Industrial emissions and Children’s Environmental Injustice in Canada: Exploring geographical patterns and an example of its relation to Children’s Cancer in Manitoba

by

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Abstract

Background: Environmental Injustice (EI) suggests that socioeconomically disadvantaged citizens/minority groups have a higher than average exposure to environmental contaminants and bear more subsequent health risks than their socioeconomically advantaged/majority group counterparts. In order to investigate EI and adverse health outcomes from environmental contaminants in Canada, a measure of SES is needed.

Objective: 1) Construct and validate an index to measure socioeconomic status (SES) and minority status in Canadian children; 2) Examine the co-localization of SES and air pollutants emitted by industry, using the index created in Aim 1. This second aim will provide evidence to support or disprove the existence of EI among Canadian children. 3) Determine if there is a difference in EI in urban versus rural areas of Canada. 4) Examine whether environmental pollutants and SES are related to childhood cancer outcomes in Manitoba.

Methods: Variables were examined at dissemination area level (DAs, regions containing 400-700 residents, n = 52970 in Canada): 1) Census data (2006): extracted from CANSIM [2]; 2) chemical data (tonnes, n=201): from National Pollutant Release Inventory (NPRI, 2006) [3]; 3) Carcinogens (International Agency for Research on Cancer class 1) (n=15, tonnes); 4) Distance from the center of DAs to nearest emitting facilities: from available latitude and longitude of each emitting facility; 5) children's cancer data (n=531) from the Manitoba Cancer Registry (1997-2007); 6) Urban and rural DAs, unique identifiers or "UARAs" (urban and rural area codes) were extracted from GeoSuites. [5] ***Aim 1***: Twenty-two Census items were used with

principle component analysis to create a valid SES index. The index was validated by examining its association with preterm birth (gestational age < 37 weeks), term low birth weight (LBW, <2500 g), small for gestational age (SGA, <10 percentile of birth weight for gestational age) and $PM_{2.5}$ (particulate matter ≤ 2.5 µm) exposures in Edmonton, Alberta (1999-2008). ***Aim 2:*** Simple correlations and geographically weighted regressions (GWR) were used to examine the relations between SES indices and 1) proximity to nearest emitting facilities, 2) chemical emissions, 3) children's population for each province and territory and for Canada as well as for Montreal, Vancouver and Toronto. Results are presented in maps. ***Aim 3:*** Simple correlations and GWR between SES indices, children's population and distances from centroids to nearest emitting facilities were also compared for urban and rural groups. SES indices were divided into quintiles and variables were examined based on each group of SES. ***Aim 4:*** t-tests (2 tails) and simple correlations were performed between groups of DAs with and without cancer cases. Negative binomial regression was performed to examine if SES, chemical and carcinogen emissions, and proximity to nearest emitting facilities could explain children's cancer outcomes. Variables were examined with gender and age at diagnosis using multiple linear regressions. DAs with cancer cases were compared between male and female cases using multiple linear regressions.

Results: ***Aim 1:*** An index used to measure SES for Canada was created and validated. ***Aim 2:*** Potential cases of EI were seen throughout Canada with the strongest indications for Northern territories: Nunavut and Northwest Territories had lowest median SES in Canada, second highest median chemical releases, closer than average proximity to emitting facilities. ***Aim 3:*** urban DAs were suggestive of EI, as these DAs contained lower SES and closer proximity to emitting facilities than rural DAs; all urban DAs were located within 3 km of an emitting facility; ***Aim 4:***

Although there were no overall links between children's cancer occurrence and proximity to nearest emitting facilities, there was a slight indication that differences may occur according to gender, being females more likely affected.

Conclusion: Our index reflects more dimensions of SES than an earlier index and it performed superiorly in capturing gradients in prevalence of pregnancy outcomes. In general, Canadian children may be experiencing environmental exposures because the majority of the Canadian population live in urban areas and regardless of SES, reside in close proximity to industrial emitting facilities. Additionally, gender-specific results and proximity to emitting facilities as well as certain cancer types, might be explored in future studies.

Preface

This thesis is an original work by Emily Chan. A version of Chapter 2 of this thesis has been published as E. Chan, J. Serrano, L. Chen, D. Stieb, M. Jerrett, and A. Osornio-Vargas, "Development of a Socioeconomic Status Index for the Study of Health Outcomes Related to Environmental Pollution", *Biomed Central Public Health*, vol 15, issue 714. Please see Appendix 1 for the published work. I contributed to study design, data acquisition, data analysis, and drafting the manuscript. LC and DS assisted with pregnancy outcome data acquisition and statistical analyses. DS and MJ contributed in helping draft the manuscript. AOV participated in the design of the study, coordination and helped draft the manuscript.

No other parts of this thesis have been previously published. However, chapters 3, 4 and 5 are in the process of being submitted for publication.

Dedication

This work is dedicated to my husband, Darren Lau; my daughter, Charlotte; my parents, Peter and Mileza; and my brother, Ellis.

Thank you all for your patience, support and encouragement during my journey throughout my my PhD training. Each one of you supported me in your own way, and I wouldn't be where I am today without you.

And a special message to Miss Charlotte Olive Lau: I planned a wedding during the beginning of my PhD program, successfully passed my candidacy with you when I was four months pregnant, published a paper two weeks after I gave birth, wrote a thesis and defended when you were three months old. You can do ANYTHING if you set your mind to it! Because of this, I know you will do great things later on in life. Trust me…you have your mom to prove that!

This was all for you.

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I would also like to thank Dr. Po-Yin Cheung, who has been my mentor for the past 12 years. My journey throughout graduate school began with being a summer student in your pharmacology lab in my second year of undergraduate studies and I am proud to say that my PhD degree is largely attributed to your encouragement, wisdom and advice throughout the years. I am also grateful for my supportive committee: Dr. Fiona Bamforth, Dr. Irena Buka, Dr. Xing-Fang Li, and Dr. Osmar Zaiane. Your abilities to challenge me intellectually in all areas have been a great inspiration and each one of you have largely contributed to the way I view and aspire to be a researcher.

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List of Abbreviations

CMA	Census Metropolitan Area
DA	Dissemination area
EI	Environmental Injustice
GIS	Geographic information system
NPRI	National Pollutant Release Inventory
SES	Socioeconomic status
UARA	Urban or rural area code

1. Introduction

1.1 Role of Environment and Health

The World Health Organization defines "Environmental Health" as "those aspects of the human health and disease that are determined by factors in the environment." [1] Environmental concerns include topics such as air quality, toxic chemical exposures, and waste management. [1] It has been estimated that environmental exposures have been attributed to 4.9 million deaths and 86 million disability adjusted life years globally, where the most vital contribution has been from particulate matter pollution in urban air. [2] Most notably has been the link between human and environmental health with superfund sites created by companies in the United States. Here, health effects such as mutations, birth defects and cancers have been associated with these exposures. [3]

Most concern has been with children's environmental exposure. This specific population is more vulnerable to these affects, and it has been suggested that these health effects may appear first in children and in more exaggerated ways than adults. [4] Indeed, numerous studies have linked adverse health outcomes in children such as cancer, to environmental exposures. For example, Knox et al. found large relative risks for children's cancer cases within 0.3 km of areas in Great Britain with large amounts of carbon monoxide, PM_{10}, nitrogen oxides, 1-3 butadiene, benzene, dioxins, benzo[a]pyrenes, and volatile releases. [5] It was determined that prenatal and early postnatal exposures to oil based combustion gases were strongly related to childhood cancers. [5] Similarly, a study in Texas showed that there were elevated risks for childhood hepatic tumors in areas with large releases of hazardous air and greater germ cell tumors in places with intense cropping and hepatic cancers near hazardous air pollutant facilities. [6] Lastly, increased childhood leukemia rates and high hazardous air pollutant exposures were observed with children in California. [7]

Some of the problems encountered when studying the impact of environmental factors on children's health is the complexity of the process. On one hand, there are problems assigning exposures since the presence of chemicals in the environment has not been completely assessed. The chemicals themselves may be released in mixtures, where the effect may not be known or difficult to interpret because of possible interactions with the chemicals amongst themselves, or with other variables like sunlight or ozone. On the other hand, the environment in which children live imply interactions with other individual and social factors, adding complexity to the problem. Indeed, socioeconomic status is frequently included in studies with environmental pollution exposures and adverse health effects, because of the strong relationship with both variables.

1.2 What is Environmental Injustice?

Environmental Injustice is the unequal distribution of environmental pollution from emitting sources and subsequent adverse health outcomes according to socioeconomic status. This concept most likely began with two historical events: 1) the widely publicized Love Canal environmental disaster of 1978, where 21,000 tons of toxic waste was discovered beneath a New York working class neighbourhood [8]; 2) the decision to chose Shoco State in North Carolina as the host for a hazardous waste landfill which included 30,000 cubic yards of polychlorinated biphenyl (PCBs), where 69% of the Shocco Township were non-Caucasian and had the third lowest per capita income in the state [9].

1.2.1. Environmental Injustice in Canada

Historically, the majority of Environmental Injustice studies have been conducted in the United States [10, 11], with few studies done in Canada. For example, one study examined forty-nine counties in Ontario, Canada, where multiple linear regressions were used to examine the predictability of pollution emission facilities from socioeconomic variables. [12] National Pollutant Release Inventory data (NPRI 1993) and socioeconomic data from Census Canada 1991 were used in the analysis. Here, urbanization variables, manufacturing employment, dwelling value, and household income were significantly related to pollution emissions, where all four variables accounted for 63% of variation in pollution emissions (adjusted R^2=0.626, $p<0.0001$). [12]

Another study examined Environmental Injustice in Hamilton, Ontario, where likely pollution values across the city based on kriging procedures using total suspended particles (TSP) from twenty-three monitoring stations in Hamilton (1985-94) were created. [13] Exposure estimates from TSPs were examined and compared with socioeconomic data using simultaneous autoregressive models (SAR) methods. Interestingly, lower dwelling values were associated with higher pollution exposure (t-statistics for SAR: -2.614, $p<0.05$). [13]

A third study investigated the relationship between pollution emissions from the NPRI (1995-1996, 2000-2001) and socio-economic characteristics (Census Canada 1996, 2001) for 27 municipalities on Montreal Island using the nonparametric Kendall Tau (Ta) correlation coefficients. [14] Pollution measures (number of reporting industries), were negatively related to average monthly amount of major payments, average income of households, proportion of tertiary sector workers, and the proportion of individuals with university education for both time periods. [14] In contrast, pollution measures were positively related to unemployment rate, the proportion of workers in the secondary sector, and the proportion of persons with less than a high school education. [14]

1.3. Environmental Injustice and Cancer

Environmental Injustice has been linked to adverse health outcomes, and we focus on examining childhood cancer in this study. Childhood cancer is a complex multifactorial disease, where genetic factors, radiation, viruses, dietary habits, socioeconomic factors and chemicals have been postulated to contribute to its development. Increased interest in "Environmental Injustice" and cancer development has recently been expressed. [15]

Although there are more studies with adult populations, [16, 17] the lack of research investigating environmental chemical emissions, proximity to emitting facilities, and SES of populations with cancer outcomes is clear within the children's population. Pastor et al. examined 148 air toxic chemical exposures and calculated lifetime cancer risks within the Los Angeles Unified School District.[15] In this study, a multivariate analysis containing the following dependent variables 1) estimated cancer and respiratory risks with air toxics, 2) the likelihood of living in close proximity to toxic, storage, and disposal facility or 3) a toxic release inventory facility, were, regressed with: 1) the proportion of ethnic students within a school, 2) the industrial land use, 3) the population density, 4) the median household income, and 5) the homeownership rate. The authors were able to show that the proportion of ethnic students could predict the cancer risk estimates, as well as the facility location. [15] This study showed that various socioeconomic and environmental determinants and racial minority status were related to modeled lifetime cancer risk. [15]

1.4 Hypotheses

In this thesis, we will attempt to examine the following hypotheses:

1) Environmental Injustice exists in Canada.
2) There are differences with Environmental Injustice between urban and rural areas.
3) Environmental Injustice is related to children's cancer cases in Manitoba.

1.5 Objectives

There are four objectives to this thesis:

1) Create and validate an index to measure socioeconomic status (SES) in Canadian children.
2) Investigate the co-localization of SES and air pollutants emitted by industry, using the index created in Objective 1, where this second objective will provide evidence to support or disprove the existence of EI among Canadian children.
3) Determine if there is a difference in EI between urban and rural areas of Canada.
4) Determine whether environmental pollutants and SES are linked to childhood cancer outcomes in Manitoba.

Chapter 2: Development of a Canadian Socioeconomic Status Index for the study of Health Outcomes related to Environmental Pollution

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2.1 Introduction

Reports such as the Canada Health Survey [19] and the Canadian Community Health Survey [19] indicated that inequalities of health resulting from socioeconomic status (SES) required urgent scrutiny.[20] Because the majority of health data is released in area-level form in comparison to individual-level form as a result of privacy concerns, geographical proxies, where the SES for small areas is linked to health data from administrative databases are often utilized.[20] Most of these studies have used neighbourhood income as the indicator of social disparity and mortality as the health indicator.[20] Measuring SES using a single indicator, however, is unlikely to completely reflect its complexity. Deprivation indices including other measures such as unemployment, social class, income, marital status, occupation, and education have been developed for Great Britain,[21] Spain,[22] and Italy.[23]

Until recently, only two deprivation indices for Canada have been developed, each with a specific purpose. Matheson et al. (2012) proposed an index called the "Can-Marg" using Census 2006 data, in which they focused on examining inequalities in health and other social problems.[24] Four deprivation criteria: residential instability, material deprivation, dependency and ethnic concentration were defined and inequalities in 18 health and behavioural problems from the Canadian Community Health Survey (CCHS) reported.[24] However, the index that is mostly used in Canadian research has been the Pampalon index, developed in Quebec. Pampalon et al. illustrated its value by linking it to overall Canadian premature mortality rates in 2001.[20] The group developed their index based on Townsend's definition of deprivation [25] and included variables such as education and marital status. More specifically, their index was divided into two components: social and material. The Pampalon index only included six variables in the analyses: employment, income, education, marital status, single parent family, and living alone, while the Canadian Census form from which the index was developed, contains over 200 variables.

Among other factors like "individual susceptibility" (e.g. genetic polymorphisms), environmental stressors such as radiation, chemicals, and viruses, as well as dietary habits, psycho-social stress, and social characteristics are known to contribute to the occurrence of common childhood conditions. There recently has been growing interest in environmental injustice, a concept suggesting that those populations with lower SES may be vulnerable to greater exposure to environmental pollutants than their higher SES counterparts, and consequently experiencing potentially increased health risks. Building on this concept, the U.S. Institute of Medicine coined the term "double jeopardy" to emphasize the combined risk often faced by socially disadvantaged groups. Specifically, groups experiencing higher environmental exposure are often more susceptible because they have higher rates of smoking, obesity, poor nutrition, and adverse occupational exposures. [26]

Thus, a need exists for a comprehensive index of socioeconomic status that is indicative of the Canadian population, which can be used for research involving environmental pollution and health outcomes. For that purpose, we aimed to develop a novel SES index that is comprehensive and more encompassing of the Canadian population, by incorporating cultural identities, examining factors relevant to health outcomes from environmental pollution, and considering other variables used in previous environmental injustice studies.

2.2 Methods

2.2.1 Data Extraction

Socioeconomic data were analyzed from the Canadian Census 2006. For our evaluation, we extracted Census data from CANSIM, Canada's socioeconomic database which provides free access to a range of the latest statistics.[27] The Census was completed on May 16, 2006 and 32.5 million people were included. One in every five households received a long questionnaire with 53 questions in comparison to 8 for the short form.[28] Here, we used data from the long questionnaire forms. These data cover all of Canada's dissemination areas (DAs), which are small regions consisting of 400 to 700 people.[29] Canada has 52,974 DAs, ranging from 34 for Nunavut to 18,923 for Ontario.

2.2.2. Variables

A set of 22 variables from the 2006 Census was selected based on: (1) cultural identities [30]; (2) potential environmental pollutants related to health outcomes [31, 32]; (3) Canadian environmental injustice studies [12-14]; and (4) variables utilized in the deprivation index for Canada proposed by Pampalon [20] (Table 2-1). Studies in the United States have indicated a clear relationship between several racial groups with regards to SES [36-38]. In an effort to investigate the phenomenon in Canada, we grouped the cultural identities reported in the census as the individual's ancestry, based on four categories from the "Human Developmental Index" (HDI): origins from (1) very high sum; (2) high sum; (3) medium sum; and (4) low sum countries.[30] The HDI takes into account the human development of a country and ranks them according to life expectancy, literacy, education and standards of living.[30] We included a category for those with aboriginal identities based on responses to the "Indian Status" and "Aboriginal identities" question on the Census and combined those who were North American Indian, Metis, Inuit, multiple Aboriginal identities, and aboriginal responses not included elsewhere. Each of the variables was expressed as proportions per dissemination area (DA). Variables obtained as raw counts of the answers to questions were converted to proportions by dividing by the number of people answering the question. Since the data used in the creation of the index were collected from questions answered with the long form of the Census questionnaire, the proportions were based on the variables corresponding to 20% of the population of Canada. Employment rate, median income and prevalence of low income after taxes were not transformed since they were originally reported as proportions per DA in the census database.

Lastly, we incorporated a variable that we thought was important for health outcomes related to environmental pollution: age of the home (construction of homes before 1946, 1946-1970, 1971-1990, 1991-2006) as a proxy for age of the neighbourhood. In the United States, it has been shown that older neighbourhoods are more likely to have lead paint [32], asbestos [31] and have more infiltration of fine particles from outdoors to indoors. [39]

2.2.3. Construction of SES Index

Principal component analysis (PCA) with a single varimax rotation (factor loadings ≥ $|60|$) was performed on the selected 22 Census socioeconomic variables (SAS 9.2, North Carolina, USA). The analyses were completed for all DAs of Canada whereupon we utilized two criteria for the selection of components: (1) Kaiser Criterion (eigenvalues ≥1); and (2) individual proportion of variances per component explaining ≥ 10% of the overall variability. The final SES index was created by averaging the factor scores (a numerical representation of the linear relationship between variables and the components) per DA, according to the three components retained. This process was completed for all DAs in Canada for overall SES indices in the country as well as for each province and territory.

2.2.4. Validation of our SES index

2.2.4.1 Adverse Birth Outcomes

We attempted to validate our index by utilizing the well- researched concept that low SES may be related to adverse birth outcomes.[40, 41] Here, data on all singleton live births between 1999 and 2008 in Edmonton were accessed through Statistics Canada (Table 2-2). Pregnancy outcomes under study were preterm birth (gestational age < 37 weeks), term low birth weight (LBW, <2,500 g), and small for gestational age (SGA, <10 percentile of birth weight for gestational age). Spearman correlations and t-tests were used to assess associations between the index and pregnancy outcomes.

2.2.4.2. Particulate Matter ($PM_{2.5}$)

We also evaluated another known [42], but less explored association between our SES index and concentrations of particulate matter with a mean aerodynamic diameter < 2.5 μm ($PM_{2.5}$). Spearman correlation and t-tests were used to examine relationships between $PM_{2.5}$ exposures and SES indices. $PM_{2.5}$ exposures were assigned by mapping the mother's six-character postal code to a monthly surface $PM_{2.5}$ concentrations, based on a North American land use regression model that incorporated observations from fixed-site monitoring stations and satellite-derived estimates of $PM_{2.5}$. Exposures were estimated for the entire duration of pregnancy. Methods are described in detail elsewhere. [43]

2.2.4.3. Comparison of Chan Index to Pampalon Index

We compared the association of our SES index and that of Pampalon's [20] with adverse birth outcomes and $PM_{2.5}$ concentrations using Spearman correlations and t-tests. The Pampalon index is a commonly used SES index in Canada that was developed using variables from the 2006 Census with: (1) known relations to health; (2) past use as geographical proxies; (3) past utilizations with the material or social dimensions of deprivation; (4) availability by DA.[20] PCA was used on the variables and two components were found that are now used as the Pampalon indices: Values for the Material and Social components. The Pampalon index value used to validate our index were accessed through their website.[20] Both indices represent the Canadian SES situation in 2006 and comparisons assume the same similar Canada wide SES distribution around the year of 2006.

2.3 Results

2.3.1 Principal Component Analysis (PCA)

Three components were extracted for Canada, with a cumulative retained variation of 58.9%. Each component yielded different conceptual meanings when variables were placed together, based on a preconceived categorical variable classification (Table 2-3). Component 1 contained variables related to: (1) social advantages, and (2) high material ownership; (Table 2-4) Component 2 included variables related to economic advantages, (Table 2-5) and Component 3 (Table 2-6) was entirely different in composition and direction and contained variables indicative of being: (1) socially disadvantaged and having (2) specific cultural identities. Interestingly, aboriginal status was not included in the cultural identities of Component 3, but instead medium sum HDI groups were incorporated. Additionally, age of the home was not included in any of the components. For this analysis, the final SES index was obtained averaging the components retained by utilizing the formula [C1+C2+ (-1*C3)]/3. Given the disadvantage connotation of the variables included in Component 3, we multiplied factor scores for Component 3 by -1 to achieve a comprehensive index for Canada, which would integrate all components for an overall meaning of "socioeconomic status".

An overall examination of the index for all of Canada shows a relatively normal distribution (median= 0.11, mean = 0.0, standard deviation= 0.58). However, an individual analysis of the distribution of indices within each province and territory per DA, according to the Canada wide index, yielded different results. Here, the SES index distribution for Canada was divided into quintiles and the number of DAs within each quintile per province and territory was investigated.

(Table 2-7) Alberta showed increasing numbers of DAs within higher values of the SES index, while Newfoundland, Northwest Territories, and Nunavut showed greater numbers of DAs within lower values of the SES index. A chi-square test examining the distribution of DAs within each quintile of SES showed that it was not homogenous among provinces (Pearson chi-square=2,637.9, $p<0.001$).

Furthermore, boxplots of the distribution of SES index by province and territory showed similarities that are more obvious and trends in outliers (Figure 2-1). Here, all provinces are mostly grouped together, but Nunavut and the Northwest Territories show the majority of DAs are lower than the country's average SES index. The mean SES index for the rest of the provinces and territories was slightly above average, with the exception of Newfoundland and Labrador. Additionally, obvious low SES index outliers were seen in Saskatchewan, British Columbia and Ontario.

2.3.2. Validation of SES Index

2.3.2.1. Prevalence of adverse pregnancy outcomes and $PM_{2.5}$ exposure

Lower quintiles in our SES index were significantly ($p<0.0001$) associated with increasing prevalence of LBW, preterm birth and SGA in Edmonton (Figure 2-2). This was corroborated with significantly lower mean SES indices for LBW (-0.227), preterm (-0.211) and SGA (-0.216) infants compared to normal weight (-0.138), term (-0.140) and appropriate for gestational age (-0.138) infants ($p<0.0001$).

Lower quintiles of our SES index were also significantly associated with higher exposure to $PM_{2.5}$ ($p<0.0001$) (Figure 2-2).

2.3.2.2. Comparisons of our SES index and Pampalon index

Both material and social components of Pampalon deprivation indices behaved similarly to our SES index when examining prevalence of LBW, PTB and SGA and $PM_{2.5}$ exposures (Figure 2-2). However, there was a more consistent gradient in prevalence of LBW, preterm birth and SGA by quintile of our index compared to the Pampalon indices, more noticeable in the case of LBW ($p<0.0001$ vs. $p<0.01$). Conversely, there was a more consistent gradient in $PM_{2.5}$ by quintile of the Pampalon material deprivation index compared to our index and the social deprivation index. Correlations between $PM_{2.5}$ and the three indices were very similar (Chan index: $r= -0.11$, $p< 0.0001$, Pampalon Material index: $r=-0.15$, $p<0.0001$, Pampalon Social index: $r=-0.15$, $p<0.0001$).

2.4 Discussion

Although our SES index is not the first to be developed for Canada, it likely reflects more fully the dimensions of SES in Canada for purposes of examining health outcomes from environmental pollution. While our index similarly includes aspects of social and material deprivation, it is novel in that we explored the contribution of: 1) age of homes as a proxy for age of neighbourhood which may in turn be an indicator of potential indoor environmental pollution; and 2) cultural identities with special attention to First Nations groups. Additionally, since our index is comprised of a single scale unlike the Pampalon indices, it is more easily communicated and better suited for presenting data directed toward studies investigating health outcomes and environmental pollution, for instance using maps.

More specifically, we examined the age of the homes as a proxy for the age of the neighbourhood. Older neighbourhoods more likely contain asbestos [31], lead paint [32] or increased indoor infiltration of fine outdoor particles.[39] Interestingly, age of the homes was not included in any of the three components for our SES index. This observation may be explained by Canada's relatively strong social programs, which may have weakened correlations between older homes and living in poverty as seen in the United States. For example, advances geared toward the development of newer government subsidized accommodations in an effort to decrease poverty have been in place with programs such as the Newfoundland and Labrador Poverty Reduction Strategy.[46] Another explanation may include a possible trend in Canada toward middle class or wealthy populations living in older, more established neighbourhoods and homes. This may also have diluted the relationship seen in the US between inhabiting older homes and living in poverty.

Cultural differences were strongly evident with our SES index. Our index differs from Matheson et al.'s "Can-Marg" in that they utilized visible minority and recent immigration status (within 5 years). We grouped cultural origins by examining "ethnic origins", which takes into account the ancestry of the Canadian population. This may be a more accurate indication of ethnicity, as recent immigration has mostly been from skilled workers from China, who generally have higher SES.[46] This effect was illustrated in the "Can-Marg" index, where ethnicity was positively associated with better health outcomes and more healthy behaviours.[24] We also examined "visible minority" and "recent immigration" in the development of our index (data not shown), and these variables were not associated with any of our components. This pattern was also seen in attempts to include ethnicity through "recent immigration" or "visible minorities" by Jerrett et al.[13] Thus, by utilizing "ethnic origins", we may be able to overcome this potential characteristic of the population. Inclusion of aboriginal groups with HDI categories in our index was novel. As 4% of Canada's population (1.2 million people) in 2006, aboriginal groups in Canada represent the second largest population in a country internationally.[47] Although there is a large population of aboriginals living in Canada (5% in Alberta, 14% in Saskatchewan and Manitoba, 85% in Nunavut, 51% in the Northwest Territories, 23% in the Yukon),[47] this variable interestingly did not appear in any of the three components of our SES index. Historically, aboriginal groups (especially in First Nations communities) have low response to the Census and this may be a source of bias in that this population's responses may be missing. Nonetheless, aboriginal identity is important to consider because aboriginal families are more likely to experience poverty than the overall population of Canada.[47] For example, those with aboriginal cultural identities are more likely than other Canadians to consist of single parent families (50% of children in census metropolitan areas).[47] Another explanation for the lack of aboriginal cultural identities contributing to any of the three components of our SES index may include dilution of the relationship with variables associated with poverty, as there may be different definitions of social and economic advantages for aboriginals living in Northern Canada, where aboriginals comprise a large proportion of the population (Yukon: 25%, NWT: 50.3%, Nunavut: 83.6% in 2006). The aspects of "wealth" and "deprivation" could easily be obscured in these areas, as the attainment of education or even the use of a vehicle in comparison to other forms of transportation may be influenced by traditional forms of living.

Because the index is novel, it was important to test its validity against an extensively used index, the Pampalon deprivation index, exploring an outcome for which associations with SES are well documented such as adverse birth outcomes and exposure to $PM_{2.5}$. Adverse birth outcomes with low SES relationships are a heavily researched area and our results showing increasing prevalence of PTB, LBW, and SGA with lower SES corroborate what has been published previously. [40, 41] Additionally, we observed a more consistent gradient of the occurrence of the outcomes with lower values of our index compared to the Pampalon index, while the reverse was true for $PM_{2.5}$ exposures during pregnancy. We established the validity of our index based on several evaluative criteria: 1) demonstrated similar findings to those reported in the literature showing correlations between SES and adverse birth outcomes; 2) showed potential for supporting our hypothesis of environmental injustice in Canada by demonstrating associations of low index values with increased $PM_{2.5}$ exposure; and 3) showed similar, but stronger findings in comparison with an older index. A clear advantage of our index is that it consists of a single value and is therefore simpler to interpret. A limitation to our index is that while a single value may be useful for easier interpretation, the Pampalon index would allow for independent analyses of material and social deprivation for public health policy and intervention purposes. However, another advantage to utilizing our index is that a background in using past indices such as the Townsend index for interpretation of the Pampalon index is also not required.

2.5 Limitation

A limitation of working with indices based on Census data in Canada is the lower number of variables collected in the most recent Census. [48] It is also assumed that SES will be stable over time, serving as a proxy in population-based studies using data from other years.

2.6 Conclusion

We focused our efforts on the development of a national index for Canada for purposes of investigating health outcomes and environmental pollution. We found that it performed superiorly to an earlier index in capturing gradients in prevalence of adverse pregnancy outcomes. We intend to use this index to investigate environmental injustice in Canada by applying aggregated geospatial analysis techniques to examine associations of SES and industrial chemical emissions and the incidence of childhood cancer and other pediatric health outcomes in Canada. Lastly, this new index has the potential to enable a better assessment of SES inequalities in a variety of health outcomes related to environmental pollution in Canada at the DA level.

2.7 Competing Interests

We do not have any competing interests.

2.8 Authors Contributions

EC contributed to study design, data acquisition, data analysis, and drafting the manuscript. JS carried out statistical analyses. LC and DS contributed to pregnancy outcome data acquisition and statistical analyses. DS and MJ participated in helping draft the manuscript. AOV participated in the design of the study, coordination and helped draft the manuscript.

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Table 2- 1 Parameters and variables used in the selection for PCA analysis.

Parameter (number of candidate variables)	**Variable (Census 2006)**
Cultural identities (n=5)	Human developmental index (HDI): very high sum; high HDI; medium HDI; low HDI; aboriginal group status
Potential existence of indoor environmental pollutants related to health outcomes (n=4)	Construction of homes: before 1946; 1946-1970; 1971-1990; 1991-2006
Environmental injustice indicators (n=7)	Marital status; prevalence of low income after taxes; car, truck, or van for commute; public transit, walking or bicycling for commute; multiple family households; owning a home; renting accommodations
Variables utilized in a previously proposed deprivation index for Canada (n=6)	Educational certificate; no educational certificate; employment rate; median income; total lone-parent families; divorced or widowed status

Table 2-2 Descriptive table of general characteristics of all birth outcomes in Edmonton. * In accordance with Statistics Canada disclosure rules, all frequencies were randomly rounded to base five, but percentages are based on unrounded data.

Variable	Preterm birth n (%)	Low birth weight n (%)	Small for gestational age n (%)	Mean $PM_{2.5}$ ($\mu g/m^3$)
Sex				
male	2945 (8.31%)	480 (1.48%)	3320 (9.37%)	9.17
female	2495 (7.39%)	665 (2.13%)	2880 (8.54%)	9.17
Maternal age				
<18	115 (9.66%)	20 (1.87%)	110 (9.28%)	9.4
18 – 29	3265 (7.77%)	705 (1.82%)	3910 (9.31%)	9.2
30 – 39	1950 (7.83%)	405 (1.76%)	2080 (8.36%)	9.11
40+	10 (10.14%)	15 (1.54%)	100 (9.26%)	9.01
Marital status				
Single	670 (9.38%)	150 (2.32%)	770 (10.79%)	10.01
Married	3295 (6.90%)	735 (1.65%)	4090 (8.58%)	9.14
Widowed	0 (0.00%)	0 (0.00%)	5 (16.67%)	9.55
Divorced	60 (9.76%)	15 (2.70%)	75 (12.20%)	10.11
Separated	0 (0.00%)	0 (0.00%)	0 (0.00%)	8.01
unknown	1415 (10.34%)	245 (2.00%)	1260 (9.22%)	8.81
Parity				
1^{st} birth	2560 (8.06%)	605 (2.07%)	3495 (11.02%)	9.14
2^{nd} birth	1525 (6.69%)	300 (1.41%)	1620 (7.11%)	9.17
3^{rd} or greater birth	1350 (9.24%)	235 (1.77%)	1075 (7.36%)	9.22
unknown	5 (20.00%)	5 (25.00%)	5 (20.00%)	9.81
Birth year				
1999	470 (7.36%)	100 (1.69%)	590 (9.23%)	10.56
2000	495 (7.96%)	100 (1.75%)	590 (9.49%)	9.96
2001	520 (8.12%)	110 (1.87%)	605 (9.45%)	9.22
2002	485 (7.66%)	110 (1.88%)	535 (8.45%)	9.71
2003	560 (8.49%)	110 (1.82%)	540 (8.19%)	9.17
2004	540 (8.08%)	90 (1.47%)	575 (8.61%)	9.83
2005	570 (8.46%)	105 (1.70%)	565 (8.40%)	7.96
2006	565 (7.62%)	130 (1.90%)	670 (9.05%)	8.84
2007	565 (7.00%)	145 (1.93%)	750 (9.31%)	7.87
2008	670 (8.02%)	145 (1.89%)	780 (9.35%)	9.07

Table 2- 3 List of new variables (Chan et al., 2015) created for analyses of components and their descriptors.

New Variable (n=8)	**Census Variables** (n=22)
1) High material ownership	Home ownership Car, truck or van for commute
2) Low material ownership	Rent accommodation Public transportation use
3) Socially advantaged	Marital status One family households
4) Economically advantaged	Employment rate Median income Certificate, diploma or degree
5) Socially disadvantaged	Single, widowed or divorced Multiple family households Lone parent families
6) Economically disadvantaged	Prevalence of low income after taxes No certificate, diploma or degree
7) Indication of potential children's environmental hazard	Construction of home ≤1946 to 1970 Construction of home 1971-1990 Construction of home 1991-2006
8) Cultural identities	Very high sum HDI High sum HDI Medium sum HDI Low sum HDI Aboriginal

Table 2-4 Factor loadings (*100) for Canada and its provinces and territories (n=13) corresponding to Component 1. (AB=Alberta, BC=British Columbia, SK=Saskatchewan, MB=Manitoba, ON=Ontario, QB= Quebec, NB=New Brunswick, NS=Nova Scotia, PEI=Prince Edward Island, NFL=Newfoundland, YK=Yukon, NV=Nunavut, NWT=Northwest Territories)

Variable	**Canada**	**AB**	**BC**	**SK**	**MB**	**ON**	**QB**	**NB**	**NS**	**PEI**	**NFL**	**YK**	**NV**	**NWT**
No certificate, degree or diploma												-89	-97	-88
Certificate, degree or diploma												90	96	90
Employment rate												78	83	88
Median income													84	78
Single, divorced or widowed	-83	-88	-80	84	-85	-86	-86	-87	-92	-92	82	-66		-74
Married	84	87	80	-82	86	85	90	87	92	93	-84	62		72
Prevalence of low income after taxes											69			
Car, van or truck for commute	76	73	79		77	79		79	82	71			76	
Public transit use	-72	-75	-79		-77	-75		-80	-82	-73			-68	
Total lone parent families				83						-71	72			
Own home	84	85	87	-64	81	82	84	90	90	92	-84	64		
Rent accommodation	-80	-83	-84	66	-86	-77	-84	-89	-87	-90	83			
Construction of home ≤ 1946 to 1970														
Construction of home 1971-1990														
Construction of home 1991-2006														
One family households	82	81	77		79	83	78	73	79	77				
Multiple family households													-65	
Very high sum HDI												85	95	91
High sum HDI												77	73	76
Medium sum HDI														69
Low sum HDI														
Aboriginal				61								-86	-96	-95

Table 2-5 Factor loadings (*100) for Canada and its provinces and territories (n=13) corresponding to Component 2. (AB=Alberta, BC=British Columbia, SK=Saskatchewan, MB=Manitoba, ON=Ontario, QB= Quebec, NB=New Brunswick, NS=Nova Scotia, PEI=Prince Edward Island, NFL=Newfoundland, YK=Yukon, NV=Nunavut, NWT=Northwest Territories)

Variable	**Canada**	**AB**	**BC**	**SK**	**MB**	**ON**	**QB**	**NB**	**NS**	**PEI**	**NFL**	**YK**	**NV**	**NWT**
No certificate, degree or diploma	-73		-40		-90	-84		-87	-89	-96	-91			
Certificate, degree or diploma	86	85	83		93	88		88	90	96	91			
Employment rate	72	75	76	73				73	68		80			
Median income	71	70	62		74	65		70	76		74			
Single, divorced or widowed												-66		
Married												62		
Prevalence of low income after taxes														
Car, van or truck for commute				79										
Public transit use														-63
Total lone parent families														
Own home				62								64	-89	63
Rent accommodation													90	
Construction of home ≤ 1946 to 1970														
Construction of home 1971-1990														
Construction of home 1991-2006														
One family households				82									-66	81
Multiple family households														
Very high sum HDI					63		-75					85		
High sum HDI							69					77		
Medium sum HDI							79							
Low sum HDI							66							
Aboriginal												-86		

Table 2-6 Factor loadings (*100) for Canada and its provinces and territories (n=13) corresponding to Component 3. (AB=Alberta, BC=British Columbia, SK=Saskatchewan, MB=Manitoba, ON=Ontario, QB= Quebec, NB=New Brunswick, NS=Nova Scotia, PEI=Prince Edward Island, NFL=Newfoundland, YK=Yukon, NV=Nunavut, NWT=Northwest Territories)

Variable	**Canada**	**AB**	**BC**	**SK**	**MB**	**ON**	**QB**	**NB**	**NS**	**PEI**	**NFL**	**YK**	**NV**	**NWT**
No certificate, degree or diploma		64		-81			-88							
Certificate, degree or diploma				76			91							
Employment rate														
Median income				64			68							
Single, divorced or widowed													89	
Married													-85	
Prevalence of low income after taxes														
Car, van or truck for commute											82			
Public transit use											-77			
Total lone parent families		61											67	
Own home														-61
Rent accommodation														68
Construction of home ≤ 1946 to 1970					94			-79		-79				82
Construction of home 1971-1990					-86			69				-77		
Construction of home 1991-2006									70	84		73		
One family households														
Multiple family households	70		72			69								
Very high sum HDI	-72		-62			-85			-65					
High sum HDI														
Medium sum HDI	76		87			81								
Low sum HDI												64		
Aboriginal		71							72					

Table 2-7 Distribution of the percentage of DAs within each quintile of Canada wide SES index according to province and territory ($p<0.001$ using Pearson chi-square), absolute numbers of DAs are indicated in brackets. (AB=Alberta, BC=British Columbia, MB=Manitoba, NB=New Brunswick, NL=Newfoundland and Labrador, NS=Nova Scotia, NT=Northwest Territories, NU=Nunavut, ON=Ontario, PE=Prince Edward Island, QC=Quebec, SK=Saskatchewan, YT=Yukon)

		quintile					Total
		1.00	2.00	3.00	4.00	5.00	
Province	AB	14.6% (763)	17.8% (932)	19.7% (1028)	21.4% (1118)	26.4% (1381)	5,222
	BC	22.3% (1557)	19.1% (1333)	19.7% (1372)	20.9% (1455)	18.1% (1260)	6,977
	MB	24.6% (508)	18.6% (383)	20.1% (415)	18.9% (390)	17.8% (368)	2,064
	NB	10.5% (147)	24.1% (338)	23.1% (324)	23.8% (333)	18.5% (260)	1,402
	NL	25.4% (262)	36.9% (381)	19.7% (203)	12.5% (129)	5.5% (57)	1,032
	NS	10.3% (165)	20.0% (322)	27.1% (436)	24.6% (396)	18.0% (290)	1,609
	NT	50% (44)	15% (12)	10% (8)	10% (8)	10% (8)	80
	NU	93.9% (31)	3.03% (1)	3.03% (1)	0% (0)	0% (0)	33
	ON	19.0% (3597)	17.0% (3222)	17.6% (3338)	20.0% (3790)	26.3% (4975)	18,922
	PE	5.54% (16)	15.6% (45)	17.6% (51)	31.1% (90)	30.1% (87)	289
	QC	24.3% (3192)	25.7% (3377)	22.7% (2992)	17.1% (2246)	10.3% (1355)	13,162

	SK	17.5% (369)	17.4% (368)	21.1% (447)	20.9% (441)	23.1% (489)	2,114
	YT	25.4% (17)	16.4% (11)	17.9% (12)	17.9% (12)	22.4% (15)	67
Total		**10668**	**10725**	**10627**	**10408**	**10545**	**52973**

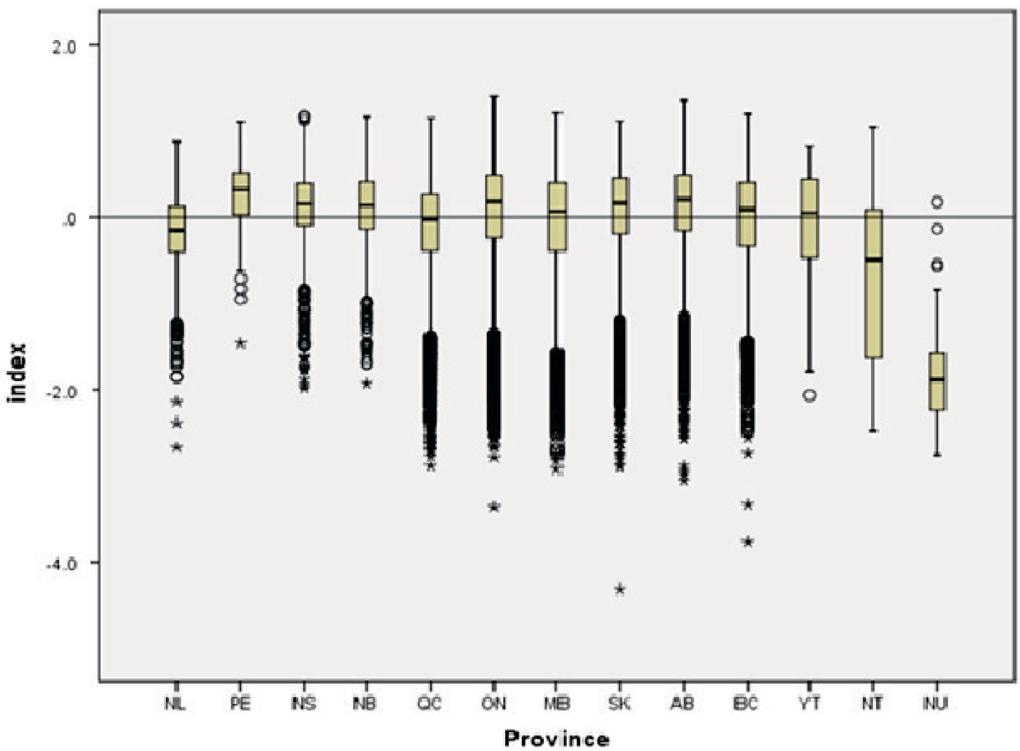

Figure 2-1 Boxplot distribution of median SES index by province and territory (n=13). Whiskers represent upper and lower range, while asterisks represent outliers. Bottom and top of boxes are the first and third quartiles, while the centerline represents medians.

(NL=Newfoundland and Labrador, PE=Prince Edward Island, NS=Nova Scotia, NB=New Brunswick, QC= Quebec, ON=Ontario, MB=Manitoba, SK=Saskatchewan, AB= Alberta, BC= British Columbia, YT= Yukon, NT= Northwest Territories, NU= Nunavut)

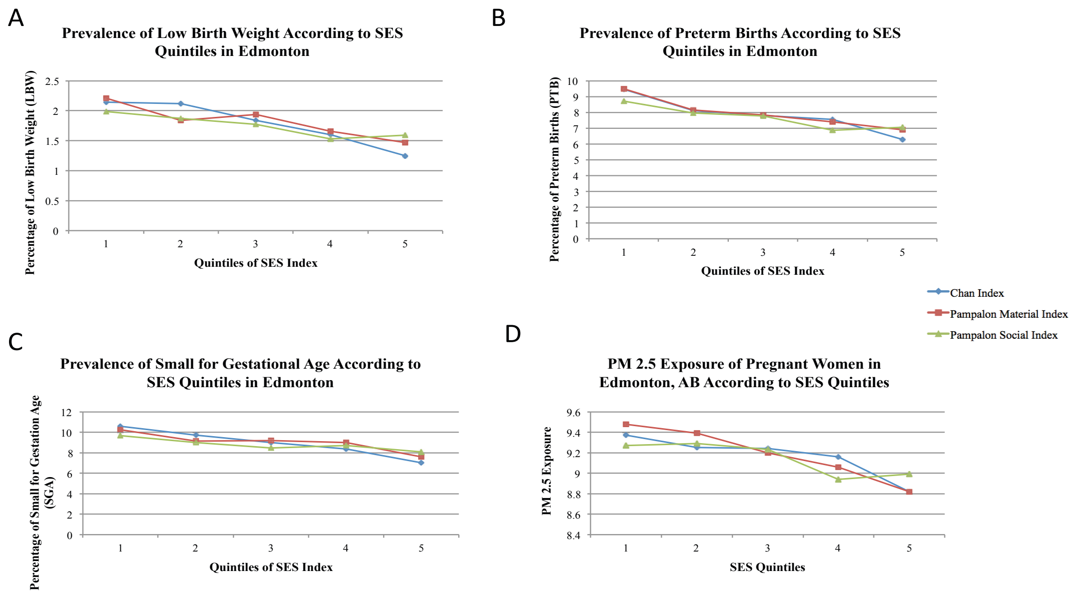

Figure 2-2 Comparison of the prevalence of low birth weight (panel A), preterm births (panel B), small for gestational age (panel C), and PM $_{2.5}$ exposures (panel D) according to Chan et al. and Pampalon et al indices

Chapter 3: Environmental Injustice in Canada: Does it Exist?

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3.1 Introduction

Few studies have been conducted on Environmental Injustice in Canada, with the majority of research being conducted in the United States. In this study, we aim to examine if Environmental Injustice exists in Canada by investigating the concept at country, provincial, and three largest Census Metropolitan Areas in Canada (Montreal, Toronto, and Vancouver).

Our Canada-wide analysis will include examining NPRI data (2006), distance from centroids to nearest emitting facilities, children's population and socioeconomic status data (2006) through simple correlations, geographically weighted regression and mapping. Provincially, we will examine the same variables through simple correlations. We will compare NPRI data (2006) and socioeconomic status through simple correlations [6] and mapping. We will examine the same variables for selected municipalities. This study is the first of its kind for Canada and we aim to bring exposure to the possibility of the existence of Environmental Injustice for the country.

3.2 Materials and Methods

3.2.1 Data Extraction

3.2.1.1. Socioeconomic Data

An index developed in house was used to measure socioeconomic status [49] for Canada's dissemination areas (DAs) from the Canadian Census 2006. [29] Principal component analysis with a single varimax rotation (factor loadings ≥ $|60|$) (SAS 9.2, North Carolina, USA) was used on SES variables (n=22) at the DA level. These variables were selected based on four parameters: (1) cultural identities [30]; (2) potential environmental pollutants related to health outcomes [16-17]; (3) Canadian environmental injustice studies [12-13]; and (4) variables utilized in the deprivation index for Canada proposed by Pampalon. [20] Higher index values indicated greater SES, while lower index values depicted lower SES.

3.2.1.2 Chemical Data

Data for chemicals were extracted from the NPRI (2006). [50] Here, we examined total chemicals released (tonnes) into the air, water, and soil from emitting facilities and total carcinogens released from those same emitting facilities (tonnes) per DA. All chemicals released from emitting facilities were summed (n=207).

We additionally, examined distances (in kilometers) from the centroid (geometric center of the DA) to the nearest emitting facility for all DAs. Emitting facilities' locations (longitude/latitude) were collected from the NPRI and distances measured using proximity mapping tools with ArcGIS 10.

In this study, we analyzed only those DAs with corresponding statistical data from Census Canada 2006 (n=52,970 out of 55,292 total DA).[10]Those DAs without population (n=2,322) consisted of industrial areas, uninhabited areas, or some First Nations communities (who did not participate in the Census).

3.2.1.3 Census Metropolitan Areas

Census Metropolitan Areas (CMAs) are described as areas having a population of 100 000 or more, with 50 000 or more living at the core. Here, we examined the three largest CMAs in Canada: Vancouver, Montreal and Toronto.

3.2.2. Analysis

3.2.2.1. Statistical Analysis

We investigated simple correlations between SES indices and: 1) distances from centroids to nearest emitting facilities; 2) chemical emissions sums from facilities; 3) children's population for each province and territory and for Canada, as well as for Montreal, Vancouver, and Toronto. We additionally examined all three variables in comparison to quartile of SES index for each province and territory and for Canada. A geographically weighted regression was analyzed to determine if distances from centroids to nearest emitting facilities, chemical emission sums, and children's population could explain socioeconomic status in Canada.

3.2.2.2. Mapping Analysis

We utilized maps to visually investigate the existence of Environmental Injustice using ArcGIS 10. We examined: 1) SES index; 2) distances from nearest emitting facilities to DA centroids; 3) chemical amounts (tonnes) and divided each of those variables into quartiles.

3.3. Results

3.3.1 Canada Analysis

Negative weak correlations were found between all SES indices and the distance from emitting facilities, sum of chemical emissions released, and the children's population. (Table 3-1) This suggests that those DAs with higher SES have shorter distances from emitting facilities, yet have decreasing levels of chemical emissions. Additionally, negative correlations were found between child populations and SES indices for all DAs in Canada. This suggests that higher SES have lower child populations.

3.3.1.1. Quintiles of SES Index for Canada

Mostly negligible correlations were found with quintiles of SES index and distance from nearest emitting facility, children's population, and chemical sum. (Table 3-1)

3.3.1.2. Geographically Weighted Regression (GWR)

A GWR was run to examine if distance from centroids to nearest emitting facilities, children's population, and chemical sum could explain SES index. Here, the latter variables were able to explain 55.3% of the variability in SES index (Adj R^2=0.5528).

3. 3. 2 Provincial Analysis

In comparison to all other provinces and territories, Nunavut showed the lowest SES median index, followed by the Northwest Territories and Newfoundland (Figure 3-1). The lowest SES outliers were found in Saskatchewan and British Columbia (-4.31 and -3.76, respectively). Comparatively, the highest median SES index was found in Alberta (0.21), Ontario (0.19), Prince Edward Island (0.32) and Saskatchewan (0.17). This suggests that the populations of these areas generally have high SES indices amongst DAs. Highest outliers of SES index belong to Alberta (1.36) and Ontario (1.4).

Upon examination of distances from nearest emitting facilities, Yukon had the highest median (150.03 km) and outlier distance (Figure 3-2). Other provinces with the median furthest distances away from emitting facilities included: Prince Edward Island, Newfoundland, and New Brunswick (9.15 km, 7.27 km, and 6.06 km, respectively). Median closest distances to nearest facilities included: Ontario, Quebec and Manitoba (1.58 km, 1.92 km, and 2.17 km, respectively).

Total chemical emissions from emitting facilities were also investigated for each DA of each province and territory (Figure 3-3). Here, Prince Edward Island (165.82 tonnes) had the largest median chemical emissions per DA or overall, followed by Nunavut (131.15 tonnes) and the Northwest Territories (68.7 tonnes). The smallest median chemical emissions released were for Ontario, Manitoba and British Columbia (3.61, 2.17, and 2.43 tonnes respectively). The highest total chemical emission outliers were found in Manitoba (197,160.5 tonnes), Saskatchewan (197,160.5 tonnes) and Ontario (191,160.3 tonnes). There were many DAs in each province that did not contain any chemical emissions.

3. 3. 3. Select City Analysis

We examined the three largest CMAs of Canada, where Toronto, Montreal, and Vancouver contained the three lowest median SES indices in comparison to the rest of CMAs in Canada (-0.14, -0.15, and -0.09 respectively). When we examined the CMAs, for proximity to emitting facilities, Montreal (1.42 km) and Toronto (1.38 km) showed DAs located closer to emitting facilities than the rest of Canadian cities (1.92 km). However, Vancouver showed DAs that were close to average (2.05 km) in comparison to the rest of the CMAs in Canada. Interestingly, Montreal and Toronto had DAs that contained lower than Canadian averages for emission sums (2 tonnes and 1.75 tonnes, respectively) while Vancouver had DAs that showed higher than average Canadian averages (11.48 vs. 8.77 tonnes).

3. 3. 4. Correlations

Correlation coefficients were examined between SES indices and distance from nearest emitting facilities, sum of chemical emissions, and children's population for all provinces and territories at the DA level. All provinces and territories showed a negative correlation with SES indices and distance to nearest emitting facilities with the exception of Ontario (Table 3-2), which showed a small positive correlation. Yukon, Saskatchewan, and Manitoba had the three highest negative correlations with SES index and distance to nearest emitting facilities (r^2= -0.42, -0.40 and -0.38 respectively). This suggests that these three provinces show a decreasing distance from emitting facilities with increasing SES, with the exception of Ontario, which shows an increasing distance with increasing SES.

Correlation coefficients between SES index and chemical emission sums were mostly low for most provinces and territories (Table 3-2). The largest correlation coefficient was found with Nunavut (r^2=0.76), while Yukon and Saskatchewan showed moderate yet negative correlation coefficients (r^2=-0.32, -0.11 respectively). Thus, this indicates that increasing SES coincides with increasing larger chemical sum emissions in DAs in Nunavut, while the opposite is observed with Yukon and Saskatchewan.

Moderate to negligible correlations were found between SES indices and children's populations. (Table 3-2) Alberta and British Columbia had mostly negligible negative correlations, while Manitoba, Nunavut, Ontario and Saskatchewan had negative moderate correlations. Mostly positive correlations were found with the rest of the provinces, with the highest positive correlation coefficient present for Yukon (r^2=0.53) and children's population. This indicates that higher SES indices coincide with increasing amounts of children.

3. 3. 5. Maps

Maps help to illustrate what was described in previous above analyses. For example, Nunavut, Northwest Territories and Newfoundland show more DAs with lower SES quintiles than other provinces. (Figures 3-1 and 3-4) Although provinces like Saskatchewan and Manitoba show large areas with the lowest SES quintiles, there are also areas with very high SES quintiles. Meanwhile, there were more DAs with higher SES quintiles seen in Alberta, Ontario and Prince Edward Island, which again, agree with SES averages discussed above (Figures 3-1 and 3-4).

Distances from centroids to nearest emitting facilities also corroborate distance averages (Figures 3-1 and 3-5). For example, there are more DAs with the highest distances away from nearest emitting facilities for Yukon, Prince Edward Island, Newfoundland, and New Brunswick. More DAs with closer distances are seen for Ontario, Quebec and Manitoba.

The largest average chemical sum (tonnes) was seen in Prince Edward Island (Figure 3-3), followed by Nunavut and the Northwest Territories, which was seen in maps. (Figure 3-6) Here, more DAs with higher chemical sums are evident in these provinces, which agree with averages. (Figure 3-6)

3. 4 Discussion

Little research has been conducted on Environmental Injustice in Canada. Literatures suggesting that Environmental Injustice should exist have determined three key demographics that would most likely be at risk: 1) resource dependent communities; 2) First Nations communities; 3) low income and ethno-racial communities. [51]

3. 4. 1 Resource Dependent Communities

Canada has historically been a natural resource dependent nation, with economic and employment opportunities from agricultural, forestry, oil, gas, mining and hydroelectric sectors. [51] Although many areas across Canada have certainly benefited from the growth in industry, less attention has been brought to the environmental impacts on the persons living within those communities or to the impacts on the people and the ecosystem after industries collapse. [51] An example of these communities includes Atlantic Canada, which has experienced the decline of several industries linked with the "old economy" which comprises mining, steel making, logging and fishing. [51] Atlantic Canada has also experienced the decrease of trade barriers due to a greater competitive global economy, a shift to knowledge and information and highly processed food factories from family farms. [51]

The existence of Environmental Injustice in the Atlantic Provinces remains open ended. Although the Atlantic provinces, with the exception of Newfoundland, mostly had median SES indices that were similar among the median of Canada, all provinces showed a median distance from centroids to emitting facility (NB: 6.06 km, NFL: 7.27 km, NS: 4.16 km, PEI: 9.15 km) that were greater than the mean of the rest of the country (3.92 km with the exception of Yukon) and differing amounts of median chemical emissions (NB: 59.9 tonnes, NFL: 11.9 tonnes, NS: 25.0 tonnes, PEI: 165.8 tonnes) released from these facilities. Thus, although Prince Edward Island had a median SES index that was among the ones at the higher end in Canada, DAs were mostly located further away from emitting facilities, but also, those with emitting facilities, emitted the greatest chemical releases in all of Canada. In comparison, Newfoundland had the second lowest median SES index in comparison to all provinces and territories, yet DAs were located further away and chemical emissions released were less than the average for all of Canada. Therefore, production of chemical emissions in these areas may suggest a means of larger incomes and more social security for those areas, or the population itself may be unique in that there may be more retirees with potentially have higher savings or retirement funds. Other factors we did not examine include wind patterns or ocean currents, which may distribute the large chemical emissions from Prince Edward Island around to poorer provinces such as Newfoundland, and will need to be explored in further research.

3. 4. 2. First Nations Communities

First Nations communities have been amongst the most affected by industrialization and development. [51] Settlement moved west in Canada and so did agriculture and natural resource development. [51] However, First Nations communities were often displaced and moved into areas that were deemed to be less habitable for European settlers. [14] As a result, this population suffered colonial oppression and post-colonial exclusion from decisions and law making from industrial development. [51]

Because Canada has the second largest aboriginal population in a country at 4% (or 1.2 million people) around the world, [52] we decided to include them into the HDI categories in our study, as part of the SES index. [30] This group of people often appeared in components for the Prairie Provinces and the Territories, which is unsurprising since the largest concentration of aboriginal people is located in the Prairies (5% in Alberta, 14% in Saskatchewan and Manitoba) and in the North (85% in Nunavut, 51% in the Northwest Territories, 23% in the Yukon). [52] Overall, Alberta, Manitoba and Saskatchewan have median SES indices that were similar amongst other provinces and territories. These provinces however, also contain very low SES outliers, suggesting that parts of the population live in very "unwealthy" circumstances. These outlier DAs may include the First Nations populations, as much literature has suggested that Aboriginal families in Western Canada are more likely than their fellow Canadians to consist of single parents (50% of children in census metropolitan areas). [52] Additionally, settlements housing aboriginals are often underprivileged, with inadequate sewage and water facilities. [53] Here, Alberta, Saskatchewan and Manitoba all had median distances from emitting facilities that were below the national average, yet median chemical emissions from these facilities were also below average as well. Closer inspection of those DAs containing First Nations settlements in these Prairie Provinces would be important for this special population.

An investigation into the Aboriginal population in the Northern territories shows a more clear picture of Environmental Injustice. Here, Nunavut had the lowest median SES index in all of Canada, and the Northwest Territories had the second lowest median SES index. Additionally, both territories were located at median distances from emitting facilities that were closer than most other provinces. Nunavut had the second highest chemical emissions released in the DAs that contained emitting facilities (131.15 tonnes) and the Northwest Territories and Yukon also contained some of the highest chemical emissions (68.70 and 71.87 tonnes). Thus, there is a strong indication of Environmental Injustice in the Northern territories.

The environment of the Northern territories is a unique mixture of traditional lifestyles of the Inuit and an expanding economy of mining industry. [54] The majority of the industry in Nunavut is comprised of mining of base metals (copper, iron, nickel, lead, silver, and zinc), precious materials (gold and diamonds), hydrocarbons (oil and gas) and radioactive elements (uranium). [54] In addition to the impacts of mining activities and the Inuit population, there has been much concern over pollutants being transferred to the North from Canada and the United States. [55] Heavy metals (e.g. mercury and lead) and organochlorines (e.g. lidane, chlorodane, toxaphene, dichlorodiphenyltricholoroethane [DDT], and polychlorinated biphenyl [PCBs]) were found in a number of studies in the 1980's and 1990's. [55] Thus, the Inuit face potential Environmental Injustice from both ends: local and through long range-atmospheric transport, waterways, and ocean currents.

3. 4. 3. Low-income and Ethno-racial Communities

As cities have expanded, urban planning has often led to benefiting middle class populations with uneven distribution examples of green space and urban waterfronts. [51] These decisions are often made by urban elite planning and policy decision-making practices, where deterioration of some parts of the city is inevitable. [51] These places are often the destinations for low-income and immigrant populations, and are frequently associated with air pollution and traffic congestion. [51]

Montreal for example, is one of the three "visible minority enclaves" in Canada, as well as Toronto and Vancouver. [56] These "enclaves" are identified as regions containing more than 70% of visible minorities. [56] For instance, Toronto has often been called "the world in a city" because as of 2006, 46% of its population was foreign born. [57] Interestingly, "enclaves" are also regions that are often associated with extreme poverty. [56] A recent report showing the impacts of initiatives implemented to improve Montreal's East End industrial sector's air quality highlights the importance of Environmental Injustice for this area: the mostly Italian and Haitian neighbourhood of Riviere-des-Prairies showed an increase in the number of poor air quality days (1.5 times greater than the refineries of East End of Montreal) with pollution from wood burning stoves and from nearby refineries. [58] Likewise, a report from Toronto showed further examples of Environmental Injustice in that the community of South Riverdale, which is inhabited by poorer residents, had lead contamination in soils because the area became the site of the Canada Metal Company. [57] In our study, both Montreal and Toronto contained the lowest median SES indices in Canada and contained DAs that were closer in proximity to nearest emitting facilities than most other Canadian cities, thus showing similar concerns for Environmental Injustice as the two previous reports. However, these cities also had DAs with lower than Canadian averages for median chemical emission sums. Only Vancouver had DAs that contained median chemical emissions that were greater than the Canadian average. Additionally, Vancouver also had one of the lowest median SES indices in comparison to the rest of the CMAs, yet the proximity to nearest emitting facilities was close to the average for the rest of Canada. Nonetheless, these cities are often ethnically and economically diverse and although chemical emission sums may not be as high as other cities, where these emissions are released and circulate are important to consider.

3. 5. Conclusion

Examination of Environmental Injustice on a country, provincial and select CMA levels showed interesting messages. Several specific areas and groups presented potential cases of Environmental Injustice. In general however, a large proportion of the country are located in close proximity to emitting facilities and thus Environmental Injustice may be a real concern for Canada.

Table 3-1. Correlation coefficients between total SES index, and SES index divided into quintiles and distance from emitting facilities, carcinogens, total chemicals, child population and total population.

	Distance	Child Population	Chemical Sum
Total SES Index	-0.040	-0.0029	-0.0051
SES quintile 1	0.065	-0.027	0.00079
SES quintile 2	0.037	-0.042	0.0024
SES quintile 3	0.048	-0.018	0.0046
SES quintile 4	0.077	0.0025	-0.039
SES quintile 5	-0.25	0.040	-0.021

Table 3-2. Correlation coefficients between SES indices and distance from nearest emitting facilities and centroids, sum of chemical emissions, sum of carcinogen emissions, sum of carcinogen risk scores, total population and children.

Province	Distance	Child Population	Chemical Sum
AB	-0.067	0.083	0.0019
BC	-0.069	0.055	-0.0050
MB	-0.38	-0.21	-0.026
NB	-0.22	0.28	-0.040
NFL	-0.35	0.14	0.050
NWT	-0.35	0.22	0.021
NS	-0.017	0.18	-0.11
NV	-0.016	-0.17	0.76
ON	0.053	-0.11	0.0089
PEI	-0.11	0.29	-0.087
QB	-0.012	0.14	0.0080
SK	-0.40	-0.14	-0.11
YK	-0.42	0.53	-0.32

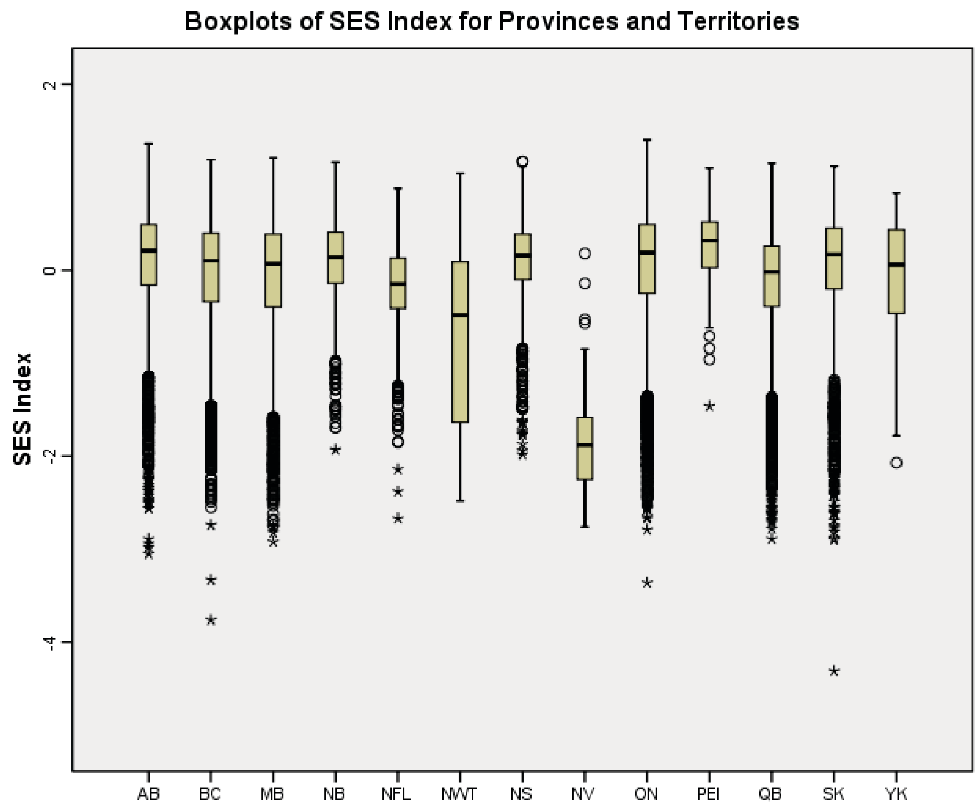

Figure 3-1. Box plot depicting SES indices for provinces and territories of Canada.

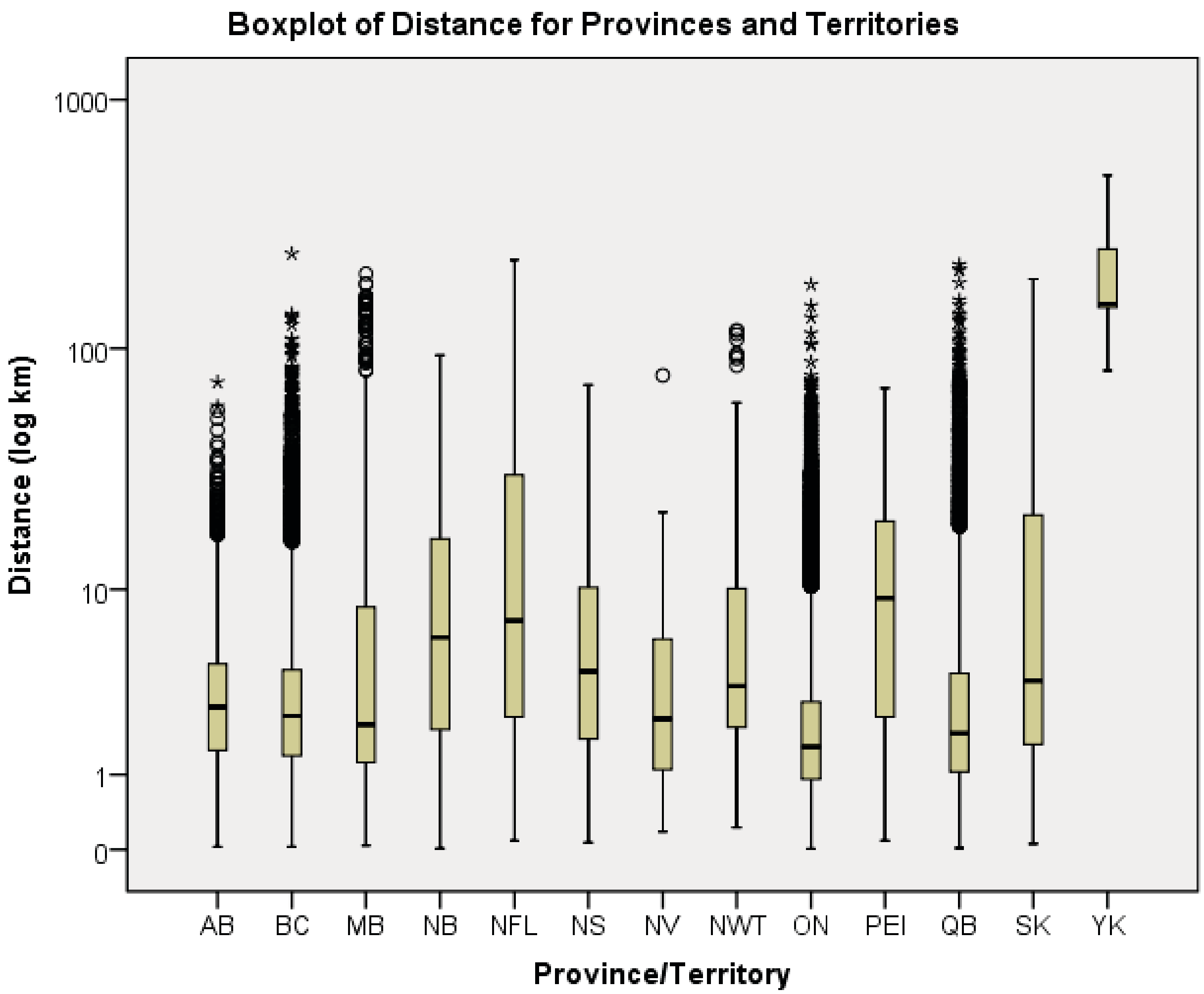

Figure 3-2. Box plot depicting distance from centroids to nearest emitting facility for provinces and territories of Canada.

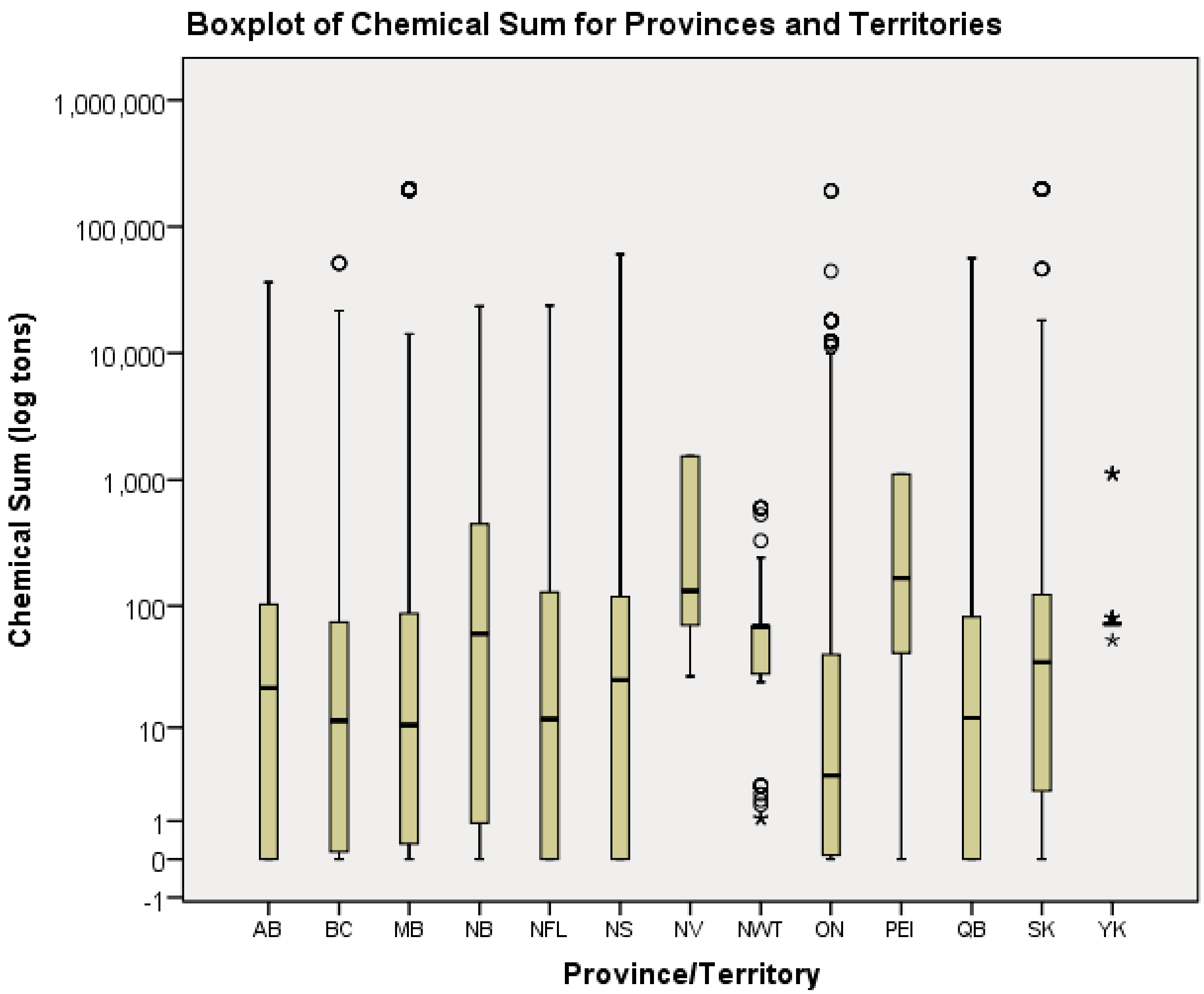

Figure 3-3. Box plot depicting sum of chemical emissions from emitting facilities for provinces and territories of Canada.

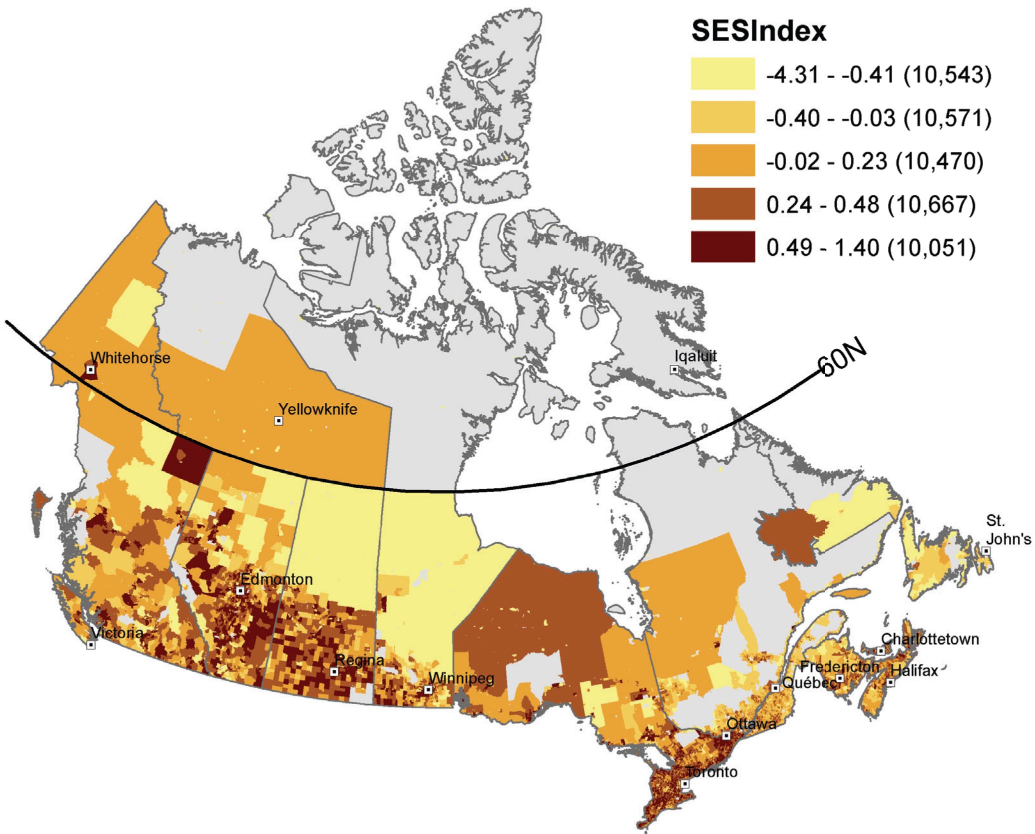

Figure 3-4. SES quintile distributions across Canada.

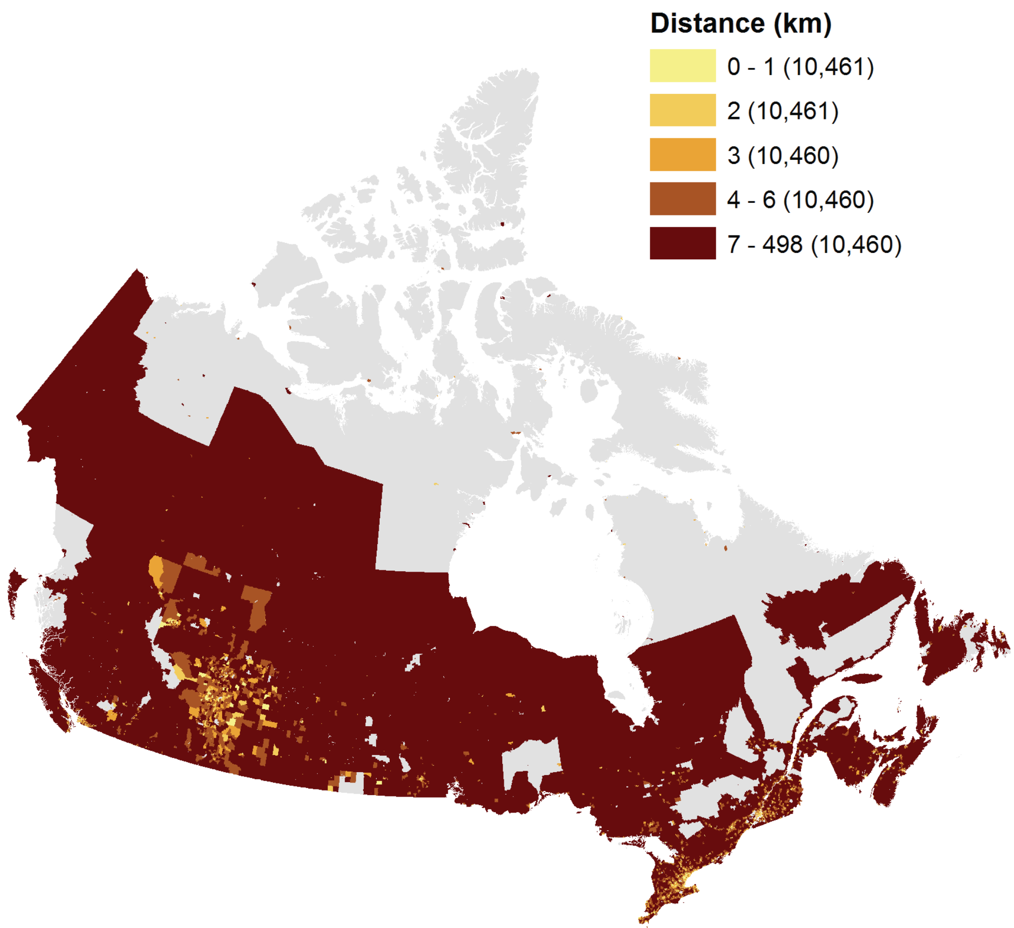

Figure 3-5. Distance from centroids to nearest emitting facilities across Canada.

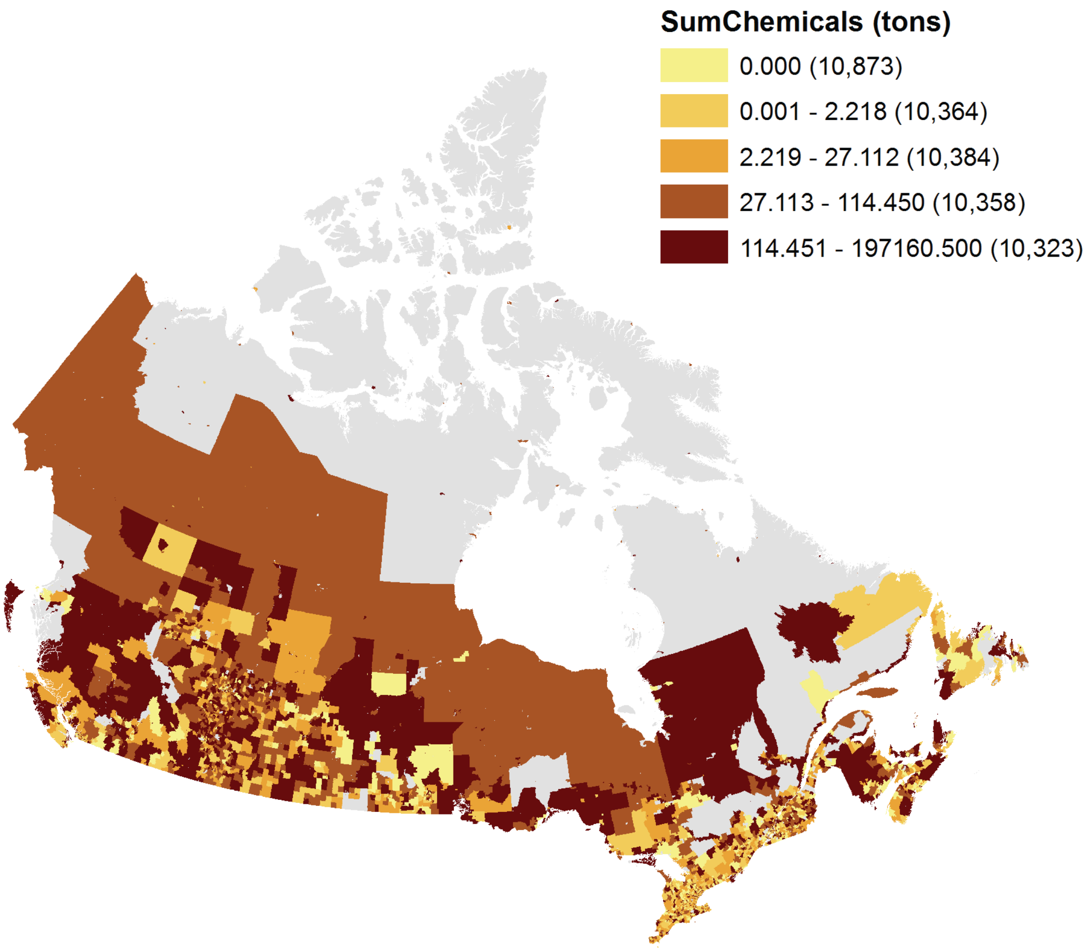

Figure 3-6. Sums of chemical emission distributions across Canada.

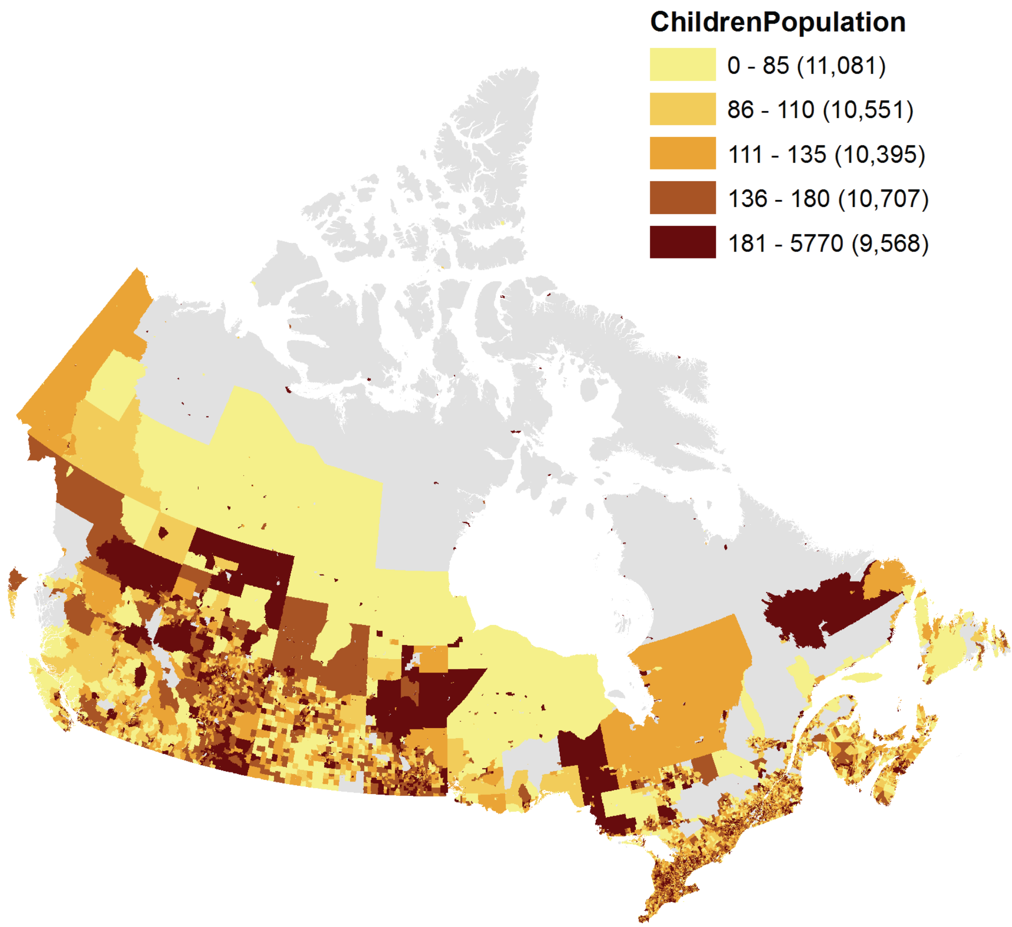

Figure 3-7. Children's population distribution across Canada.

Chapter 4: Children Population, Socioeconomic Status and Proximity to Industrial Emitting Facilities in Canada: Is there a Difference between Urban and Rural Areas?

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4.1 Introduction

The majority of these Environmental Injustice studies have often taken place in urban areas, with a lack of research investigating rural populations. In Canada, approximately 81% of the population lives in urban areas. [59] However, the urban/rural population across Canada is unevenly distributed, where some provinces and territories have rural populations that are significantly higher than the national average. [60]

In this study, we attempt to investigate whether there are differences between urban and rural communities, with regard to population SES and proximity to industrial pollutants emitting facilities. Our geographical unit (area) of study was the dissemination area (DA), which is the smallest geographical area with census data available, containing 400-600 people. DAs were then divided into rural and urban groups, and we examined differences between the two populations based on: 1) distances from nearest industrial emitting facilities (km); 2) socioeconomic status; 3) children's population.

4.2 Materials and Methods

4.2.1 Data Extraction

4.2.1.1 Socioeconomic Data

Socioeconomic status was examined from an index developed in house using the Canadian Census of 2006. [49] Methods are described elsewhere (see Chapter 2).

4.2.1.2 Distance Data

The distance from DA centroids (geometric center of DAs) to the nearest emitting facilities for all DAs were investigated. Emitting facilities locations (longitude/latitude) were collected from the NPRI 2006, [50] where we examined all facilities releasing chemicals and carcinogens into the air, water, and soil. Centroids and the distances were measured using the ArcGIS 10 proximity mapping tools.

4.2.1.3 Children Population Data

Children's population data were extracted from the Canada wide population Census Canada 2006. [28] Here, the population of children (0-19 years old) was selected for each corresponding DA.

4.2.2 Analysis

We initially analyzed only those DAs with corresponding statistical data from Census Canada 2006 (n=52,970 out of 55,292 total DA).[10]Those DAs without population (n=2,322) consisted of industrial areas, uninhabited areas, or some First Nations communities (who did not participate in the Census). In this study, only DAs within provinces were analyzed due to large areas of missing data, low populations, and low number of emitting facilities in the territories Selected provincial DAs (n= 52,122) were then divided into urban (n=40,050 DAs) and rural (n=12,072 DAs) groups, using GeoSuites, a program provided by Statistics Canada as a tool for data retrieval, according to a corresponding urban or rural area code (urban areas and rural areas or UARAs: are four digit codes with unique markers to denote whether a DA is urban or rural).

[61] Statistics Canada defines "urban" as an area with a population of at least 1,000 and no less than 400 persons per square kilometer. [61]

4.2.2.1 Exploratory Analysis

We compared rural and urban DAs of Canada by examining overall differences in children's population, SES indices, and distances from DA centroids to nearest emitting facility. Simple correlations between SES indices, children's population and distances from centroids to nearest emitting facilities were also compared for both groups. SES indices were divided into quintiles and variables were examined based on each group of SES. Correlation tests were also conducted for each quintile of SES index and each subsequent variable.

4.2.2.2 Spatial Analysis

Using ArcGIS' spatial statistics toolbox, we compared rural and urban DAs, by using geographically weighted regression (GWR) to determine if both distance from centroids to nearest emitting facilities and children's population could explain SES indices. GWR is a type of linear regression, which is used to model spatially varying relationships and was appropriate for our analysis given high spatial autocorrelation due to the nature of aggregating data by DAs.

4.2.3 Mapping

The maps were generated using Esri ArcGIS 10.x software with dissemination area (DA) boundary data from Statistics Canada [29], provincial boundary and city location data from Natural Resources Canada [62], and NPRI facility location data from Environment Canada [50].

4.3 Results

4.3.1 Maps

The DAs were symbolized as urban (red) and rural (tan) in Figure 4-1. The SES Index values were joined to the DA boundaries and symbolized by quintiles of the SES distribution index values, where darker shades indicate higher SES in Figure 4-2. The NPRI locations were overlaid with the provincial boundaries in Figure 4-3. Many of the DAs with lower SES indices were seen in the largely rural areas of Saskatchewan, Manitoba and Quebec (Figure 4-2). Additionally, lower SES indices were seen in the Atlantic Provinces, while the highest SES indices were seen in the areas more populated within provinces (e.g., Alberta and Ontario). Interestingly, NPRI locations were also examined and a clear majority of facilities were seen in Alberta, Ontario and Quebec. (Figure 4-3)

4.3.2 General Description

Upon examination of urban versus rural DAs of Canada, several differences were found. The mean SES indices were higher for rural areas versus urban areas (0.102 ± 0.604 and -0.0276 ± 0.563, respectively) (Figure 4-4). However, the maximum SES index was highest for urban areas (1.40) in comparison to rural areas (1.31), while the minimum SES index was lowest for rural areas (-4.31) versus urban areas (-3.36) (Figure 4-4). Rural DAs clearly had larger distances from centroids to nearest emitting facilities (14.8 ± 18.7 km) than urban DAs (2.55 ± 4.94 km) (Figure 4-5). Not surprisingly, rural DAs also had the largest maximum distances from centroids to nearest emitting facilities (241.4 km) in comparison to urban DAs (148.3 km) (Figure 4-5). Rural DAs contained lower children's population (134.9 ± 80.6 children per DA) in comparison to urban DAs (148.4 ± 139.2 children per DA) (Figure 4-6). Rural DAs also had lower maximum children's population (2025 children per DA) than urban DAs (5770 children per DA) (Figure 4-6).

4.3.3 Quintile Analysis

SES index was divided into quintiles and compared between urban and rural DAs (Figure 4-7). Unlike contrasts with total urban and rural DAs, the lowest SES quintile (or quintile one) for rural DAs contained mean SES indices (-1.308 ± 0.68) that were comparatively lower than urban SES (-0.837 ± 0.384) quintile one. Urban and rural DAs distributions were relatively similar across the rest of the SES quintiles.

The first SES quintile for rural DAs had the largest distance from centroids to nearest emitting facilities (33.9 ± 0.68 km) in comparison to the rest of the rural quintiles, as well as all other urban quintiles (Figure 4-8). Rural DAs showed decreasing distance from nearest emitting facilities with increasing SES quintiles. Conversely, urban DAs showed closest proximity to nearest emitting facilities with the lowest SES quintile, but distances were relatively similar across all other SES quintiles (Figure 4-8).

Urban and rural DAs both showed similar children's densities for all SES quintiles. Therefore, no discernable patterns were found between all quintiles for urban and rural DAs. (Figure 4-9)

4.3.4 Correlations

Correlations were tested between SES indices and distances from centroids to nearest emitting facilities (Table 4-1). Positive low correlations for urban DAs were found between SES index and distance (r^2=0.039, $p<0.01$), which suggests that as SES indices increase, the distance from centroids to nearest emitting facilities increase as well. Comparatively, rural DAs showed stronger negative correlations between SES index and distance to nearest emitting facilities (r^2= -0.36, $p<0.01$). This suggests that as SES indices increase, the distance from centroids to nearest emitting facilities decrease. These observations corroborate what was seen with quintile analyses where increasing distances from nearest emitting facilities were observed with increasing SES index quintiles for urban DAs, and where decreasing distances from nearest emitting facilities were observed with increasing SES index quintiles for rural DAs (Table 4-1).

SES indices were divided into quintiles and then correlated with each quintile of the distance to nearest emitting facility. We found that correlation coefficients for urban DA quintiles were from very weak to mostly negligible, whereas those for rural DAs were slightly higher for each quintile. (Table 4-1)

4.3.5 Spatial Regressions

We tried to examine the relationship between SES, centroids to nearest emitting facilities, and children's population through spatial regressions (Table 4-2). According to the GWR results, both distance to emitting facility and children's population accounted for over half the variation of SES Index in urban DAs ($AdjR^2 = 0.564$) and to a lesser extent for rural ($AdjR^2 = 0.550$) DAs (Table 4-6).

4.6 Discussion

The majority of Environmental Injustice studies which examined proximity to emitting facilities or Toxics Release Inventory (TRI) facilities and SES have been conducted in the United States. Most of the published literature has found positive statistical correlations between sociodemographic characteristics of populations (lower SES and race) and proximity to TRI's facilities. [10, 11] For example, Perlin et al. (1999) indicated that African Americans and those living below the poverty level in areas between New Orleans and Baton Rouge ("Cancer Alley") were more likely to live closer to the nearest TRI facility and to live within 2 miles of multiple TRI facilities. [11]

Unique to this body of literature, is the examination of urban versus rural areas and Environmental Injustice; where until recently, studies have focused exclusively on urban areas. In our studies, there were indeed differences found between overall examinations of urban versus rural DAs. Here, urban DAs were slightly suggestive of Environmental Injustice, as these DAs contained lower SES and closer proximity to emitting facilities than rural DAs. Additionally, distance and children's population in urban DAs were also able to explain more SES variability than in rural DAs (58.2% and 49.8% comparatively). This may be as a result of smaller distance variability in the urban areas, than in rural DAs where facilities and children are more physically dispersed throughout the area.

Upon closer inspection with SES quintile analysis, urban and rural DAs contained different patterns for variables examined. Urban DAs showed that the lowest SES quintile also contained the closest distance to nearest emitting facilities. Interestingly however, although the lowest SES populations seemed to experience the greatest Environmental Injustice, most alarming is that the rest of the children population, are not immune to the problem. In fact, all DAs in urban areas were located within 3 km of an emitting facility, which is in stark contrast to studies examined in the United States. Studies examining health effects and environmental pollution exposures of children have mostly concluded that those in the lowest SES are the most vulnerable due to closer proximity to emitting facilities. Here however, all children are vulnerable to exposures and this is worrisome since there is a consensus that children may be more susceptible to the health effects of environmental pollution as a result of their obvious differences in metabolism, physiology, absorption and exposure patterns. [63] It has also been suggested that these health effects may appear first in children and in more exaggerated ways than adults. [63]

Our initial hypothesis asserted that rural populations would contain lower SES, and therefore greater proximity to emitting facilities. However, these findings were observed within urban DAs and results for rural DAs proved the opposite. In rural DAs, the poorest SES quintiles were associated with further distances from nearest emitting facilities and an overall trend was observed, where distances increased as SES decreased. This may be explained by perhaps more people in rural DAs with jobs living closer to their work. These suggestions are important for rural DAs because overall, rural communities are comprised of higher poverty populations with generally lower levels of education, and jobs that are lower earning and less likely to need a university degree. [64] In addition, a study from Statistics Canada (2002) which examined reading assessment differences between urban and rural populations, found that rural students were more likely to come from families with lower SES backgrounds, and the parents of these children tended to be less educated and less likely to have professional occupations (and therefore less SES and lower income) such as bankers, lawyers or doctors. [64] This population of Canada is therefore quite vulnerable in itself.

4.7 Limitations

The study and its data were limited to the year 2006. We wanted to keep the time period constant, especially since our SES index was created using Census 2006. Additionally, future research could include data from chemical emissions from a greater number of years, to further investigate differences between urban and rural areas.

4.8 Conclusion

Differences in SES levels, children's population, and proximity to emitting facilities were demonstrated between urban and rural DAs of Canada. Although initial analysis would suggest a slight predisposition to Environmental Injustice for the lowest SES groups in urban DAs, the majority of Canadian children, regardless of SES live in close proximity to industrial emitting facilities and may be experiencing environmental exposures. Possible barriers to achieving justice for these communities are unique and future research should focus on potential health effects of these emissions on this population.

4.9 Acknowledgements

Funding for this project was provided by 1) the Queen Elizabeth II Studentship (Province of Alberta), the Faculty of Medicine and Dentistry's 75th Anniversary Award (University of Alberta), and the Faculty of Medicine and Dentistry's Graduate Student Scholarship (University of Alberta) which was awarded to Emily Chan, and 2) an Emerging Research Team Grant, Faculty of Medicine and Dentistry, University of Alberta. Census Canada 2006 data was provided by Chuck Humphrey (Department of Library and Information Studies, University of Alberta). Dr. Tali Neta provided distance from centroids to nearest emitting facilities.

4.10 Author Disclosure Statement

The authors have no conflicts of interest or financial ties to disclose.

Table 4-1. Correlation coefficients for quintiles of SES index and distance from nearest emitting facility to centroids for urban and rural DAs.

SES Quintile	Urban DAs	Rural DAs
1	-0.042	-0.14
2	0.029	-0.15
3	-0.0065	-0.084
4	0.0058	-0.079
5	-0.0045	-0.091

Table 4-2. GWR (geographically weighted regression) results examining if children population and the proximity to the nearest emitting facilities can predict SES for urban and rural DAs.

Region	Quintile	GWR $AdjR^2$
Urban	All	0.564
	1	0.336
	2	0.023
	3	0.001
	4	0.009
	5	0.104
Rural	All	0.550
	1	0.482
	2	0.055
	3	0.024
	4	0.039
	5	0.139

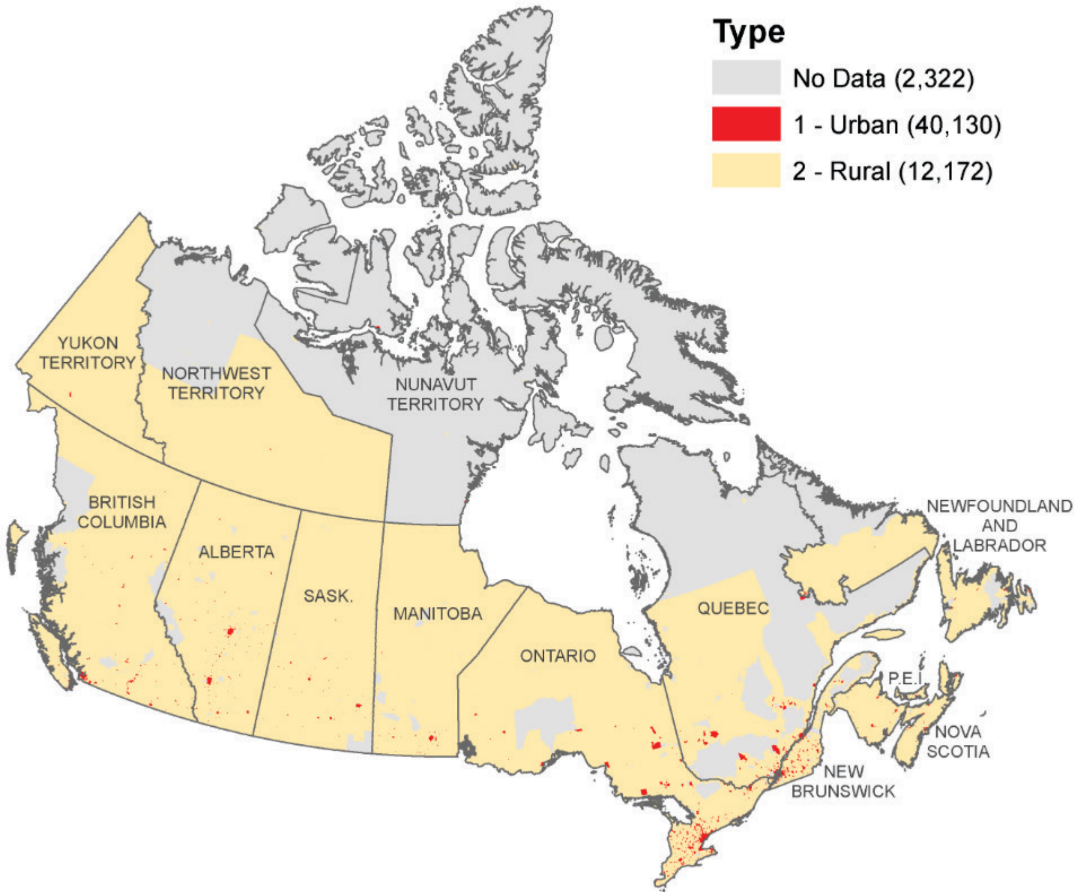

Figure 4-1. Distribution of Canada's urban (red) and rural (tan) dissemination areas.

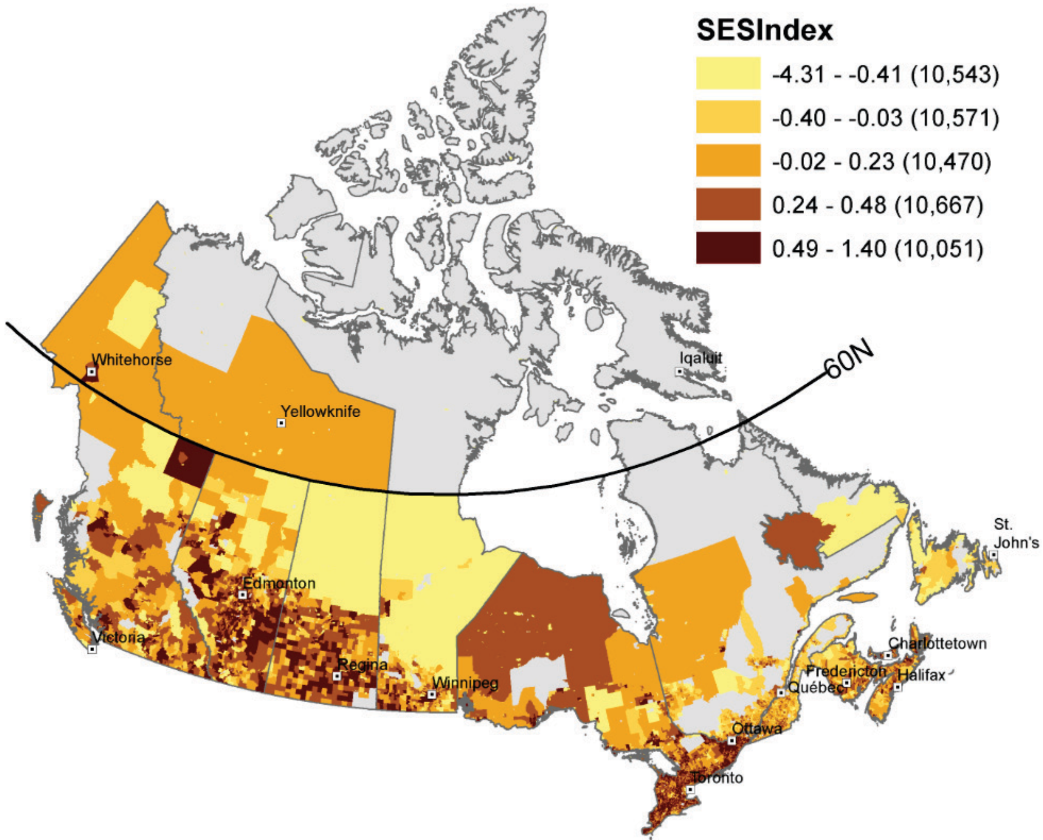

Figure 4-2. Map of distribution of Canada's dissemination areas according to SES index by quintile.

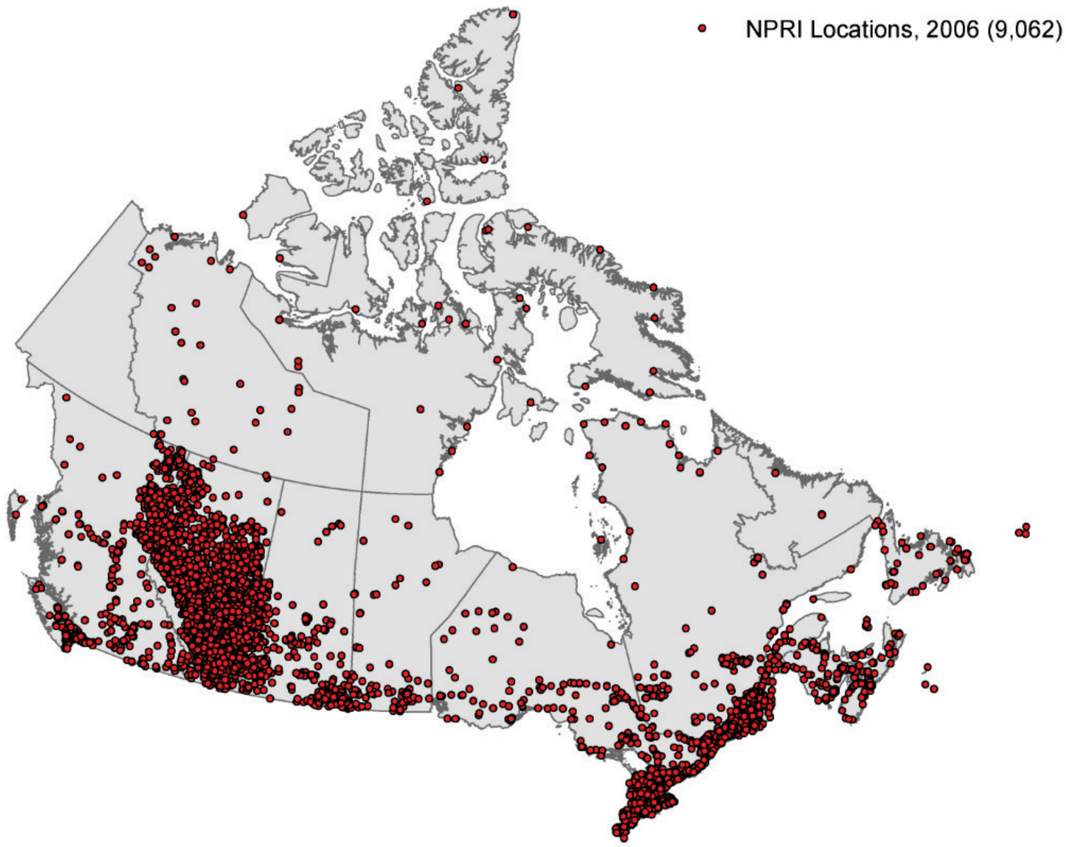

Figure 4-3. NPRI locations across Canada.

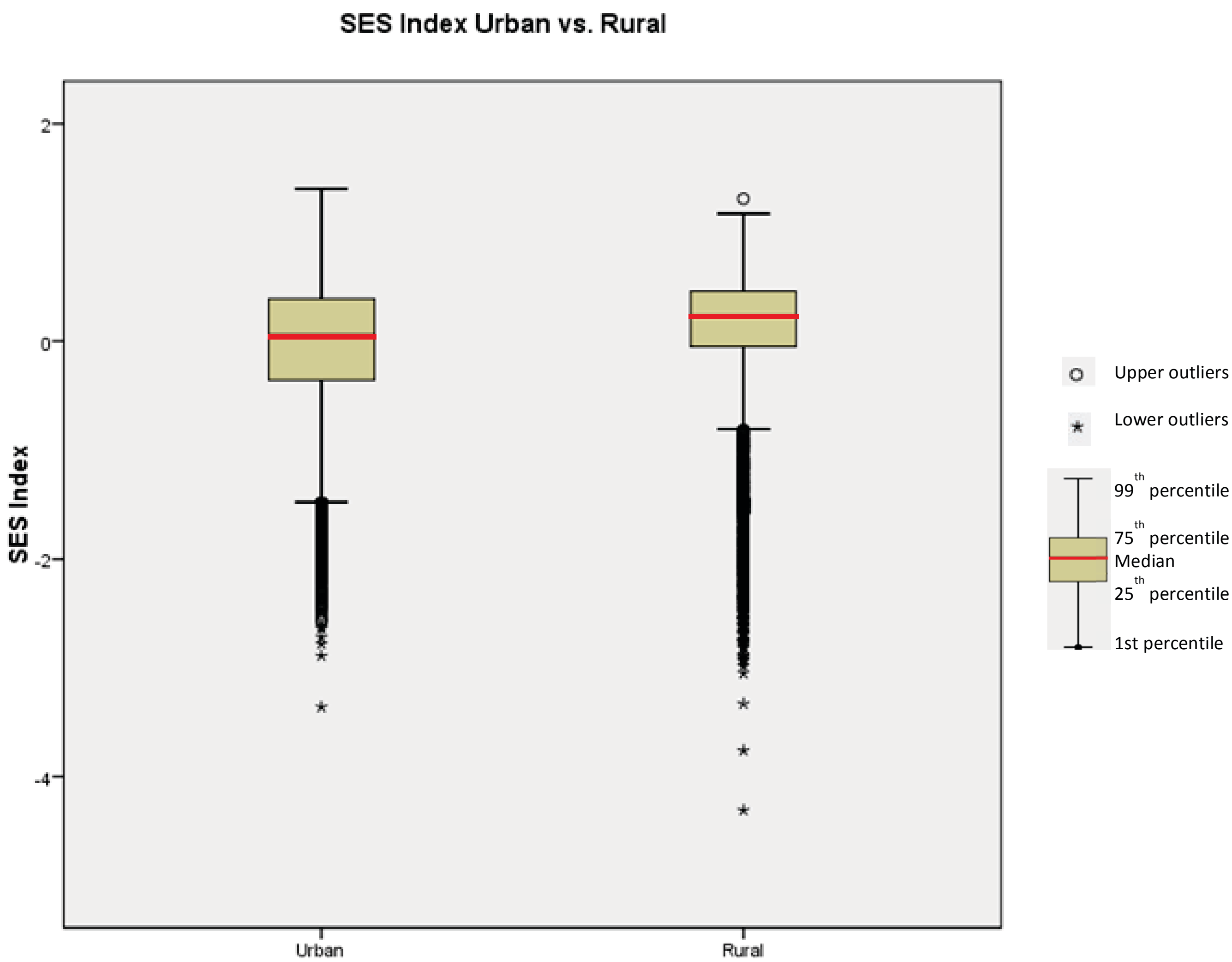

Figure 4-4. Distribution of SES indices in the urban and rural DAs.

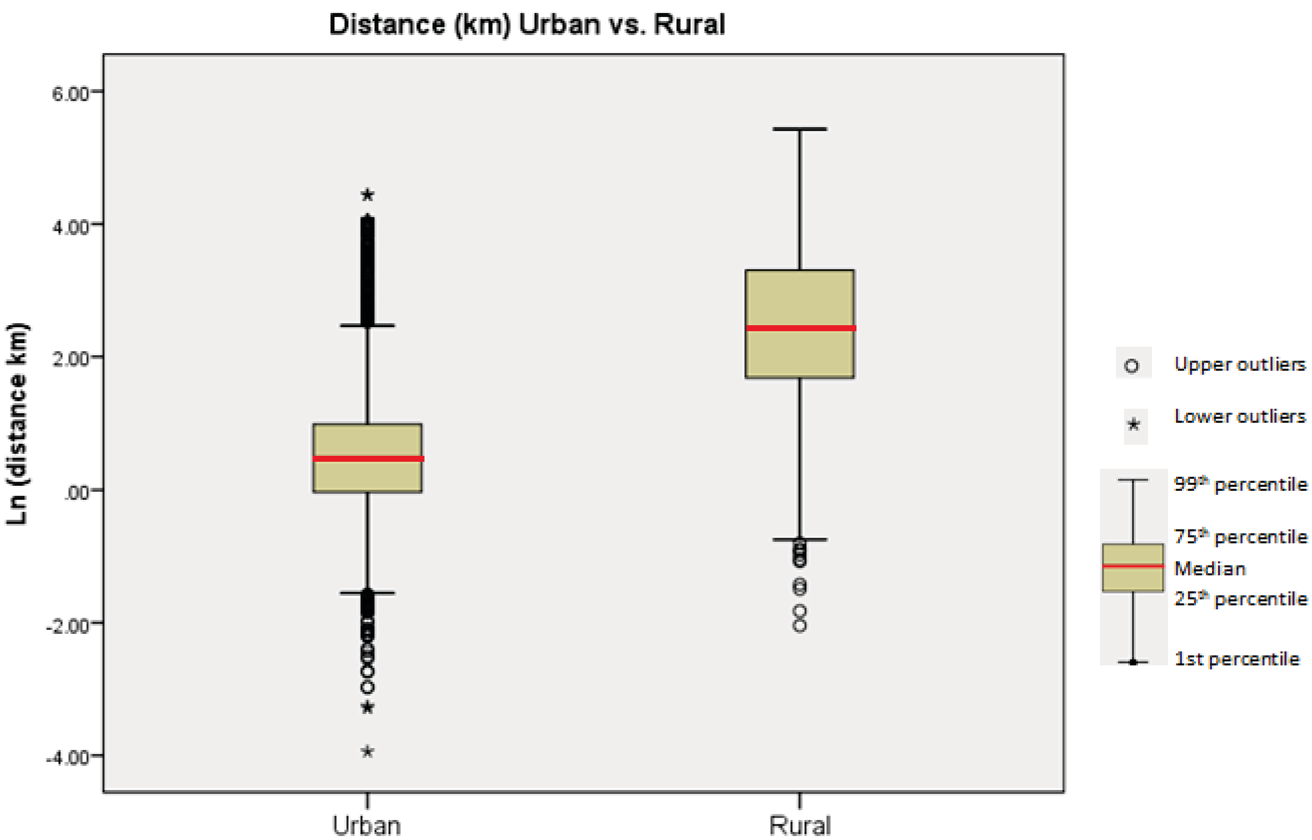

Figure 4-5. Distributions of the distances from DA's centroids to nearest emitting facilities in urban and rural Canada.

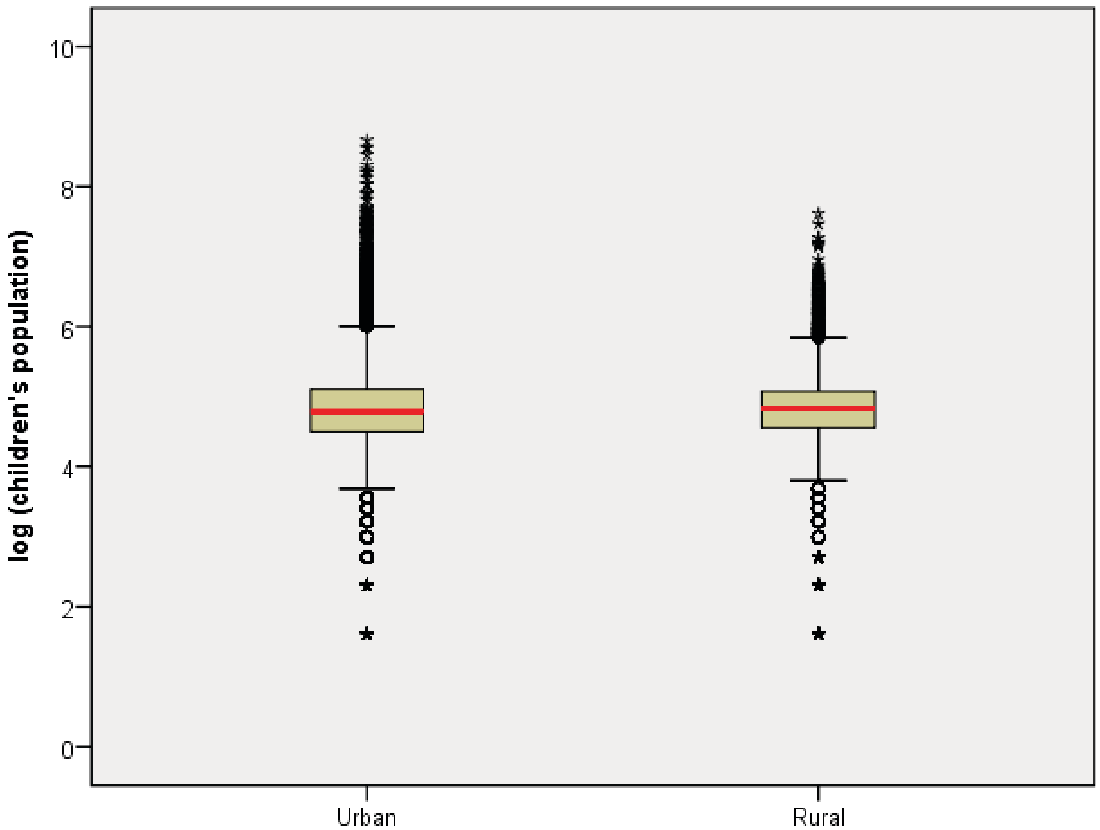

Figure 4-6. Comparative distributions of the children's population in the urban (1) and rural (2) DAs. Children's populations were log transformed for graphical comparison.

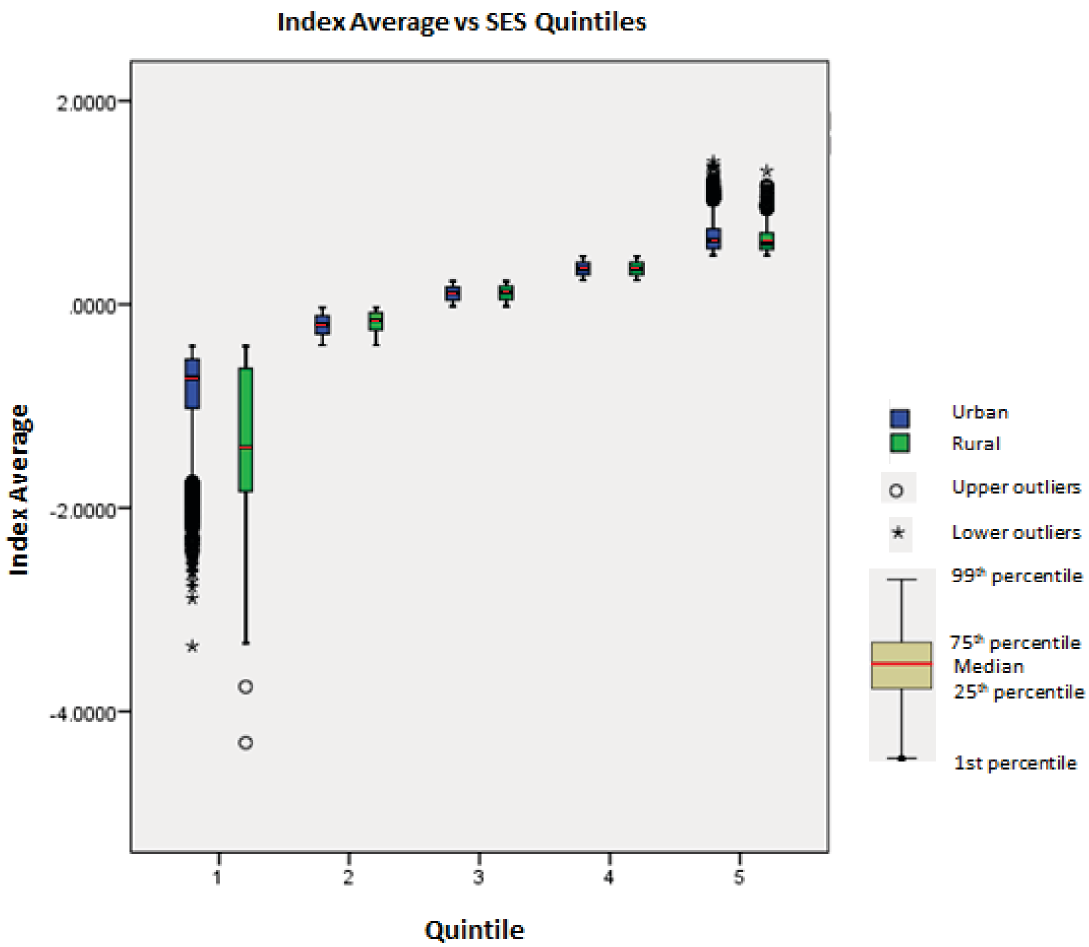

Figure 4-7. Distributions of the SES indices according to quintiles in urban and rural DAs.

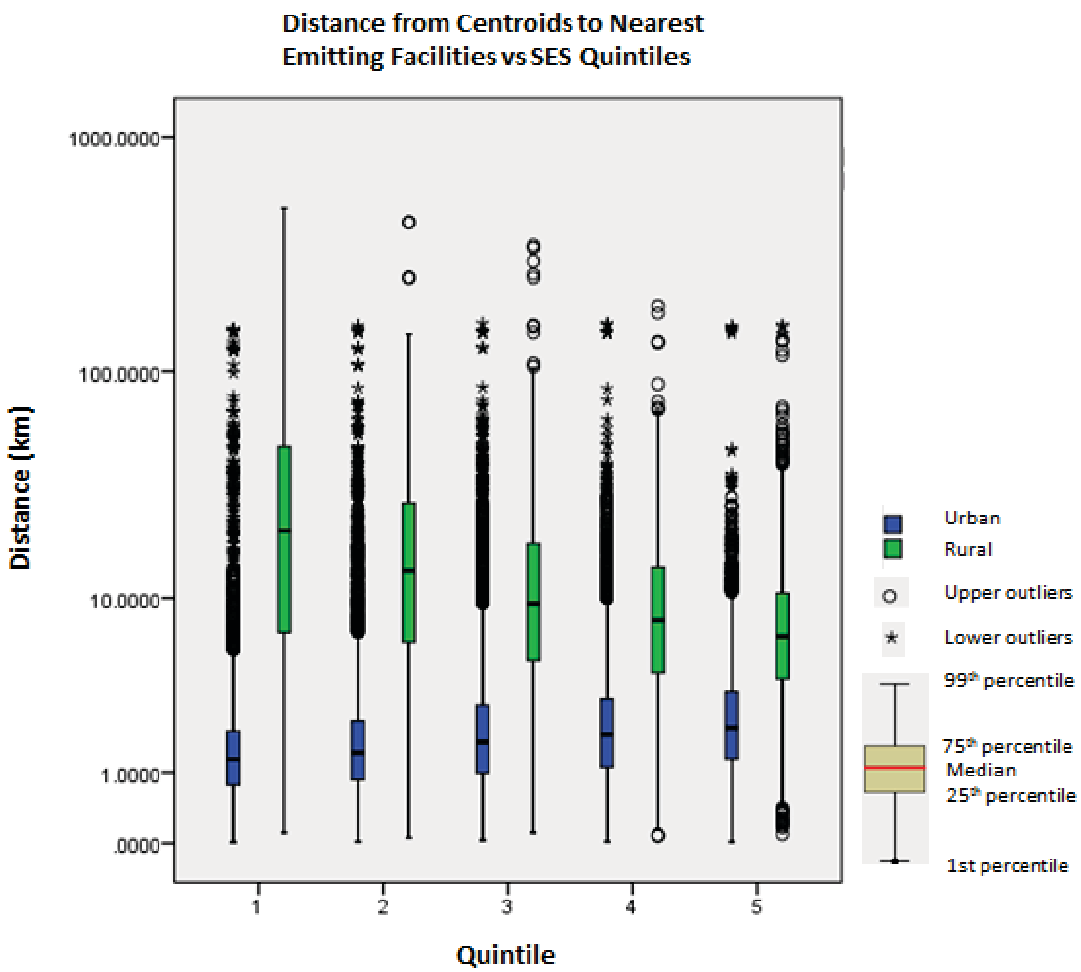

Figure 4-8. Distributions of the SES according to quintiles of the distance from centroids of DAs to the nearest emitting facilities between urban and rural areas.

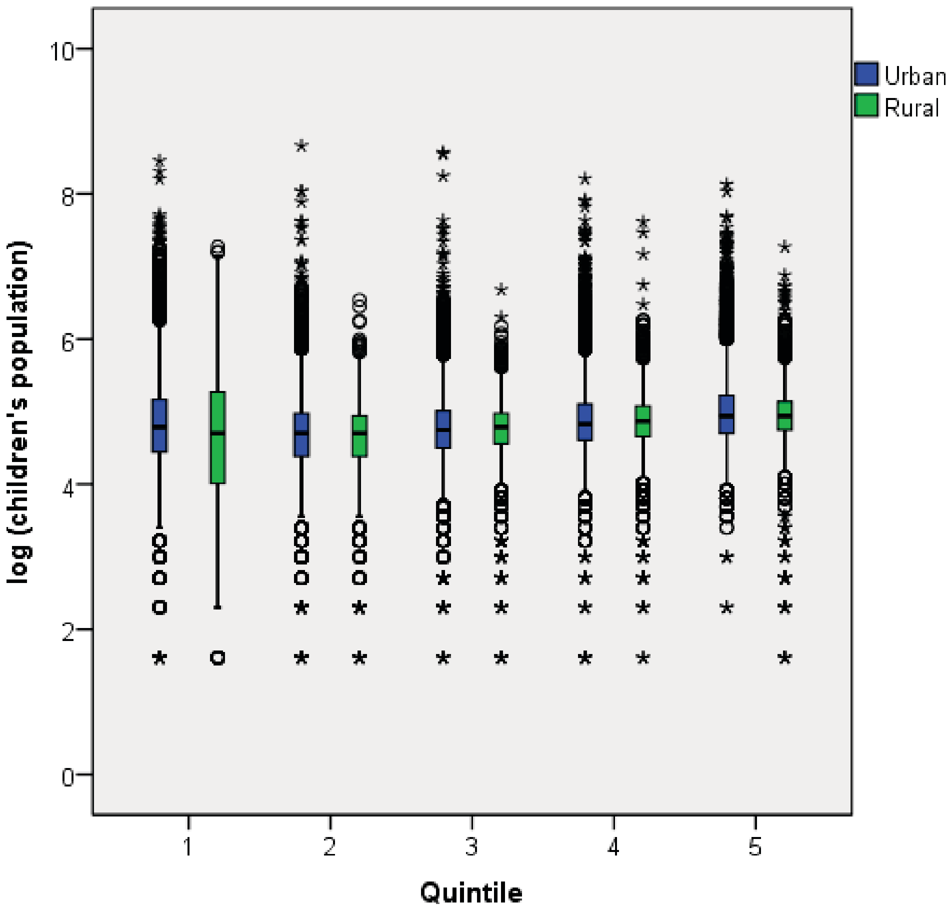

Figure 4-9. Comparative distributions of the SES in quintiles, for children's population in urban (1) and rural (2) DAs. Children's populations were log transformed for graphical comparisons.

Chapter 5: Environmental Injustice and Children's Cancer in Manitoba, Canada

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5.1 Introduction

Environmental Injustice not only examines the unequal distributions of environmental pollution exposure and SES, but also includes investigating the link with adverse health outcomes from these inequalities. The general lack of studies linking health effect outcomes such as cancer, with environmental factors in children is worrisome since there is a consensus that children may be more susceptible to the health effects of environmental pollutants because of their obvious differences in metabolism, physiology, and absorption and exposure patterns. [63]

Additionally, the studies that do exist do not use actual cancer risks, but rather utilize "estimated" cancer risk. Indeed, the use of modeled cancer risk is debatable, but the cost of using a comprehensive epidemiological study would be high, and is the primary hindrance in its practice. A clear advantage, however, is that the use of risk assessment tools may be applicable when dealing with chronic diseases that experience a lag time in its development, such as cancer. Moreover, it is difficult to produce a cause and effect model with respect to air toxicity and adverse health effects because of the complexity of real life situations, such as exposure to chemical mixtures. [4] Thus, the majority of studies have focused on the location of pollution sources and adult populations groups as opposed to the health risks themselves. [4]

In an effort to bridge the gaps between investigating environmental chemical emissions, proximity to emitting facilities, SES and health implications, we conducted an ecological study examining cancer as an adverse health effect in children from one Canadian province, Manitoba. There is existing evidence indicating geographical variability in the overall adult cancer rates, highest in Atlantic Canada and Quebec, third highest in Manitoba, and lowest in British Columbia. [64]

5.2 Materials and Methods

We examined the province based on dissemination areas (DAs), which are smallest geographical areas (containing 400-600 people) with available Census information. We additionally acquired children's cancer cases from the Manitoba Cancer Registry (1997-2007). Our first analysis examined proximity to nearest emitting facilities, total chemical and carcinogen emissions, and socioeconomic status between groups of DAs with and without cancer cases. Exploratory data analyses were conducted, as well as simple correlation tests and t-tests. Our second analysis examined the relationship between cancer rates, proximity to nearest emitting facilities, SES, and total chemical and carcinogen emissions, using negative binomial regression. We further examined the relationship between SES, proximity to nearest emitting facilities, children's population, total chemical and carcinogen emissions, age at diagnosis, and gender for those DAs with cancer cases by a multiple linear regression. Lastly, we compared the relationships between male and female cancer cases using multiple linear regressions.

Research ethics board approval was granted from the University of Alberta and the University of Manitoba.

5.2.1 Socioeconomic Data Extraction

We developed an index using the Canadian Census of 2006 to measure socioeconomic data. [23] Methods are described elsewhere in Chapter 2 and [23]

5.2.2 Chemical Data Extraction

Chemical data was extracted from the National Pollutant Release Inventory (NPRI) from 2006. [50] We examined: 1) total chemicals released (n=207) from emitting facilities (tonnes); 2) total carcinogens released (n=11) from emitting facilities (tonnes). Examples of total chemicals released from emitting facilities into the air included, toluene, volatile organic carbons and selenium. Carcinogens investigated included: 1, 3-butadiene; 2, 3, 7, 8-TCDD; acetaldehyde; arsenic; asbestos; benzene; benzo[a]pyrene; cadmium; chromium 6; ethyl alcohol; ethylene oxide; formaldehyde; nickel; p,p'methylenebis(2-chloroaniline); and vinyl chloride. Distances from centroids (geometric center of DAs) to nearest emitting facilities (km) were also examined and obtained from ArcGIS programming (Release 10, ESRI, Redlands, CA).

5.2.3 Cancer Data Extraction

Children's cancer data (age 0-19) was extracted from the Manitoba Cancer Registry (1997-2007). Data was released in cases per postal code and was transformed into cases per DA (using 2006 definitions) with GeoSuites (Statistics Canada, Government of Canada), a program used to link all levels of geography and geographic codes, names, population, and dwelling counts.[61] In total, 870 cancer cases were recorded. However, 2% of these cases (n=18) had invalid postal codes and thus could not be transformed into DAs. From these 752 cases, we filtered and used only those classified as 3 and above which included: 3) malignant; 6) malignant, metastatic; 9) malignant, uncertain whether primary or metastatic site based on topology and the histology of neoplasms from the International Classification of Diseases for Oncology (ICDO 9). Only 531 cases remained to be grouped by DA.

These cases were then merged with SES indices, sums of chemical emissions, sums of carcinogen emissions (tonnes), and distance data using Stata Version 9.2 (StataCorp, College Station, Texas, USA). The 531 cases were then transformed into standardized rates by: [(DA cancer rate- Provincial cancer rate)]/Provincial standard error]. Here, dividing the number of cancer cases by the children's population in 2006 for that DA created DA cancer rates, and expressed by 100,000. Similarly, the provincial cancer rate was calculated by dividing the total number of cancer cases by the total population of children for the year 2006. Those DAs with cancer (n=392) were then compared to the remaining DAs with a children population but no cancer cases (n=1511).

5.2.4 Analysis

5.2.4.1 DAs with Cancer cases vs. DAs with non-cancer cases

DAs were divided based on those with cancer cases (n= 392) and those without cancer cases (n= 1511). Summary statistics including means, standard deviations, minimum and maximum values, were examined for each variable and compared between those DAs with and without cancer cases. T-tests (2 tails) were performed between groups of DAs with and without cancer cases for each variable to determine if there were any significant differences. Correlation coefficients were examined between SES indices and: 1) chemical sum emissions (tonnes); 2) carcinogen sum emissions (tonnes); and 3) distances from centroids to nearest emitting facilities.

5.2.4.2 Negative Binomial Regression

Negative binomial regression was performed to examine if SES, chemical and carcinogen emissions, and proximity to nearest emitting facilities could explain children's cancer outcomes. (Figure 5-2)

5.2.4.3 Gender and Age at Diagnosis

Variables were then examined with gender and age at diagnosis using multiple linear regressions. Further analysis was performed for those DAs with cancer cases and compared between male and female cases using multiple linear regressions.

5.2.4.4 Quintiles

In an effort to examine the studied variables more closely according to cancer rates, quintiles of standardized cancer rates were determined. Summary statistics were performed for subsequent variables and compared between each quintile of cancer rate for DAs. ANOVA was performed to determine differences between groups. Correlation coefficients were also examined between SES indices and subsequent variables.

5.3 Results

5.3.1 Cancer Data

Of the 531 cancer cases, 254 patients were female and 277 patients were male. The most common cancer diagnoses for Manitoba children aged 0 to 19 years were: hematopoietic and reticuloendothelial systems (37.9%); eye, brain, and other CNS (19.9%); and bone and connective tissue cancers (11.1%) (Figure 5-1). The least common cancer diagnoses were: breast (0.19%); unknown primary (0.19%); and peripheral nerves and autonomic nervous system (0.38%).

5.3.2 General

Overall, SES indices were lower in those DAs with cancer cases (-0.12 ± 0.72) in comparison to those without cancer cases (-0.0716 ± 0.695). (Table 5-1) Maximum SES index values were lower for those DAs with cancer cases (1.07) than those DAs without cancer cases (1.21). Additionally, the minimum SES outlier was also different for those DAs with cancer cases (-2.53) in comparison to those DAs without cancer cases (-2.92). Moreover, those DAs with cancer cases had similar emissions from sums of chemicals (3,272.38± 23,971.3 tonnes) than those DAs without cancer cases (3,940.40± 26,341.86 tonnes). The maximum chemical emissions values were similar between DAs with and without cancer cases (1.97e5 and 2.0e5 tonnes, respectively). Sums of carcinogens emitted were also similar between those DAs with and without cancer cases (3.03 and 3.29 tonnes, respectively). Lastly, mean distance from centroids to nearest emitting facilities was slightly closer for those DAs with cancer cases (9 ± 21.17 km) in comparison to those DAs without cancer cases (10.95 ± 21.79 km). Maximum distances away from emitting facilities were smaller for DAs with cancer cases (150.38 km) than DAs without cancer cases (182.03 km). Meanwhile, minimum distances were further for DAs with cancer cases (0.12 km) than those without cancer cases (0.038 km). T-tests were performed (non-paired, 2 tailed) between each variable for DAs with and without cancer, and all differences were not significantly different ($p>0.05$).

Correlations were tested between SES indices and: 1) chemical sum emissions; 2) carcinogen sum emissions; 3) distance from centroids to nearest emitting facilities. (Table 5-2) For both groups of DAs, directions of correlation coefficients were similar between each group and SES index. More specifically, negative correlations were found between SES index and chemical sum emissions, carcinogen sum emissions and distance from centroids to emitting facilities. However, slightly stronger negative correlations were found for those DAs with cancer cases and SES with chemical sum emissions (r^2=-0.0736), and carcinogen sum emissions (r^2=-0.104) than those DAs without cancer cases.

5.3.3 Quintiles of Cancer Cases

Quintiles of standardized cancer rates were determined (Quintile 1: -0.42, n=83; Quintile 2: -0.11, n=76; Quintile 3: 0.13, n=78; Quintile 4: 0.40, n=127; Quintile 5: >0.41, n=31). No significant differences were found ($p>0.05$, ANOVA) with SES, distance from centroids to nearest emitting facilities, chemical and carcinogen emissions between quintiles of cancer rates. (Table 5-3)

5.3.4 Negative binomial regression analysis

Examination of the relationship between children's cancer outcome and SES, proximity to nearest emitting facility, and total chemical and carcinogen emissions through negative binomial regression analysis did not show any statistical significance ($p>0.05$).

5.3.5 Multiple linear regression analysis

Overall, average SES indices (females: -0.112, males: -0.113), and age at diagnosis (females: 10.5 years, males: 10.3 years) were very similar when cancer cases were divided into gender groups. However, females showed a shorter distance from centroids to nearest emitting facilities (9.30 km) in comparison to their male counterparts (13.2 km). Additionally, females also had higher chemical emission sums (4,076.6 tonnes vs. 1,226.3 tonnes), and higher carcinogen sums (3.65 tonnes vs. 1.27 tonnes). The top three cancer types for females were: 1) hematopoetic and reticuloendothelial systems (35.0%), 2) eye, brain, and other CNS (16.1%); 3) thyroid and other endocrine glands (14.2%). For males, the top three cancer types were: 1) hematopoetic and reticulendothelial systems (49.8%); 2) eye, brain and other CNS (23.6%); 3) bones and connective tissue (13.5%).

Multiple regression analysis was performed to examine if gender and age at diagnosis, children's population, distance, total chemical and carcinogen releases, were related to SES for those DAs with cancer cases. The model was significant ($p<0.0001$), where distance ($p<0.001$) and the number of children ($p<0.01$) were able to explain socioeconomic status, while controlling for chemical and carcinogen releases, age, and gender. Here, an increase in 1 km of distance from centroids to nearest emitting facility decreased SES index by -0.012. An increase in 100 children per DA resulted in a decrease in SES index by -0.054. No differences were seen with chemical and carcinogen releases, age at diagnosis, or gender and SES.

Multiple regression analyses were performed for separate genders to examine if distance, children's population, total chemical and carcinogen releases, and age at diagnosis were related to SES. For both males and females, models were significant ($p<0.0001$). For male cases, an increase in 1 km of distance to nearest emitting facilities resulted in a decrease of SES by 0.01 ($p<0.001$). Similarly, the female cases showed an increase in 1 km of distance to nearest emitting facilities resulted in a decrease of 0.0142 in SES ($p<0.001$).

5. 4 Discussion

In Canada, only a few studies have investigated relationships between cancer incidence and environmental risk factors. The most recent study from Milewski et al. (2012) examined SES (education, employment, income) from 14 communities in New Brunswick, where Saint John (Canada's largest oil refinery), Dalhousie (site of a zinc concentration storage facility, a chlor-alkali chemical manufacturing plant, and a pulp mill), and Belledune (which has a lead smelter) are located. [65] Unlike our study, chemical emissions and other parameters involving the industrial emissions were not measured. In their study, multivariate ordination techniques, hierarchal clustering, and permutation procedures did not show that SES variables were related to cancer clusters. Similar results were seen in another Canadian study by Mezei et al. [66] Their study examined neighborhood income as a proxy for socioeconomic status and the incidence of childhood solid tumors and lymphomas (1985-2001) using Poisson regression and concluded that observations were consistent with random variation when comparing incidence rates amongst richest to poorest quintile incomes. [66] A study by Borugian et at al. (2005) examining childhood leukemia (1985-2001) and neighborhood income as a measure for socioeconomic status in Canada showed that the poorest quintiles of income had a slightly lower relative risk for childhood leukemia than the highest quintiles of income.[67] Thus when focusing on childhood leukemia itself, higher SES may be a risk factor.

In our study, overall comparisons between DAs with and without cancer showed small but non-significant differences with environmental chemical emissions, proximity to emitting facilities, or cancer rates. A negative binomial regression analysis showed that there was no significant relationship between SES and environmental chemical emissions or distance for those with and without cancer cases. We previously examined SES indices amongst all DAs in provinces and territories in the development of the SES index, and showed that the distribution of SES was normal (median=0.11, mean= 0.0, standard deviation= 0.58). [49] However, significant differences were found between provinces and territories, which may be indicative of differences amongst populations. [49] In this study, we focused only on Manitoba and as a result, differences between SES, chemical or carcinogen variables may not have been as evident because of similar historical or geographical parameters within the province. Additionally, we examined overall cancer rates and did not investigate specific cancers as Mezei or Borugian et al. [65, 67] Because the availability of children's cancer data for this study was limited to a 10 year span instead of a 16 year span done in other studies, [65, 67] we decided to examine overall cancer rates (a greater n value) in favor of more robust analyses.

Interestingly, when examining gender itself for those cancer cases, there were no significant differences seen with its relation to SES ($p>0.05$) when controlling for distance, children's population, total chemical and carcinogen sums, and age at diagnosis. However, there was a significant difference with distance and SES when controlling for gender, distance, children's population, total chemical and carcinogen sums, and age at diagnosis, where increasing distance by 1 km was related to decreasing SES by 0.012 ($p<0.001$). When examining the male and female cases separately, increasing distance by 1 km was related to decreasing SES by similar units of index (0.010 and 0.014, $p<0.001$). Thus, increasing SES for cancer cases was related to living closer to emitting facilities while controlling for gender. In a related study, we examined differences between proximity to nearest emitting facilities and SES between urban and rural DAs. We found that rural populations tended to have higher SES populations living closer to emitting facilities, as seen here. Thus, it is possible that more of these DAs with cancer cases could be rural DAs or that they exude behaviors similar to rural DAs in that higher SES populations could be living closer to work.

5.5 Limitations

Our research focused on the year 2006 for exposure. Initial motivations were to retain the year 2006 as constant because the SES index was created using Census 2006. However, given that there is a lower number of variables collected in the most recent Census, it is assumed that SES will be stable over time and will be able to serve as a proxy in population based studies using data from other years. Thus, exposure can be examined from a greater period to properly assess those cancer cases that developed before the exposure year of 2006.

Because children in Manitoba generally live in close proximity to emitting facilities (Table 1), further studies need to examine the issue on a larger scale. Our initial motivation for this study involved including cancer registries for all provinces and territories, but privacy concerns, legislation, and other factors prevented data transfer. Future studies with all provincial and territorial data may show stronger evidence that those with lower SES not only suffer higher burdens from environmental chemical emissions, but also experience greater cancer outcomes in their children in comparison to their higher SES counterparts. Additionally, most of the population in Manitoba lives in close proximity to emitting facilities, and this in itself may contribute to potential impacts on future studies with adult cancers.

Lastly, significant relationships between distance and SES were observed when comparing male and female cancer cases. This effect could not be tested between genders for those with and without cancer cases using a negative binomial regression, because gender was not available for those DAs without cancer cases. Should the data become available, this would be an interesting area for further research.

5.6 Conclusion

Evidence has shown that cancers are related to industrial pollution. [68] In this study, we found that overall cancer occurrence is not related to the proximity to emitting facilities. Nevertheless, there is a slight indication that differences may occur according to females, favoring the participation of higher SES and shorter distances. Therefore, because industrial emissions and rates of children's cancer differ between each province, it would be vital to investigate the link between the two variables in Canada as a whole for future research. Additionally, gender-specific results and proximity to emitting facilities as well as certain cancer types, might be explored in future studies. Therefore, future work should include the study of SES participation..

5.7 Acknowledgements

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Table 5-1. Summary statistics for total children's population, total population, SES index, chemical emission sum, carcinogen emissions sum, distance from centroids to nearest emitting facilities between those DAs with cancer cases (n=391) and those without cancer cases (n=1511), (all p>0.05).

	DAs	Mean	Median	Standard Deviation	Minimum	Maximum
Total Children's Population	With cancer cases	177.73	150	129.86	0	1495
	Without cancer cases	140.09	130	74.22	0	945
Total Population	With cancer cases	638.98	569.50	351.18	0	4414
	Without cancer cases	528.66	504	178.94	0	2447
SES Index	With cancer cases	-0.12	0.04	0.72	-2.53	1.07
	Without cancer cases	-0.0716	0.1	0.695	-2.92	1.21
Chemical emissions sum (tonnes)	With cancer cases	3272.38	15.28	23971.30	0	200000
	Without cancer cases	3940.40	10.51	26341.86	0	197160.47
Carcinogen emissions sum (tonnes)	With cancer cases	3.04	0.00003	23.52	0.00003	207.25
	Without cancer cases	3.29	0	24.07	0	207.25
Distance from centroid to emitting facility	With cancer cases	9.00	1.85	21.17	0.12	150.38
	Without cancer cases	10.95	2.33	21.79	0.038	182.03

Table 5-2. Correlation coefficients between SES index and sum of chemicals emitted, sum of carcinogens emitted, and distance from centroids to emitting facilities for DAs with cancer cases.

	DAs	Sum of Chemicals Emitted (tonnes)	Sum of Carcinogens Emitted (tonnes)	Distance from Centroids to Emitting Facilities (km)
SES Index	With cancer cases	-0.0736	-0.104	-0.376
	Without cancer cases	-0.0190	-0.0340	-0.378

Table 5-3. Averages of SES index, distance from centroids to nearest emitting facilities, sums of chemical and carcinogen emissions, and children's population according to quintiles of cancer rates.

Quintile	SES index	Distance (km)	Sum of chemicals	Sum of carcinogens	Children's population
Quintile 1 (-0.42)	-0.490	13.2	5113.0	5.65	317.7
Quintile 2 (-0.12)	-0.0624	5.51	290.3	0.0380	177.9
Quintile 3 (0.14)	-0.00167	5.65	4741.15	3.13	140.2
Quintile 4 (0.41)	0.0865	7.0050	5610.47	5.84	127.2
Quintile 5 (>0.41)	-0.0674	13.3	390.72	0.329	111.4

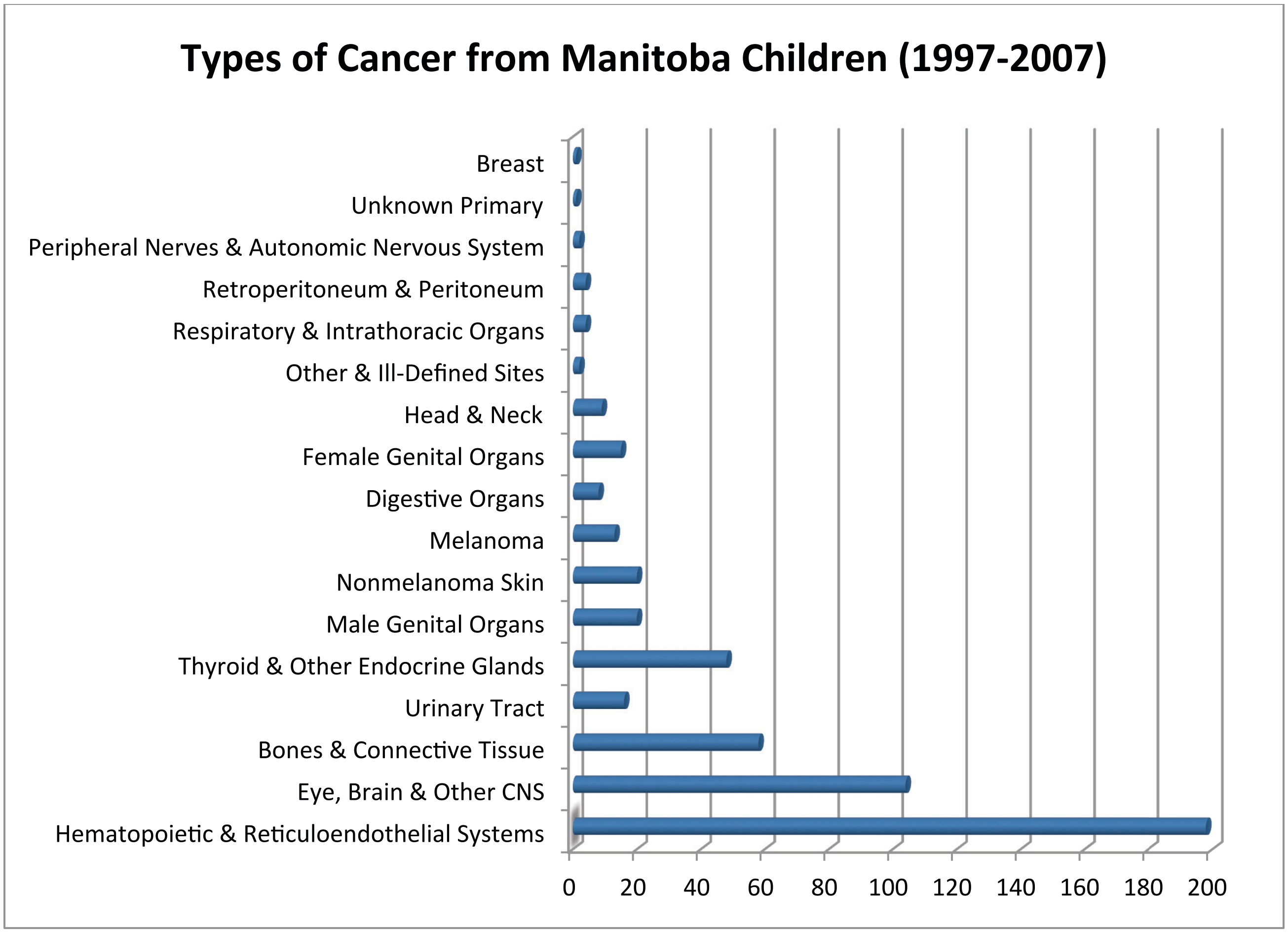

Figure 5-1. Cancer diagnoses for Manitoba children from 1997-2007, expressed in counts.

log (cancer count) / log (offset) = $\alpha_1 + \beta_1$(SES)+ β_2(proximity to nearest emitting facility)+ β_3 (total chemical emissions) + β_4 (total carcinogen emissions) + log (children's population) + error

Figure 5-2. Negative binomial equation with cancer rates as the dependent variable and distance to nearest emitting facilities, SES, total chemical and carcinogen emissions as independent variables. Offset term is the total children's population.

Chapter 6: Conclusion

6.1 General Conclusions

We have created a Canada wide SES index with the specific aim to be used in environmental health studies since there is a need for a comprehensive index of SES that describes the Canadian population, which can be used for research involving environmental pollution and health outcomes. The index was validated by examining its association with preterm birth (gestational age < 37 weeks), term low birth weight (LBW, <2500 g), small for gestational age (SGA, <10 percentile of birth weight for gestational age) and $PM_{2.5}$ (particulate matter ≤ 2.5 μm) exposures in Edmonton, Alberta (1999-2008). This unique index reflects more dimensions of SES than an earlier index and it performed superiorly in capturing gradients in prevalence of pregnancy outcomes.

This index was then used to examine the existence of Environmental Injustice. In our analysis, we examined these phenomena at the Canada, provincial, territorial, and selected Census Metropolitan Areas (CMA). Our initial results show that overall, Canada does not experience classical Environmental Injustice, as only little over a half of the variability of SES (Adj R^2=0.5528) was explained by children's population, proximity to emitting facilities, and chemical sums. Additionally, although higher SES has lower chemical emissions, they were also located closer to emitting facilities.

However, because Canada is such a large and diverse area with different populations and traditions, it is not surprising that specific areas show differences in comparison to the entire country, where results may have been diluted. Here, closer inspection of provinces, territories and select CMAs show stronger suggestions of classical Environmental Injustice. For example, Nunavut and Vancouver had DAs with lower SES living closer to emitting facilities and having higher chemical releases.

In the previous analysis, we examined the three largest CMAs in Canada. However, we also investigated Environmental Injustice in overall urban areas and compared them to rural areas. Interestingly, there were overall differences between urban and rural DAs, where rural DAs had greater mean SES indices than urban DAs (0.102 ± 0.604 and -0.0276 ± 0.563, respectively). Rural DAs were also located further away to emitting facilities (14.8 ± 18.7 km) than urban DAs (2.55 ± 4.94 km) and had lower children's population (134.9 ± 80.6 children per DA) in comparison to urban DAs (148.4 ± 139.2 children per DA). Thus, urban areas showed potential signs of Environmental Injustice with these populations having lower SES living closer to emitting facilities, similar to what was seen with the CMA analyses.

Environmental Injustice not only examines the unfair distribution of environmental pollution among populations according to SES, but also the development of adverse health outcomes, or in our case, childhood cancer. Although our initial motivation was to investigate children's cancer as an adverse health outcome across Canada, privacy laws and concerns did not allow us to obtain the data for examining this. Our results using only data from Manitoba showed that there is a slight indication that differences may occur according to gender, favoring the participation of higher SES and shorter distances. Here, increasing by 1 km the distance from the residence of cancer cases to the emitting facilities resulted in decreases of SES by 0.0098 for males and 0.014

for females. Thus, living further away from an emitting facility would result in a lower SES for cancer cases. This pattern was similar to our findings for rural areas in our previous urban versus rural analysis (r^2= -0.36, p<0.01).

6.2 Applications and Future Research

Methodologies to investigate Environmental Injustice in our research could be utilized to examine if the concept exists in First Nations communities. Although this group did not show in the PCA for Canada as a whole, factor loadings were significant when examining separate provinces, such as Alberta (Table 2-6), which have large proportions of these populations. It would therefore be vital to investigate if Environmental Injustice exists in these communities, especially as there have been evidence in places such as the Beaver Lake Cree Nation in Northern Alberta with oil sands.

Should all provincial and territorial cancer data be available in the future, potential links to Environmental Injustice could be examined as the patterns we observed may only be unique to only Manitoba. It would therefore be important to investigate the link between Environmental Injustice and children's cancer for the rest of the country, especially since the majority of Canada lives in urban areas where close proximity to emitting facilities and low SES has been demonstrated.

Next steps could include focusing on certain cancer types such as leukemias and lymphomas, which have been shown to have clearer linkages to chemicals. Moreover, although the data was not available in this study, other sources of potential pollutants include agricultural activities and traffic emissions. Unfortunately, Canada has few monitoring stations to capture these emissions and although these sources have been linked to cancer, we were not able to examine the relationship.

The most ideal unit to create specificity in the study would be at the individual level. Because this simply would was not practical for our ecological studies with the population of Canada, we used the DA as our geographic unit in an attempt to capture the most homogeneity in our studies. However, future research could perhaps examine smaller populations of individuals living in buffer areas around emitting facilities. Partnering with toxicologists could also incorporate other information such as biomonitoring, which could further provide evidence of chemical exposures, rather than by just using distance as a proxy.

The Chan SES index can be utilized for Canadian municipalities, provinces and territories, and for Canada as a whole, as well as for future research involving any other adverse health outcomes (for example asthma) subsequent to potential environmental pollution exposures. Although the index itself is exclusive for the Canadian population, the methodology in its creation may be utilized for other countries to adopt their versions of the index.

As current Censuses no longer utilize the long version of the questionnaire, future plans to revitalize the Chan index in the future may include lobbying the government of Canada to keep the following variables so that the index could be regenerate using current data: 1) marital status; 2) mode of transportation; 3) home ownership; 4) one family households; 5) education; 6) median income; 7) employment rate; 8) cultural origins; 9) age of home. Because newer homes tend to contain chemicals that were not used in older homes (such as perfluorinated acids or flame retardants), it would be important to include the age of the home in future versions of the Chan index to acknowledge this new type of indoor pollution.

Lastly, the Chan index will be utilized in a variety of other projects with current students: 1) in assessing if SES and environmental pollution are related to adverse birth outcomes in DOMINO (Data Mining and Neonatal Outcomes); 2) if SES are related to congenital heart diseases and environmental pollution.

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Appendix

Chapter 1: Development of a Canadian Socioeconomic Status Index for the study of Health Outcomes related to Environmental Pollution

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1.1 Introduction

Reports such as the Canada Health Survey [1] and the Canadian Community Health Survey [2] indicated that inequalities of health resulting from socioeconomic status (SES) required urgent scrutiny.[3] Because the majority of health data is released in area-level form in comparison to individual-level form as a result of privacy concerns, geographical proxies, where the SES for small areas is linked to health data from administrative databases are often utilized.[3] Most of these studies have used neighbourhood income as the indicator of social disparity and mortality as the health indicator.[3] Measuring SES using a single indicator, however, is unlikely to completely reflect its complexity. Deprivation indices including other measures such as unemployment, social class, income, marital status, occupation, and education have been developed for Great Britain,[4] Spain,[5] and Italy.[6]

Until recently, only two deprivation indices for Canada have been developed, each with a specific purpose. Matheson et al. (2012) proposed an index called the "Can-Marg" using Census 2006 data, in which they focused on examining inequalities in health and other social problems.[7] Four deprivation criteria: residential instability, material deprivation, dependency and ethnic concentration were defined and inequalities in 18 health and behavioural problems from the Canadian Community Health Survey (CCHS) reported.[7] However, the index that is mostly used in Canadian research has been the Pampalon index, developed in Quebec. Pampalon et al. illustrated its value by linking it to overall Canadian premature mortality rates in 2001.[3] The group developed their index based on Townsend's definition of deprivation [8] and included variables such as education and marital status. More specifically, their index was divided into two components: social and material. The Pampalon index only included six variables in the analyses: employment, income, education, marital status, single parent family, and living alone, while the Canadian Census form from which the index was developed, contains over 200 variables.

Among other factors like "individual susceptibility" (e.g. genetic polymorphisms), environmental stressors such as radiation, chemicals, and viruses, as well as dietary habits, psycho-social stress, and social characteristics are known to contribute to the occurrence of common childhood conditions. There recently has been growing interest in environmental injustice, a concept suggesting that those populations with lower SES may be vulnerable to greater exposure to environmental pollutants than their higher SES counterparts, and consequently experiencing potentially increased health risks. Building on this concept, the U.S. Institute of Medicine coined the term "double jeopardy" to emphasize the combined risk often faced by socially disadvantaged groups. Specifically, groups experiencing higher environmental exposure are often more susceptible because they have higher rates of smoking, obesity, poor nutrition, and adverse occupational exposures. [9]

Thus, a need exists for a comprehensive index of socioeconomic status that is indicative of the Canadian population, which can be used for research involving environmental pollution and health outcomes. For that purpose, we aimed to develop a novel SES index that is comprehensive and more encompassing of the Canadian population, by incorporating cultural identities, examining factors relevant to health outcomes from environmental pollution, and considering other variables used in previous environmental injustice studies.

1.2 Methods

1.2.1 Data Extraction

Socioeconomic data were analyzed from the Canadian Census 2006. For our evaluation, we extracted Census data from CANSIM, Canada's socioeconomic database which provides free access to a range of the latest statistics.[10] The Census was completed on May 16, 2006 and 32.5 million people were included. One in every five households received a long questionnaire with 53 questions in comparison to 8 for the short form.[11] Here, we used data from the long questionnaire forms. These data cover all of Canada's dissemination areas (DAs), which are small regions consisting of 400 to 700 people.[12] Canada has 52,974 DAs, ranging from 34 for Nunavut to 18,923 for Ontario.

1.2.2 Variables

A set of 22 variables from the 2006 Census was selected based on: (1) cultural identities [13]; (2) potential environmental pollutants related to health outcomes [14, 15]; (3) Canadian environmental injustice studies [16-18]; and (4) variables utilized in the deprivation index for Canada proposed by Pampalon[3] (Table 1). Studies in the United States have indicated a clear relationship between several racial groups with regards to SES [19-21]. In an effort to investigate the phenomenon in Canada, we grouped the cultural identities reported in the census as the individual's ancestry, based on four categories from the "Human Developmental Index" (HDI): origins from (1) very high sum; (2) high sum; (3) medium sum; and (4) low sum countries.[13] The HDI takes into account the human development of a country and ranks them according to life expectancy, literacy, education and standards of living.[13] We included a category for those with aboriginal identities based on responses to the "Indian Status" and "Aboriginal identities" question on the Census and combined those who were North American Indian, Metis, Inuit, multiple Aboriginal identities, and aboriginal responses not included elsewhere. Each of the variables was expressed as proportions per dissemination area (DA). Variables obtained as raw counts of the answers to questions were converted to proportions by dividing by the number of people answering the question. Since the data used in the creation of the index were collected from questions answered with the long form of the Census questionnaire, the proportions were based on the variables corresponding to 20% of the population of Canada. Employment rate, median income and prevalence of low income after taxes were not transformed since they were originally reported as proportions per DA in the census database.

Lastly, we incorporated a variable that we thought was important for health outcomes related to environmental pollution: age of the home (construction of homes before 1946, 1946-1970, 1971-1990, 1991-2006) as a proxy for age of the neighbourhood. In the United States, it has been shown that older neighbourhoods are more likely to have lead paint [15], asbestos [14] and have more infiltration of fine particles from outdoors to indoors. [22]

1.2.3. Construction of SES Index

Principal component analysis (PCA) with a single varimax rotation (factor loadings ≥ |60|) was performed on the selected 22 Census socioeconomic variables (SAS 9.2, North Carolina, USA). The analyses were completed for all DAs of Canada whereupon we utilized two criteria for the selection of components: (1) Kaiser Criterion (eigenvalues ≥1); and (2) individual proportion of variances per component explaining ≥ 10% of the overall variability. The final SES index was created by averaging the factor scores (a numerical representation of the linear relationship between variables and the components) per DA, according to the three components retained. This process was completed for all DAs in Canada for overall SES indices in the country as well as for each province and territory.

1.2.4. Validation of our SES index

1.2.4.1 Adverse Birth Outcomes

We attempted to validate our index by utilizing the well- researched concept that low SES may be related to adverse birth outcomes.[23,24] Here, data on all singleton live births between 1999 and 2008 in Edmonton were accessed through Statistics Canada (Supplement 1). Pregnancy outcomes under study were preterm birth (gestational age < 37 weeks), term low birth weight (LBW, <2,500 g), and small for gestational age (SGA, <10 percentile of birth weight for gestational age). Spearman correlations and t-tests were used to assess associations between the index and pregnancy outcomes.

1.2.4.2. Particulate Matter ($PM_{2.5}$)

We also evaluated another known [25], but less explored association between our SES index and concentrations of particulate matter with a mean aerodynamic diameter < 2.5 μm ($PM_{2.5}$). Spearman correlation and t-tests were used to examine relationships between $PM_{2.5}$ exposures and SES indices. $PM_{2.5}$ exposures were assigned by mapping the mother's six-character postal code to a monthly surface $PM_{2.5}$ concentration, based on a North American land use regression model that incorporated observations from fixed-site monitoring stations and satellite-derived estimates of $PM_{2.5}$. Exposures were estimated for the entire duration of pregnancy. Methods are described in detail elsewhere. [26]

1.2.4.3. Comparison of Chan Index to Pampalon Index

We compared the association of our SES index and that of Pampalon's [3] with adverse birth outcomes and $PM_{2.5}$ concentrations using Spearman correlations and t-tests. The Pampalon index is a commonly used SES index in Canada that was developed using variables from the 2006 Census with: (1) known relations to health; (2) past use as geographical proxies; (3) past utilizations with the material or social dimensions of deprivation; (4) availability by DA.[3] PCA was used on the variables and two components were found that are now used as the Pampalon indices: Values for the Material and Social components. The Pampalon index value used to validate our index were accessed through their website.[3, 27] Both indices represent the Canadian SES situation in 2006 and comparisons assume the same similar Canada wide SES distribution around the year of 2006.

1.3 Results

1.3.1 Principal Component Analysis (PCA)

Three components were extracted for Canada, with a cumulative retained variation of 58.9%. Each component yielded different conceptual meanings when variables were placed together, based on a preconceived categorical variable classification (Table 2). Component 1 contained variables related to: (1) social advantages, and (2) high material ownership; (Supplement 2) Component 2 included variables related to economic advantages, (Supplement 3) and Component 3 (Supplement 4) was entirely different in composition and direction and contained variables indicative of being: (1) socially disadvantaged and having (2) specific cultural identities. Interestingly, aboriginal status was not included in the cultural identities of Component 3, but instead medium sum HDI groups were incorporated. Additionally, age of the home was not included in any of the components. For this analysis, the final SES index was obtained averaging the components retained by utilizing the formula [C1+C2+ (-1*C3)]/3. Given the disadvantage connotation of the variables included in Component 3, we multiplied factor scores for Component 3 by -1 to achieve a comprehensive index for Canada, which would integrate all components for an overall meaning of “socioeconomic status”.

An overall examination of the index for all of Canada shows a relatively normal distribution (median= 0.11, mean = 0.0, standard deviation= 0.58). However, an individual analysis of the distribution of indices within each province and territory per DA, according to the Canada wide index, yielded different results. Here, the SES index distribution for Canada was divided into quintiles and the number of DAs within each quintile per province and territory was investigated. (Supplement 5) Alberta showed increasing numbers of DAs within higher values of the SES index, while Newfoundland, Northwest Territories, and Nunavut showed greater numbers of DAs within lower values of the SES index. A chi-square test examining the distribution of DAs within each quintile of SES showed that it was not homogenous among provinces (Pearson chi-square=2,637.9, $p<0.001$).

Furthermore, boxplots of the distribution of SES index by province and territory showed similarities that are more obvious and trends in outliers (Figure 1). Here, all provinces are mostly grouped together, but Nunavut and the Northwest Territories show the majority of DAs are lower than the country's average SES index. The mean SES index for the rest of the provinces and territories was slightly above average, with the exception of Newfoundland and Labrador. Additionally, obvious low SES index outliers were seen in Saskatchewan, British Columbia and Ontario.

1.3.2 Validation of SES Index

1.3.2.1 Prevalence of adverse pregnancy outcomes and $PM_{2.5}$ exposure

Lower quintiles in our SES index were significantly ($p<0.0001$) associated with increasing prevalence of LBW, preterm birth and SGA in Edmonton (Figure 2). This was corroborated with significantly lower mean SES indices for LBW (-0.227), preterm (-0.211) and SGA (-0.216) infants compared to normal weight (-0.138), term (-0.140) and appropriate for gestational age (-0.138) infants ($p<0.0001$).

Lower quintiles of our SES index were also significantly associated with higher exposure to $PM_{2.5}$ ($p<0.0001$) (Figure 2).

1.3.2.2. Comparisons of our SES index and Pampalon index

Both material and social components of Pampalon deprivation indices behaved similarly to our SES index when examining prevalence of LBW, PTB and SGA and $PM_{2.5}$ exposure (Figure 2). However, there was a more consistent gradient in prevalence of LBW, preterm birth and SGA by quintile of our index compared to the Pampalon indices, more noticeable in the case of LBW ($p<0.0001$ vs. $p<0.01$). Conversely, there was a more consistent gradient in $PM_{2.5}$ by quintile of the Pampalon material deprivation index compared to our index and the social deprivation index. Correlations between $PM_{2.5}$ and the three indices were very similar (Chan index: $r= -0.11$, $p< 0.0001$, Pampalon Material index: $r=-0.15$, $p<0.0001$, Pampalon Social index: $r=-0.15$, $p<0.0001$).

1.4 Discussion

Although our SES index is not the first to be developed for Canada, it likely reflects more fully the dimensions of SES in Canada for purposes of examining health outcomes from environmental pollution. While our index similarly includes aspects of social and material deprivation, it is novel in that we explored the contribution of: 1) age of homes as a proxy for age of neighbourhood which may in turn be an indicator of potential indoor environmental pollution; and 2) cultural identities with special attention to First Nations groups. Additionally, since our index is comprised of a single scale unlike the Pampalon indices, it is more easily communicated and better suited for presenting data directed toward studies investigating health outcomes and environmental pollution, for instance using maps.

More specifically, we examined the age of the homes as a proxy for the age of the neighbourhood. Older neighbourhoods more likely contain asbestos [14], lead paint [15] or increased indoor infiltration of fine outdoor particles.[22] Interestingly, age of the homes was not included in any of the three components for our SES index. This observation may be explained by Canada's relatively strong social programs, which may have weakened correlations between older homes and living in poverty as seen in the United States. For example, advances geared toward the development of newer government subsidized accommodations in an effort to decrease poverty have been in place with programs such as the Newfoundland and Labrador Poverty Reduction Strategy.[28] Another explanation may include a possible trend in Canada toward middle class or wealthy populations living in older, more established neighbourhoods and homes. This may also have diluted the relationship seen in the US between inhabiting older homes and living in poverty.

Cultural differences were strongly evident with our SES index. Our index differs from Matheson et al.'s "Can-Marg" in that they utilized visible minority and recent immigration status (within 5 years). We grouped cultural origins by examining "ethnic origins", which takes into account the ancestry of the Canadian population. This may be a more accurate indication of ethnicity, as recent immigration has mostly been from skilled workers from China, who generally have higher SES.[29] This effect was illustrated in the "Can-Marg" index, where ethnicity was positively associated with better health outcomes and more healthy behaviours.[7] We also examined "visible minority" and "recent immigration" in the development of our index (data not shown), and these variables were not associated with any of our components. This pattern was also seen in attempts to include ethnicity through "recent immigration" or "visible minorities" by Jerrett et al.[17] Thus, by utilizing "ethnic origins", we may be able to overcome this potential characteristic of the population. Inclusion of aboriginal groups with HDI categories in our index was novel. As 4% of Canada's population (1.2 million people) in 2006, aboriginal groups in Canada represent the second largest population in a country internationally.[30] Although there is a large population of aboriginals living in Canada (5% in Alberta, 14% in Saskatchewan and Manitoba, 85% in Nunavut, 51% in the Northwest Territories, 23% in the Yukon),[30] this variable interestingly did not appear in any of the three components of our SES index. Historically, aboriginal groups (especially in First Nations communities) have low response to the Census and this may be a source of bias in that this population's responses may be missing. Nonetheless, aboriginal identity is important to consider because aboriginal families are more likely to experience poverty than the overall population of Canada.[30] For example, those with aboriginal cultural identities are more likely than other Canadians to consist of single parent families (50% of children in census metropolitan areas).[30] Another explanation for the lack of aboriginal cultural identities contributing to any of the three components of our SES index may include dilution of the relationship with variables associated with poverty, as there may be different definitions of social and economic advantages for aboriginals living in Northern Canada, where aboriginals comprise a large proportion of the population (Yukon: 25%, NWT: 50.3%, Nunavut: 83.6% in 2006). The aspects of "wealth" and "deprivation" could easily be obscured in these areas, as the attainment of education or even the use of a vehicle in comparison to other forms of transportation may be influenced by traditional forms of living.

Because the index is novel, it was important to test its validity against an extensively used index, the Pampalon deprivation index, exploring an outcome for which associations with SES are well documented such as adverse birth outcomes and exposure to $PM_{2.5}$. Adverse birth outcomes with low SES relationships are a heavily researched area and our results showing increasing prevalence of PTB, LBW, and SGA with lower SES corroborate what has been published previously. [23,24] Additionally, we observed a more consistent gradient of the occurrence of the outcomes with lower values of our index compared to the Pampalon index, while the reverse was true for $PM_{2.5}$ exposures during pregnancy. We established the validity of our index based on several evaluative criteria: 1) demonstrated similar findings to those reported in the literature showing correlations between SES and adverse birth outcomes; 2) showed potential for supporting our hypothesis of environmental injustice in Canada by demonstrating associations of low index values with increased $PM_{2.5}$ exposure; and 3) showed similar, but stronger findings in comparison with an older index. A clear advantage of our index is that it consists of a single value and is therefore simpler to interpret. A limitation to our index is that while a single value may be useful for easier interpretation, the Pampalon index would allow for independent analyses of material and social deprivation for public health policy and intervention purposes. However, another advantage to utilizing our index is that a background in using past indices such as the Townsend index for interpretation of the Pampalon index is also not required.

1.5 Limitation

A limitation of working with indices based on Census data in Canada is the lower number of variables collected in the most recent Census. [31] It is also assumed that SES will be stable over time, serving as a proxy in population-based studies using data from other years.

1.6 Conclusion

We focused our efforts on the development of a national index for Canada for purposes of investigating health outcomes and environmental pollution. We found that it performed superiorly to an earlier index in capturing gradients in prevalence of adverse pregnancy outcomes. We intend to use this index to investigate environmental injustice in Canada by applying aggregated geospatial analysis techniques to examine associations of SES and industrial chemical emissions and the incidence of childhood cancer and other pediatric health outcomes in Canada. Lastly, this new index has the potential to enable a better assessment of SES inequalities in a variety of health outcomes related to environmental pollution in Canada at the DA level.

1.7 Competing Interests

We do not have any competing interests.

1.8 Authors Contributions

EC contributed to study design, data acquisition, data analysis, and drafting the manuscript. JS carried out statistical analyses. LC and DS contributed to pregnancy outcome data acquisition and statistical analyses. DS and MJ participated in helping draft the manuscript. AOV participated in the design of the study, coordination and helped draft the manuscript.

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Table 1- 1 Parameters and variables used in the selection for PCA analysis.

Parameter (number of candidate variables)	**Variable (Census 2006)**
Cultural identities (n=5)	Human developmental index (HDI): very high sum; high HDI; medium HDI; low HDI; aboriginal group status
Potential existence of indoor environmental pollutants related to health outcomes (n=4)	Construction of homes: before 1946; 1946-1970; 1971-1990; 1991-2006
Environmental injustice indicators (n=7)	Marital status; prevalence of low income after taxes; car, truck, or van for commute; public transit, walking or bicycling for commute; multiple family households; owning a home; renting accommodations
Variables utilized in a previously proposed deprivation index for Canada (n=6)	Educational certificate; no educational certificate; employment rate; median income; total lone-parent families; divorced or widowed status

Table 1- 2 List of new variables (Chan et al., 2015) created for analyses of components and their descriptors.

New Variable (n=8)	**Census Variables** (n=22)
9) High material ownership	Home ownership Car, truck or van for commute
10) Low material ownership	Rent accommodation Public transportation use
11) Socially advantaged	Marital status One family households
12) Economically advantaged	Employment rate Median income Certificate, diploma or degree
13) Socially disadvantaged	Single, widowed or divorced Multiple family households Lone parent families
14) Economically disadvantaged	Prevalence of low income after taxes No certificate, diploma or degree
15) Indication of potential children's environmental hazard	Construction of home ≤1946 to 1970 Construction of home 1971-1990 Construction of home 1991-2006
16) Cultural identities	Very high sum HDI High sum HDI Medium sum HDI Low sum HDI Aboriginal

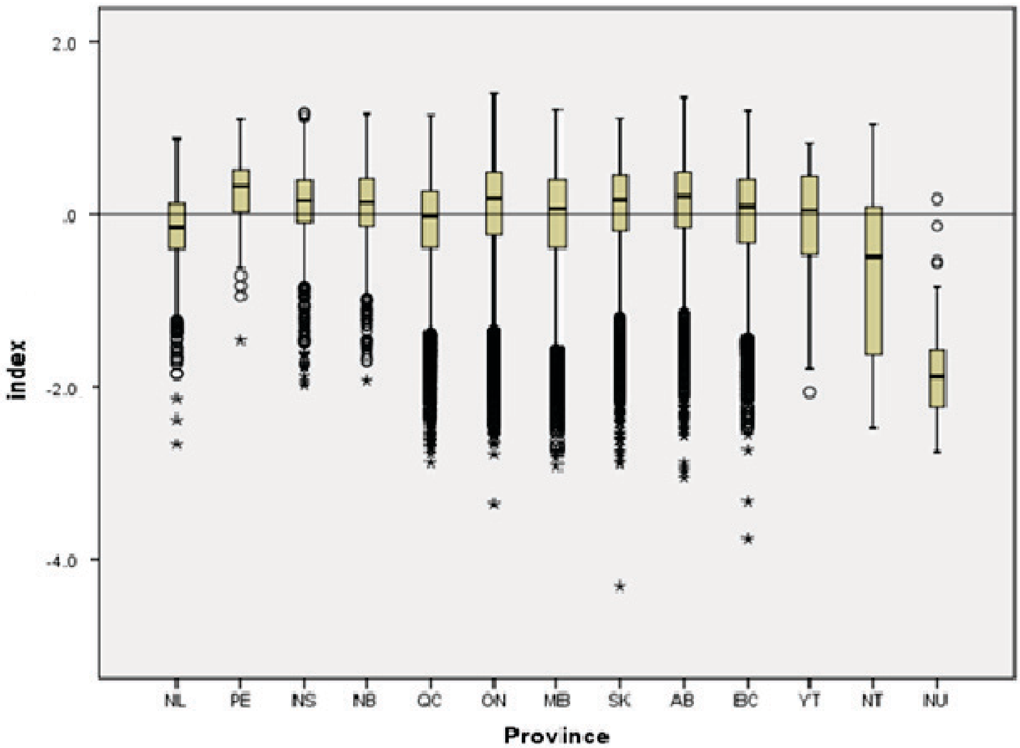

Figure 1-1 Boxplot distribution of median SES index by province and territory (n=13). Whiskers represent upper and lower range, while asterisks represent outliers. Bottom and top of boxes are the first and third quartiles, while the centerline represents medians.

(NL=Newfoundland and Labrador, PE=Prince Edward Island, NS=Nova Scotia, NB=New Brunswick, QC= Quebec, ON=Ontario, MB=Manitoba, SK=Saskatchewan, AB= Alberta, BC= British Columbia, YT= Yukon, NT= Northwest Territories, NU= Nunavut)

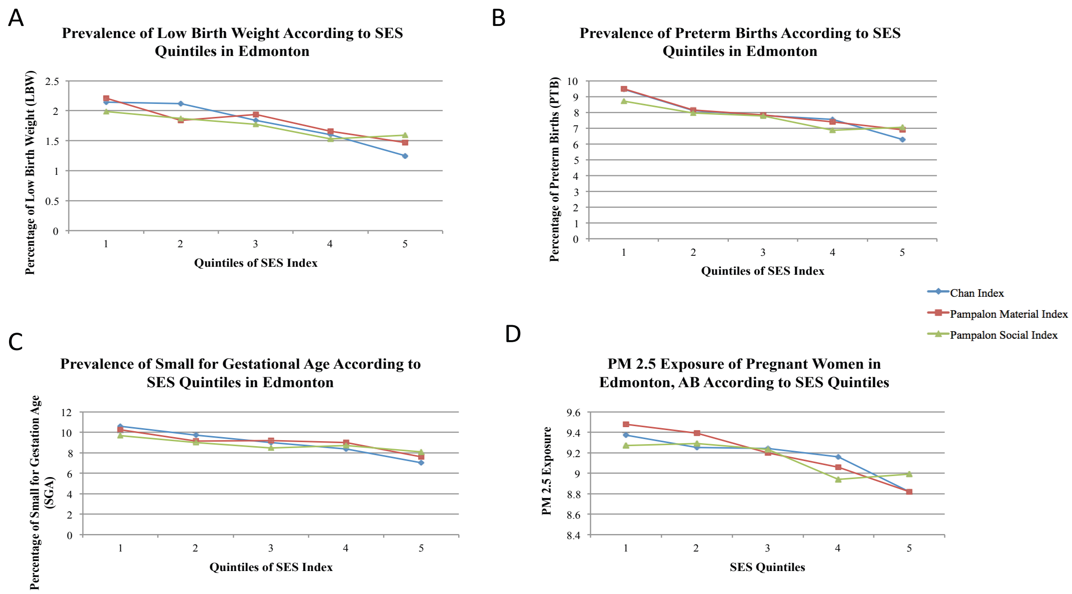

Figure 1-2 Comparison of the prevalence of low birth weight (panel A), preterm births (panel B), small for gestational age (panel C), and PM $_{2.5}$ exposures (panel D) according to Chan et al. and Pampalon et al indices.

Variable	Preterm birth n (%)	Low birth weight n (%)	Small for gestational age n (%)	Mean $PM_{2.5}$ ($\mu g/m^3$)
Sex				
male	2945 (8.31%)	480 (1.48%)	3320 (9.37%)	9.17
female	2495 (7.39%)	665 (2.13%)	2880 (8.54%)	9.17
Maternal age				
<18	115 (9.66%)	20 (1.87%)	110 (9.28%)	9.4
18 – 29	3265 (7.77%)	705 (1.82%)	3910 (9.31%)	9.2
30 – 39	1950 (7.83%)	405 (1.76%)	2080 (8.36%)	9.11
40+	10 (10.14%)	15 (1.54%)	100 (9.26%)	9.01
Marital status				
Single	670 (9.38%)	150 (2.32%)	770 (10.79%)	10.01
Married	3295 (6.90%)	735 (1.65%)	4090 (8.58%)	9.14
Widowed	0 (0.00%)	0 (0.00%)	5 (16.67%)	9.55
Divorced	60 (9.76%)	15 (2.70%)	75 (12.20%)	10.11
Separated	0 (0.00%)	0 (0.00%)	0 (0.00%)	8.01
unknown	1415 (10.34%)	245 (2.00%)	1260 (9.22%)	8.81
Parity				
1st birth	2560 (8.06%)	605 (2.07%)	3495 (11.02%)	9.14
2nd birth	1525 (6.69%)	300 (1.41%)	1620 (7.11%)	9.17
3rd or greater birth	1350 (9.24%)	235 (1.77%)	1075 (7.36%)	9.22
unknown	5 (20.00%)	5 (25.00%)	5 (20.00%)	9.81
Birth year				
1999	470 (7.36%)	100 (1.69%)	590 (9.23%)	10.56
2000	495 (7.96%)	100 (1.75%)	590 (9.49%)	9.96
2001	520 (8.12%)	110 (1.87%)	605 (9.45%)	9.22
2002	485 (7.66%)	110 (1.88%)	535 (8.45%)	9.71
2003	560 (8.49%)	110 (1.82%)	540 (8.19%)	9.17
2004	540 (8.08%)	90 (1.47%)	575 (8.61%)	9.83
2005	570 (8.46%)	105 (1.70%)	565 (8.40%)	7.96
2006	565 (7.62%)	130 (1.90%)	670 (9.05%)	8.84
2007	565 (7.00%)	145 (1.93%)	750 (9.31%)	7.87
2008	670 (8.02%)	145 (1.89%)	780 (9.35%)	9.07

Supplement 1-1 Descriptive table of general characteristics of all birth outcomes in Edmonton. * In accordance with Statistics Canada disclosure rules, all frequencies were randomly rounded to base five, but percentages are based on unrounded data.

Variable	Canada	AB	BC	SK	MB	ON	QB	NB	NS	PEI	NFL	YK	NV	NWT
No certificate, degree or diploma												-89	-97	-88
Certificate, degree or diploma												90	96	90
Employment rate												78	83	88
Median income													84	78
Single, divorced or widowed	-83	-88	-80	84	-85	-86	-86	-87	-92	-92	82	-66		-74
Married	84	87	80	-82	86	85	90	87	92	93	-84	62		72
Prevalence of low income after taxes											69			
Car, van or truck for commute	76	73	79		77	79		79	82	71			76	
Public transit use	-72	-75	-79		-77	-75		-80	-82	-73			-68	
Total lone parent families				83						-71	72			
Own home	84	85	87	-64	81	82	84	90	90	92	-84	64		
Rent accommodation	-80	-83	-84	66	-86	-77	-84	-89	-87	-90	83			
Construction of home ≤ 1946 to 1970														
Construction of home 1971-1990														
Construction of home 1991-2006														
One family households	82	81	77		79	83	78	73	79	77				
Multiple family households													-65	
Very high sum HDI												85	95	91
High sum HDI												77	73	76
Medium sum HDI														69
Low sum HDI														
Aboriginal				61								-86	-96	-95

Supplement 1- 2 Factor loadings (*100) for Canada and its provinces and territories (n=13) corresponding to Component 1. (AB=Alberta, BC=British Columbia, SK=Saskatchewan, MB=Manitoba, ON=Ontario, QB= Quebec, NB=New Brunswick, NS=Nova Scotia, PEI=Prince Edward Island, NFL=Newfoundland, YK=Yukon, NV=Nunavut, NWT=Northwest Territories)

Variable	Canada	AB	BC	SK	MB	ON	QB	NB	NS	PEI	NFL	YK	NV	NWT
No certificate, degree or diploma	-73		-40		-90	-84		-87	- 89	-96	-91			
Certificate, degree or diploma	86	85	83		93	88		88	90	96	91			
Employment rate	72	75	76	73				73	68		80			
Median income	71	70	62		74	65		70	76		74			
Single, divorced or widowed												-66		
Married												62		
Prevalence of low income after taxes														
Car, van or truck for commute				79										
Public transit use														-63
Total lone parent families														
Own home				62								64	-89	63
Rent accommodation													90	
Construction of home ≤ 1946 to 1970														
Construction of home 1971-1990														
Construction of home 1991-2006														
One family households				82									-66	81
Multiple family households														
Very high sum HDI					63		-75					85		
High sum HDI							69					77		
Medium sum HDI							79							
Low sum HDI							66							
Aboriginal												-86		

Supplement 1- 3 Factor loadings (*100) for Canada and its provinces and territories (n=13) corresponding to Component 2. (AB=Alberta, BC=British Columbia, SK=Saskatchewan, MB=Manitoba, ON=Ontario, QB= Quebec, NB=New Brunswick, NS=Nova Scotia, PEI=Prince Edward Island, NFL=Newfoundland, YK=Yukon, NV=Nunavut, NWT=Northwest Territories)

Variable	Canada	AB	BC	SK	MB	ON	QB	NB	NS	PEI	NFL	YK	NV	NWT
No certificate, degree or diploma		64		-81			-88							
Certificate, degree or diploma				76			91							
Employment rate														
Median income				64			68							
Single, divorced or widowed													89	
Married													-85	
Prevalence of low income after taxes														
Car, van or truck for commute											82			
Public transit use											-77			
Total lone parent families		61											67	
Own home														-61
Rent accommodation														68
Construction of home ≤ 1946 to 1970					94			-79		-79				82
Construction of home 1971-1990					-86			69				-77		
Construction of home 1991-2006									70	84		73		
One family households														
Multiple family households	70		72			69								
Very high sum HDI	-72		-62			-85			-65					
High sum HDI														
Medium sum HDI	76		87			81								
Low sum HDI												64		
Aboriginal		71							72					

Supplement 1- 4 Factor loadings (*100) for Canada and its provinces and territories (n=13) corresponding to Component 3. (AB=Alberta, BC=British Columbia, SK=Saskatchewan, MB=Manitoba, ON=Ontario, QB= Quebec, NB=New Brunswick, NS=Nova Scotia, PEI=Prince Edward Island, NFL=Newfoundland, YK=Yukon, NV=Nunavut, NWT=Northwest Territories)

		quintile					Total
		1.00	2.00	3.00	4.00	5.00	
Province	AB	14.6% (763)	17.8% (932)	19.7% (1028)	21.4% (1118)	26.4% (1381)	5,222
	BC	22.3% (1557)	19.1% (1333)	19.7% (1372)	20.9% (1455)	18.1% (1260)	6,977
	MB	24.6% (508)	18.6% (383)	20.1% (415)	18.9% (390)	17.8% (368)	2,064
	NB	10.5% (147)	24.1% (338)	23.1% (324)	23.8% (333)	18.5% (260)	1,402
	NL	25.4% (262)	36.9% (381)	19.7% (203)	12.5% (129)	5.5% (57)	1,032
	NS	10.3% (165)	20.0% (322)	27.1% (436)	24.6% (396)	18.0% (290)	1,609
	NT	50% (44)	15% (12)	10% (8)	10% (8)	10% (8)	80
	NU	93.9% (31)	3.03% (1)	3.03% (1)	0% (0)	0% (0)	33
	ON	19.0% (3597)	17.0% (3222)	17.6% (3338)	20.0% (3790)	26.3% (4975)	18,922
	PE	5.54% (16)	15.6% (45)	17.6% (51)	31.1% (90)	30.1% (87)	289
	QC	24.3% (3192)	25.7% (3377)	22.7% (2992)	17.1% (2246)	10.3% (1355)	13,162
	SK	17.5% (369)	17.4% (368)	21.1% (447)	20.9% (441)	23.1% (489)	2,114
	YT	25.4% (17)	16.4% (11)	17.9% (12)	17.9% (12)	22.4% (15)	67
Total		**10668**	**10725**	**10627**	**10408**	**10545**	**52973**

Supplement 1- 5 Distribution of the percentage of DAs within each quintile of Canada wide SES index according to province and territory ($p<0.001$ using Pearson chi-square), absolute numbers of DAs are indicated in brackets. (AB=Alberta, BC=British Columbia, MB=Manitoba, NB=New Brunswick, NL=Newfoundland and Labrador, NS=Nova Scotia, NT=Northwest Territories, NU=Nunavut, ON=Ontario, PE=Prince Edward Island, QC=Quebec, SK=Saskatchewan, YT=Yukon)

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