Data					
Number of DAs	**9**	**4**	**3**	**9**	**1**

The highest concentration range of 4,140,344.9-37,706,712.0 kg/km^2, most greatly affect the residents of Underprivileged Areas. A total of 416,905 people living in Underprivileged Areas (31.4% of the population of the cluster group, representing 16.5% of Toronto's total population) are exposed to the top two highest ranges of emissions, as compared to 334,320 people (28.7% of the population of the cluster group, representing 13.4% of Toronto's total population) for Areas of Affluence. An excess of 82,585 of Toronto's residents residing in Underprivileged Areas are exposed annually to the two highest concentration ranges of TEP Non-Carcinogens.

CHAPTER 6. Conclusions

6.1. Summary

This preliminary investigation of NPRI air pollution data using K-Means cluster analysis and kernel density estimation indicates that the DAs classified as Underprivileged Areas were typically impacted by a higher concentration of chemical contaminants than the DAs identified as Areas of Affluence. This demonstrates that DAs defined by low income, and segregation along racial lines, had a greater probability of being exposed to air pollution in 2006 than would be expected based on population distribution alone.

Although the DAs classified as Areas of Affluence represented a larger land surface area of the City of Toronto, Underprivileged Areas have a significantly higher population density. It must be noted that even though a larger proportion of people living in Underprivileged Areas were exposed to the highest concentrations of contaminants, large proportions of Toronto's population classified as Areas of Affluence were also affected. While the data suggest the presence of social and environmental injustice with regards to air pollution dispersion, society as a whole was being detrimentally impacted by the release of toxic chemicals into the air.

6.2. Recommendations

Limiting the emission of harmful pollutants is advantageous to everyone in society. This paper endeavours to prompt government regulators and environmental researchers to work with the owners of the polluting facilities monitored by Environment Canada on finding ways to become better community partners. By recognizing specific facilities in

Toronto that are the greatest emitters of pollutants, solutions can be implemented to reduce the mass of chemicals that would ordinarily be released into the environment.

Air filtration technologies capable of recycling, or at least limiting air pollutants, are currently available on the market, and have demonstrated tremendous success in reducing the mass of emissions being released into the atmosphere. For instance, the Toronto based company Pond Biofuels Incorporated, has been pioneering technology in close cooperation with the Government of Canada since 2009 that is capable of converting heavy industrial emissions into micro-algae biomass. Rather than being released into the atmosphere, the biomass that is created from the emissions can be converted into both diesel fuel and a renewable coal substitute. Furthermore, electricity can be generated from implementing such technology that can both be used to enable facility operations, and to power surrounding neighbourhoods (Pond Biofuels Incorporated, 2011).

The primary recommendation that became evident during the drafting of this research relates to the development of meteorological dispersion models in future studies to determine how pollutants are dispersed across the urban landscape. Although numerous meteorological dispersion models are currently available, the CALPUFF model in particular has been endorsed by the USEPA as being among the foremost means of calculating pollutant dispersion.

6.3. Limitations and Future Research

In examining the distribution of NPRI monitored emissions in Toronto, a number of limitations in the research have been outlined. The meteorological data that were summarized in this paper has indicated that emissions dispersion in the City of Toronto will not follow a uniform pattern, and will be distributed outwards from the source facility in all directions at varying rates of speed. To accurately model the direction and speed of the emissions outflow, precise upper atmospheric data and high accuracy surface data will be required in future research.

Although a total of 67 variables were developed from the 2006 Canadian census, additional data can be implemented in future studies. The census variables used in this research represent age and gender, marital status, primary language, citizenship and immigration status, region of ethnic origin, education, employment, after-tax individual income, after-tax low income, housing ownership, housing era of construction, and housing type. A multitude of census variables are available from the 2006 census that can be used to augment the information discussed in this research.

The NPRI data as they relate to toxic equivalency potentials is another area that can be developed further in future research. The primary limitation with the pollution data in this study relates to the calculation of the TEP for NA-M16 - Volatile Organic Compounds. Although the NA-M16 data represents 53.4% of all emissions in Toronto in 2006, Scorecard does not list a toxic equivalency for this chemical classification because it represents a large range of VOCs, each with its own TEP. Chemicals classified as VOCs by the NPRI, and were reported for Toronto in 2006, were extracted from the pollution database. Using the average TEP scores for the 33 VOCs monitored by the NPRI for Toronto, multipliers values of 20.42 were calculated for carcinogenic TEP and 8.79 for non-carcinogenic TEP. The multiplier values were then combined with the NA-

M16 data reported by facilities to provide an estimate of relative toxicity of the NA-M16 compound. The limitation of this approach is that it assumes the TEP of NA-M16 is indeed the average of VOCs measured by the NPRI. The Scorecard database is continually updated as chemical analysis confirms the toxicity of airborne contaminants. The chemicals that were not provided a TEP score in this research paper will in time have the necessary analysis completed.

The primary limitation of kernel density estimation relates to the limited number of input variables. Although concentration values can be developed using kernel density estimation, this method assumes that no other variables aside from the input points are influencing the spread of pollutants across the City of Toronto. The necessary meteorological dispersion variables, such as prevailing winds, surface topography, atmospheric pressure, and precipitation, are not included in the calculation. The kernel density estimation calculation provides a generalized raster output that can serve an approximation regarding the dispersion of pollutants in Toronto.

A second limitation of the application of kernel density estimation in this paper was the use of the pollution density at each DA centroid point as the pollution value for the entire DA. Instead, zonal statistics should be applied to calculate the average emissions concentrations from the kernel density estimation raster datasets for each DA. The subsequent classification into quintiles for further analysis would be based on more accurate estimates of DA-wide pollution. Similar techniques have been used in environmental research conducted by Copeland et al. (2009) and Sonwalkar et al. (2010).

Future research of airborne pollution in Toronto should attempt to expand upon the kernel density estimation technique used in this paper by implementing meteorological dispersion simulations using the NPRI data and enhanced GIS modelling techniques as they become available. However, significant funding will be necessary to collect the required data for the model, and to purchase the necessary meteorological modelling software capable of analyzing the results. As meteorological data and pollutant dispersion modelling technology becomes more readily available, risk assessments of affected areas will become both increasingly common and more accurate.

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APPENDICES

A.1. Selected 2006 Census Variables

Variables	Aggregated by Statistics Canada	Standardized by Statistics Canada	Numerator	Denominator
Gender and Age				
Males	No	No	Total male population	Total population
- Ages 0-19	No	No	Total male population between the ages of 0 to 19	Total population
- Ages 20-64	No	No	Total male population between the ages of 20 to 64	Total population
- Ages 65 and Over	No	No	Total male population between the ages of 65 and over	Total population
Females	No	No	Total female population	Total population
- Ages 0-19	No	No	Total female population between the ages of 0 to 19	Total population
- Ages 20-64	No	No	Total female population between the ages of 20 to 64	Total population
- Ages 65 and Over	No	No	Total female population between the ages of 65 and over	Total population
Marital Status				
Single	Yes	No	Total population 15 years and over never legally married (single)	Total population 15 years and over by legal marital status
Married	Yes	No	Total population 15 years and over legally married (and not separated)	Total population 15 years and over by legal marital status
Separated	Yes	No	Total population 15 years and over separated (still legally married)	Total population 15 years and over by legal marital status
Divorced	Yes	No	Total population 15 years and over divorced	Total population 15 years and over by legal marital status
Widowed	Yes	No	Total population 15 years and over widowed	Total population 15 years and over by legal marital status

Variables	Aggregated by Statistics Canada	Standardized by Statistics Canada	Numerator	Denominator
<u>Primary Language</u>				
English	Yes	No	Total English responses (single responses)	Total population by mother tongue (single responses)
French	Yes	No	Total French responses (single responses)	Total population by mother tongue (single responses)
Non-Official	Yes	No	Total Non-Official responses (single responses)	Total population by mother tongue (single responses)
<u>Citizenship and Immigration Status</u>				
Canadian Citizen	Yes	No	Total Canadian citizens	Total population
Non-Citizen	Yes	No	Total Non-Canadian citizens	Total population
Born Canadian	Yes	No	Total non-immigrants	Total population
Immigrant	Yes	No	Total immigrants	Total population
- Immigrated Prior to 2001	No	No	Total immigrant population by period of immigration (all years prior to 2001)	Total population
- Recent Immigrant (2001 and After)	Yes	No	Total immigrant population by period of immigration (2001 and 2006)	Total population
Non-Permanent Resident	Yes	No	Total non-permanent residents	Total population
<u>Region of Ethnic Origin</u>				
British Isles	Yes	No	Total population by British Isles origins	Total population
French	Yes	No	Total population by French origins	Total population
Aboriginal	Yes	No	Total population by Aboriginal origins	Total population
North American	Yes	No	Total population by North American origins	Total population
Caribbean	Yes	No	Total population by Caribbean origins	Total population

Variables	Aggregated by Statistics Canada	Standardized by Statistics Canada	Numerator	Denominator
Central and South American	Yes	No	Total population by Central and South American origins	Total population
European	Yes	No	Total population by European origins	Total population
African	Yes	No	Total population by African origins	Total population
Arab	Yes	No	Total population by Arab origins	Total population
West Asian	Yes	No	Total population by West Asian origins	Total population
South Asian	Yes	No	Total population by South Asian origins	Total population
Southeast Asian	Yes	No	Total population by Southeast Asian origins	Total population
Oceania	Yes	No	Total population by Oceania origins	Total population
Education				
Certificate	Yes	No	Total population 15 years and over by certificate, diploma or degree	Total population 15 years and over by highest certificate, diploma or degree
No Certificate	Yes	No	Total population 15 years and over by no certificate, diploma or degree	Total population 15 years and over by highest certificate, diploma or degree
Employment				
Employment Rate	Yes	Yes		
- Management	Yes	No	Total labour force 15 years and over by management	Total labour force 15 years and over by occupation
- Natural and Applied Sciences	Yes	No	Total labour force 15 years and over by natural and applied sciences	Total labour force 15 years and over by occupation
- Business, Finance and Administration	Yes	No	Total labour force 15 years and over by business, finance and administration	Total labour force 15 years and over by occupation

Variables	Aggregated by Statistics Canada	Standardized by Statistics Canada	Numerator	Denominator
- Health	Yes	No	Total labour force 15 years and over by heath	Total labour force 15 years and over by occupation
- Art, Culture, Recreation and Sports	Yes	No	Total labour force 15 years and over by art, culture, recreation and sports	Total labour force 15 years and over by occupation
- Social Science, Education, Government Service and Religion	Yes	No	Total labour force 15 years and over by social sciences, education, government service and religion	Total labour force 15 years and over by occupation
- Sales and Services	Yes	No	Total labour force 15 years and over by sales and services	Total labour force 15 years and over by occupation
- Trades, Transport and Equipment Operators	Yes	No	Total labour force 15 years and over by trades, transport and equipment operators	Total labour force 15 years and over by occupation
- Primary Industry	Yes	No	Total labour force 15 years and over by primary industry	Total labour force 15 years and over by occupation
- Secondary Industry	Yes	No	Total labour force 15 years and over by secondary industry	Total labour force 15 years and over by occupation
Unemployment Rate	Yes	Yes		
After-Tax Individual Income				
Less than $25,000	No	No	Total population with an after-tax income of $0 to $24,999	Total after-tax income of population 15 years and over
$25,000 to $49,999	No	No	Total population with an after-tax income of $25,000 to $49,999	Total after-tax income of population 15 years and over
$50,000 and Over	Yes	No	Total population with an after-tax income of $50,000 and over	Total after-tax income of population 15 years and over
After-Tax Low Income				
Family Low Income	Yes	Yes		
Non-Family Low Income	Yes	Yes		

Variables	Aggregated by Statistics Canada	Standardized by Statistics Canada	Numerator	Denominator
<u>Housing Ownership</u>				
Owned	Yes	No	Total number of owned occupied private dwellings by housing tenure	Total number of occupied private dwellings by housing tenure
Rented	Yes	No	Total number of rented occupied private dwellings by housing tenure	Total number of occupied private dwellings by housing tenure
<u>Housing Era of Construction</u>				
Built Prior to 1981	No	No	Total number of occupied private dwellings (built all years prior to 1981)	Total number of occupied private dwellings by period of construction
Built 1981 and After	No	No	Total number of occupied private dwellings (built 1981 and after)	Total number of occupied private dwellings by period of construction
<u>Housing Type</u>				
Semi-Detached	Yes	No	Total number of occupied private semi-detached dwellings	Total number of occupied private dwellings by structural type of dwelling
Single Detached	Yes	No	Total number of occupied private single detached dwellings	Total number of occupied private dwellings by structural type of dwelling
Apartment Duplex	Yes	No	Total number of occupied private apartment duplexes	Total number of occupied private dwellings by structural type of dwelling
Row House	Yes	No	Total number of occupied private row houses	Total number of occupied private dwellings by structural type of dwelling
Apartment, Less than Five Stories	Yes	No	Total number of occupied private apartments, less than five stories	Total number of occupied private dwellings by structural type of dwelling
Apartment, Five Stories or More	Yes	No	Total number of occupied private apartments, five stories or more	Total number of occupied private dwellings by structural type of dwelling
Single Attached	Yes	No	Total number of occupied private single attached dwellings	Total number of occupied private dwellings by structural type of dwelling

Variables	Aggregated by Statistics Canada	Standardized by Statistics Canada	Numerator	Denominator
Movable	Yes	No	Total number of occupied private movable dwellings	Total number of occupied private dwellings by structural type of dwelling

A.2. Aggregated 2006 NPRI Air Pollution Data

CAS Number	Chemical Name	Total (kg)	Carcinogenic TEP Score	Total (kg)	Non-Carcinogenic TEP Score	Total (kg)
100-41-4	Ethylbenzene	15613	0.00	0.00	0.14	2185.82
100-42-5	Styrene	106189	0.00	0.00	0.08	8495.12
103-23-1	Bis(2-ethylhexyl) adipate	1130				
107-13-1	Acrylonitrile	118	3.90	460.20	38.00	4484.00
107-21-1	Ethylene glycol	2199	0.00	0.00	0.25	549.75
108-05-4	Vinyl acetate	4414	0.00	0.00	1.50	6621.00
108-10-1	Methyl isobutyl ketone	47908	0.00	0.00	0.03	1437.24
108-88-3	Toluene	547286	0.00	0.00	1.00	547286.00
108-95-2	Phenol (and its salts)	5450	0.00	0.00	0.38	2071.00
110-54-3	n-Hexane	37171	0.00	0.00	0.03	1115.13
110-82-7	Cyclohexane	64	0.00	0.00	0.02	1.28
11104-93-1	Nitrogen oxides (expressed as NO2)	1510184	0.00	0.00	2.20	3322404.80
111-42-2	Diethanolamine (and its salts)	17330	0.00	0.00	310.00	5372300.00
111-76-2	2-Butoxyethanol	67885				
115-07-1	Propylene	1832	0.00	0.00	0.02	36.64
1163-19-5	Decabromodiphenyl oxide	1				
118-74-1	Hexachlorobenzene	0.024	2200.00	52.80	21000.00	504.00
121-44-8	Triethylamine	144	0.00	0.00	0.40	57.60
122-39-4	Diphenylamine	1267	0.00	0.00	14.00	17738.00

CAS Number	Chemical Name	Total (kg)	Carcinogenic TEP Score	Total (kg)	Non-Carcinogenic TEP Score	Total (kg)
127-18-4	Tetrachloroethylene	423	0.96	406.08	65.00	27495.00
128-37-0	2,6-Di-t-butyl-4-methylphenol	2065	0.00	0.00	98.00	202370.00
131-11-3	Dimethyl phthalate	100	0.00	0.00	0.02	2.00
1330-20-7	Xylene (all isomers)	168669	0.00	0.00	0.27	45540.63
140-88-5	Ethyl acrylate	46	0.07	3.22	1.60	73.60
141-32-2	Butyl acrylate	247	0.07	17.29	1.60	395.20
1717-00-6	HCFC-141b	1655				
26471-62-5	Toluenediisocyanate (mixed isomers)	29				
50-00-0	Formaldehyde	180	0.02	3.60	16.00	2880.00
584-84-9	Toluene-2,4-diisocyanate	3				
630-08-0	Carbon monoxide	906559	0.00	0.00	0.14	126918.26
67-56-1	Methanol	240830	0.00	0.00	0.09	21674.70
67-63-0	Isopropyl alcohol	456296	0.00	0.00	0.01	4562.96
71-36-3	n-Butyl alcohol	33442	0.00	0.00	0.71	23743.82
71-43-2	Benzene	187	1.00	187.00	8.10	1514.70
7429-90-5	Aluminum (fume or dust)	15877	0.00	0.00	61.00	968497.00
7446-09-5	Sulphur dioxide	203080	0.00	0.00	3.10	629548.00
75-05-8	Acetonitrile	10900	0.00	0.00	30.00	327000.00
75-07-0	Acetaldehyde	14027	0.01	140.27	9.30	130451.10
75-09-2	Dichloromethane	38965	0.20	7793.00	7.00	272755.00

CAS Number	Chemical Name	Total (kg)	Carcinogenic TEP Score	Total (kg)	Non-Carcinogenic TEP Score	Total (kg)
75-45-6	HCFC-22	17618	0.00	0.00	1.40	24665.20
75-68-3	HCFC-142b	169153	0.00	0.00	1.00	169153.00
7632-00-0	Sodium nitrite	24479				
7647-01-0	Hydrochloric acid	4939	0.00	0.00	12.00	59268.00
7664-39-3	Hydrogen fluoride	1	0.00	0.00	3.60	3.60
7664-93-9	Sulphuric acid	797				
7697-37-2	Nitric acid	2241	0.00	0.00	2.10	4706.10
78-83-1	i-Butyl alcohol	19277	0.00	0.00	0.26	5012.02
78-92-2	sec-Butyl alcohol	1	0.00	0.00	0.57	0.57
78-93-3	Methyl ethyl ketone	298822	0.00	0.00	0.05	14941.10
79-01-6	Trichloroethylene	359	0.05	17.95	0.63	226.17
79-10-7	Acrylic acid (and its salts)	6	0.00	0.00	62.00	372.00
80-05-7	p,p'-Isopropylidenediphenol - Bisphenol A	159	0.00	0.00	7.90	1256.10
80-62-6	Methyl methacrylate	15859	0.00	0.00	0.53	8405.27
85-44-9	Phthalic anhydride	63	0.00	0.00	3.00	189.00
872-50-4	N-Methyl-2-pyrrolidone	8712				
91-20-3	Naphthalene	8359	0.00	0.00	18.00	150462.00
95-63-6	1,2,4-Trimethylbenzene	7767	0.00	0.00	11.00	85437.00
98-82-8	Cumene	434	0.00	0.00	0.41	177.94
NA - 01	Antimony (and its compounds)	1	0.00	0.00	8100.00	8100.00

CAS Number	Chemical Name	Total (kg)	Carcinogenic TEP Score	Total (kg)	Non-Carcinogenic TEP Score	Total (kg)
NA - 02	Arsenic (and its compounds)	3.7	16000.00	59200.00	84000.00	310800.00
NA - 03	Cadmium (and its compounds)	6.97	26000.00	181220.00	1900000.00	13243000.00
NA - 04	Chromium (and its compounds)	358	130.00	46540.00	2400.00	859200.00
NA - 05	Cobalt (and its compounds)	1400	0.00	0.00	31000.00	43400000.00
NA - 06	Copper (and its compounds)	772	0.00	0.00	13000.00	10036000.00
NA - 07	Cyanides (ionic)	1	0.00	0.00	580.00	580.00
NA - 08	Lead (and its compounds)	455.899	28.00	12765.17	580000.00	264421420.00
NA - 09	Manganese (and its compounds)	205	0.00	0.00	780.00	159900.00
NA - 10	Mercury (and its compounds)	2.92	0.00	0.00	14000000.00	40880000.00
NA - 11	Nickel (and its compounds)	20	2.80	56.00	3200.00	64000.00
NA - 14	Zinc (and its compounds)	3321	0.00	0.00	190.00	630990.00
NA - 16	Ammonia (total)	90057	0.00	0.00	3.80	342216.60
NA - 19	Hexavalent chromium (and its compounds)	127.779	130.00	16611.27	2400.00	306669.60
NA - 20	Nonylphenol and its ethoxylates	17796				
NA - 22	Phosphorus (total)	119				
NA - D/F	Dioxins and furans - total	0.00022	1200000000.00	264000.00	880000000000.00	193600000.00
NA - M08	PM - Total Particulate Matter	461940				
NA - M09	PM10 - Particulate Matter <= 10 Microns	475583.3	0.00	0.00	1.50	713374.95
NA - M10	PM2.5 - Particulate Matter <= 2.5 Microns	357919	0.00	0.00	17.00	6084623.00

CAS Number	Chemical Name	Total (kg)	Carcinogenic TEP Score	Total (kg)	Non-Carcinogenic TEP Score	Total (kg)
NA - M16	Volatile Organic Compounds (VOCs)	7328035	20.42	149638474.70	8.79	64413427.65

A.3. Ten Principal Contributors of NPRI Total Emissions

NPRI ID	Company Name	Address	Total Emissions (kg)	Percent of Emissions (%)
0000000511	O-I Canada Corp. – Plant #30 Toronto	777 Kipling Avenue	965112.6	7.0
0000003553	Chemtura Canada – West Hill	10 Chemical Court	812780.0	5.9
0000004518	Alcan Packaging	130 Arrow Road	730118.0	5.3
0000011041	Hymopack Ltd.	41 Medulla Avenue	693273.0	5.0
0000001480	Sapa Canada Inc. – Toronto Division	7 Alloy Court	523871.0	3.8
0000003447	Quebecor Media Inc.	2250 Islington Avenue	481284.0	3.5
0000007435	Atlantic Packaging Products Ltd. – Gran Packaging	255 Brimley Road	366396.0	2.7
0000010154	Mundet Canada – Scarborough Plant	210 Midwest Road	338836.0	2.5
0000000423	The International Group Inc. – Agincourt Plant	50 Salome Drive	301091.0	2.2
0000003989	Jacobs & Thompson Inc.	89 Kenhar Drive	294267.0	2.1

A.4. Ten Principal Contributors of NPRI VOCs

NPRI ID	Company Name	Address	VOCs (kg)	Percent of Emissions (%)
0000003553	Chemtura Canada – West Hill	10 Chemical Court	756000.0	7.8
0000004518	Alcan Packaging – Arrow Road	130 Arrow Road	728911.0	7.5
0000011041	Hymopack Ltd.	41 Medulla Avenue	692221.0	7.2
0000003447	Quebecor Media Inc.	2250 Islington Avenue	479910.0	5.0
0000007435	Atlantic Packaging Products Ltd. – Gran Packaging	255 Brimley Road	366396.0	3.8
0000010154	Mundet Canada – Scarborough Plant	210 Midwest Road	338836.0	3.5
0000003989	Jacobs & Thompson Inc.	89 Kenhar Drive	294267.0	3.0
0000000538	Crown Metal Packaging Canada LP. – PLT. 245	21 Fenmar Drive	293276.0	3.0
0000011175	Allied-Halo Industries Inc.	341 Nantucket Boulevard	285864.0	3.0
0000005937	Fleetwood Fine Furniture LP.	75 Brown's Line	283077.0	2.9

A.5. Ten Principal Contributors of NPRI Heavy Metals

NPRI ID	Company Name	Address	Heavy Metals (kg)	Percent of Emissions (%)
0000001870	Cascades Canada Inc. – Cascades Boxboard Group Toronto Mill	495 Commissioner's Street	23925.0	21.2
0000007205	Kraft Canada – Lakeshore Bakery	2150 Lake Shore Boulevard West	22180.0	19.7
0000007248	Kraft Canada – East York Bakery	5 Bermondsey Road	19440.0	17.2
0000001993	Coretec – Ellesmere Facility	2020 Ellesmere Road	16396.6	14.5
0000003141	Tower Automotive	158 Sterling Road	10516.0	9.3
0000001480	Sapa Canada Inc. – Toronto Division	7 Alloy Court	5361.0	4.8
0000002065	Rohm and Haas Canada LP. – West Hill Plant	2 Manse Road	5252.0	4.7
0000007334	Quality Meat Packers Ltd.	2 Tecumseth Street	2200.0	2.0
0000005605	Unicell Ltd.	50 Industrial Street	1400.0	1.2
0000011330	City View Platers Inc.	121 City View Drive	745.0	0.7

A.6. Ten Principal Contributors of NPRI Miscellaneous Compounds

NPRI ID	Company Name	Address	Miscellaneous Compounds (kg)	Percent of Emissions (%)
0000000511	O-I Canada Corp. – Plant #30 Toronto	777 Kipling Avenue	941277.0	23.6
0000001480	Sapa Canada Inc. – Toronto Division	7 Alloy Court	375630.0	9.4
0000007657	Enwave District Energy – Walton Street Steam Plant	95 Walton Street	266300.0	6.7
0000004435	City of Toronto – Highland Creek Treatment Plant	51 Beechgrove Drive	257990.0	6.5
0000010421	Canroof – CRC Toronto	560 Commissioners Street	254081.0	6.4
0000002016	Redpath Sugar Ltd. – Toronto Refinery	95 Queen's Quay East	190271.0	4.8
0000000282	Dow Chemical Canada ULC. – Weston	122 Arrow Road	189605.0	4.8
0000000327	Irving Tissue – Weston Site	1551 Weston Road	144610.0	3.6
0000007656	Enwave District Energy – Pearl Street Steam Plant	120 Pearl Street	122200.0	3.1
0000010279	National Silicates Partnership	429 Kipling Avenue	108560.0	2.7

A.7. Ten Principal Contributors of NPRI TEP Carcinogens

NPRI ID	Company Name	Address	TEP Carcinogens (kg)	Percent of Emissions (%)
0000011041	Hymopack Ltd.	41 Medulla Avenue	14135152.8	9.4
0000004518	Alcan Packaging	130 Arrow Road	13575011.8	9.0
0000003553	Chemtura Canada – West Hill	10 Chemical Court	12476620.0	8.3
0000010154	Mundet Canada – Scarborough Plant	210 Midwest Road	6919031.1	4.6
0000003447	Quebecor Media Inc.	2250 Islington Avenue	6182971.8	4.1
0000011175	Allied-Halo Industries Inc.	341 Nantucket Boulevard	5427758.5	3.6
0000000538	Crown Metal Packaging Canada LP. – PLT. 245	21 Fenmar Drive	4861593.6	3.2
0000007256	Weston Bakeries Ltd.	462 Eastern Avenue	3894910.8	2.6
0000007435	Atlantic Packaging Products Ltd. – Gran Packaging	255 Brimley Road	3740903.2	2.5
0000005937	Fleetwood Fine Furniture LP.	75 Brown's Line	3629818.4	2.4

A.8. Ten Principal Contributors of NPRI TEP Non-Carcinogens

NPRI ID	Company Name	Address	TEP Non-Carcinogens (kg)	Percent of Emissions (%)
0000001480	Sapa Canada Inc. – Toronto Division	7 Alloy Court	152942786.2	23.5
0000000642	The Canada Metal Company Ltd. – Toronto Oxide Plant	721 Eastern Avenue	78363800.0	12.0
0000004435	City of Toronto – Highland Creek Treatment Plant	51 Beechgrove Drive	72201875.0	11.1
0000010613	Joseph Robertson Foundries Ltd.	24 Milford Avenue	63800000.0	9.8
0000005605	Unicell Ltd.	50 Industrial Street	43403633.3	6.7
0000000455	Ingot Metal Company Ltd.	111 Fenmar Drive	36819679.0	5.7
0000004624	A.T. Designs Insignia	70 Production Drive	34220000.0	5.3
0000001993	Coretec – Ellesmere Facility	2020 Ellesmere Road	20280795.7	3.1
0000007066	IBIS Products Ltd.	17 & 21 Munham Gate	17312892.2	2.7
0000001169	Celestica International – Toronto Site	844 Don Mills Road	10485731.5	1.6