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Title: Application of a global environmental equity index in Montreal: diagnostic and further implications

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Abstract

Urban living environments are known to influence human well-being and health. The literature on environmental equity focuses especially on the distribution of nuisances and resources, which, because of the unequal spatial distribution of different social groups, leads to an increased exposure to risks or to less access to beneficial elements for certain populations. Little work has been done on the multidimensionality of different environmental burdens and the lack of resources in some urban environments. This paper has two main objectives. The first objective is to construct an environmental equity index that takes into consideration seven components of the urban environment (traffic-related pollutants, proximity to major roads and to highways, vegetation, access to parks, access to supermarkets, and the urban heat island effect). The second objective is to determine whether groups vulnerable to different nuisances—namely, individuals under 15 years old and the elderly—and those who tend to be located in the most problematic areas according to the environmental justice literature—i.e. visible minorities and low-income populations—are affected by environmental inequities associated with the application of the composite index at the city block level. The results obtained by using four statistical techniques show that, on the Island of Montreal, low-income persons and, to a lesser extent, visible minorities are more frequently located in city blocks close to major roads, and with higher concentrations of NO_2 and less vegetation. Finally, the environmental equity index is significantly lower in areas with high concentrations of low-income populations in comparison with the wealthiest areas.

Keywords

Environmental equity, GIS, Deprivation, Nuisances and Urban resources

1. Introduction

The central principle of environmental justice is that all individuals in a given society, regardless of their particular characteristics, have the right to live in a healthy environment with certain basic territorial resources (distributional equity), as well as the right to participate in the process of formulating laws, policies and environmental regulations (decisional equity or procedural fairness). One of the most often examined dimensions in the environmental justice literature is environmental equity. The literature on environmental equity focuses especially on the distribution of nuisances and urban amenities, which, because of the unequal spatial distribution of different social groups, leads to an increased exposure to risks or to less access to beneficial elements for certain populations according to their socioeconomic status, their age or their ethnic origin. One current view associated with environmental equity can be defined as follows: "Environmental justice policies seek to create environmental equity: the concept that all people should bear a proportionate share of environmental pollution and health risk and enjoy equal access to environmental amenities" (Harner et al. 2002). An overview of the literature on distributional equity enables us to distinguish between two main types of studies: those that are concerned with nuisances (various sources of pollution, proximity to hazardous waste sites, etc.), and those that concentrate on urban resources deemed to be beneficial (proximity to major urban amenities, essential businesses, vegetation, and so on). But most of these studies only consider one aspect of the urban environment at a time (i.e. air pollution, noise pollution, or proximity to supermarkets, parks, etc.). This article intends to analyze the relationships between the distribution of various populations and several aspects of the Montreal urban environment, in focusing on both nuisances and urban resources. It also intends to create a composite index that will combine these various elements. This combined analysis of both positive and negative aspects will allow us to determine whether certain populations are concentrated in areas characterized by both their close proximity to urban nuisances and their distance from beneficial resources and other positive elements.

Or will a more nuanced profile emerge from our results, stemming from the cumulative analysis of both negative and positive aspects of the urban environment?

The article is organized as follows. We first provide a brief review of the literature in concentrating on the seven components of the urban environment that we have selected and in emphasizing either their respective benefits or their negative effects. Three elements support the selection of each component. Firstly, each of the related datasets was available for the totality of the study area. Secondly, each of these components is individually associated with a potential increase in various risks to human health (for example, the risk of cancer). Thirdly, we have considered components of the urban environment that have been recently studied in the environmental equity literature.

We then explain the methods used to measure each of these components of the urban environment. Finally, we employ various statistical tests to evaluate environmental equity in order to determine whether any of the four population groups that show either particular vulnerabilities to the selected elements or tend to live in lower-quality environments are overrepresented in areas with fewer urban resources and with significantly higher levels of nuisances.

2. Review of the literature

The first studies in the environmental equity stream, carried out in the United States in the 1980s, found that African-American and low-income populations were overrepresented in areas containing various sources of environmental nuisances (Bowen 2002; Payne-Sturges and Gee 2006). More recent studies performed in Sweden (Chaix et al. 2006), New Zealand (Pearce, Kingham, and Zawar-Reza 2006), the United Kingdom (Briggs, Abellan, and Fecht 2008) and Canada (Crouse, Ross, and Goldberg 2009) have shown that low-income populations are likely to live in areas that are more polluted from various sources compared with the environments where wealthier people live. Low-income populations are also said to be more vulnerable to the negative effects of their environment because of their economic insecurity (O'Neill et al. 2003). Various factors have been pinpointed to explain the high levels of nuisances in especially deprived urban areas, such as the dynamics of the housing market (Been 1994), the urban planning institutional framework in effect (zoning regulations) (Maantay 2001), and procedural unfairness, that is, certain groups' lack of representation in decision-making processes (Morello-Frosch et al. 2002).

A number of components of the urban environment have been considered in environmental equity studies. The first studies concentrated on the socioeconomic profile of residential areas around hazardous waste disposal and storage sites in the United States (Bullard 1983; GAO 1983; UCC 1987). Some of the more recent environmental equity studies have expanded their area of concern by looking at new population groups (Walker 2009, 2011) and at the spatial distribution of other components of the urban environment, such as parks (Boone et al. 2009; Maroko et al. 2009), vegetation (Landry and Chakraborty 2009) and access to supermarkets (Walker, Keane, and Burke 2010). This section of the article focuses on the components of the urban environment that are most often examined in the environmental equity literature, in emphasizing either their positive or negative effects and in considering the population groups that are most likely to live in the environments where such elements are concentrated.

2.1 Environmental nuisances

Residential proximity to major traffic arteries and the concentrations of various road transportation-related pollutants clearly have effects on human health. It has been determined that the concentrations of air pollutants and the levels of road traffic noise generated by major traffic arteries are highest when less than 200 meters from the source and then gradually decline as the distance from the source increases (Brugge, Durant, and Rioux 2007; Rioux et al. 2010; Zhu et al. 2002). A number of studies have moreover indicated that people living less than 200 meters from a highway or major road with a daily traffic volume of tens of thousands of vehicles are more likely to develop cardiovascular illnesses (Brugge, Durant, and Rioux 2007), lung disease (Gauderman, Vora, and McConnell 2007) and problems with asthma (Jerrett, Shankardass, and Berhane 2008). The first studies in the United States in the environmental equity stream also showed that low-income populations are more likely to live near major traffic arteries (Gunier et al. 2003; Houston et al. 2004). Similarly, high concentrations of road transportation-related pollutants such as NO_2, CO, NO_x, and $PM_{2.5}$ and PM_{10} particles can lead to an increase in cardiopulmonary disease (Brauer et al. 2002; Fan et al. 2008; Yorifuji et al. 2013), heart problems (Adar et al. 2007; Peters et al. 2000) and cognitive difficulties (Power et al. 2011). A higher prevalence of lung cancers has also been associated with high concentrations of NO_2 (Vineis et al. 2006) and PM particles (Choi, Inoue, and Shinozaki 1997).

It was subsequently shown that lower-income households are more often located in environments that are more polluted by road transportation than higher-income households in the United States (Morello-Frosch, Pastor, and Sadd 2001; Grineski 2007; Grineski et al. 2015). Similar results have also been obtained in Canada (Carrier et al. 2014; Crouse, Ross, and Goldberg 2009; Jerrett et al. 2007; Sider et al., 2013), the United Kingdom (Briggs, Abellan, and Fecht 2008; Mitchell 2005; Mitchell and Dorling 2003), New Zealand (Kingham, Pearce, and Zawar-Reza 2007), Germany (Schikowski et al. 2008), Finland (Rotko et al. 1999), France (Havard et al. 2009) and Norway (Næss et al. 2007). However, the link between air pollutant levels and the distribution of ethnic or racial groups seems to be less clear, and tends to vary in different geographic contexts (Pastor, Sadd, and Hipp 2001; Ringquist 1997). In the United States, Chakraborty (2009), Pastor et al. (2001) and Grineski et al. (2007) found significant and positive relationships between the proportions of African Americans and Hispanics and air pollutant concentrations in Tampa Bay, Los Angeles and Phoenix respectively. More recently, Grineski et al. (2015) and Chakraborty et al. (2014) also found that neighborhoods in Houston characterized by a higher presence of Hispanic residents and a lower percentage of homeowners faced a significantly greater exposure to both chronic and acute pollution risks. In Miami, Grineski et al. (2013) determined that Cuban and Colombian neighborhoods were affected by a significantly increased cancer risk from vehicular air pollution. For their part, Chakraborty et al. (2016) and Collins et al. (2015) found that the risk burdens from vehicular air pollution in Miami were higher for Hispanics of Cuban origin and unemployed people. However, studies performed in Canada have obtained contradictory results, which, it should be noted, are based on different variables related to immigration than those used in the U.S. studies. In Montreal, a positive and significant relationship was observed between the proportion of visible minorities and nitrogen dioxide (NO_2) concentrations (Carrier et al. 2014; Crouse, Ross, and Goldberg 2009). In Toronto, on the other hand, the results of Buzelli and Jerrett (2007) showed a significant and negative relationship between the percentage of recent immigrants and NO_2 concentrations. Older people and children, for their part, have been found to be vulnerable to negative elements in their environment when the levels of these elements exceed certain thresholds. Individuals under 15 years old are at greater risk of developing pulmonary disease and childhood cancers and of having delayed cognitive development when exposed to high levels of air pollutants in their immediate environment (Brugge, Durant, and Rioux 2007; Rioux et al. 2010). A number of factors explain this increased vulnerability: their organs and nervous systems are not fully developed (Bolte, Tamburlini, and Kohlhuber 2010); they breathe in more air per unit of body mass (Landrigan, Rauh, and Galvez 2010); and they spend a great deal of time in their immediate environment. People aged 65 and over are also physiologically vulnerable to air pollution as their immunity to illnesses may be reduced, particularly due to the aging of their vital organs (Pawelec 2006).

High summertime temperatures can also cause various health problems for populations living in areas where this situation is especially marked (Frumkin et al. 2008; Kovats and Hajat 2008; O'Neill et al. 2009; Patz et al. 2005; Ebi, Kovats, and Menne 2006). From a physiological viewpoint, young children and the elderly have been found to be more vulnerable to high temperatures in summer (Kovats and Hajat 2008). In addition, mortality risks for vulnerable people are greater in sectors with the highest temperatures (Gabriel and Endlicher 2011; Smargiassi et al. 2009). One study in California also noted that this phenomenon seemed to be intensified in areas with high concentrations of low-income individuals and visible minorities (Shonkoff et al. 2011). With the aim of reducing the negative effects of high temperatures, initiatives have been undertaken, particularly in New York, to create more green spaces in areas with high proportions of low-income and visible minority populations (Rosenzweig et al. 2009).

2.2 Distribution of urban resources found to be beneficial

In environmental equity studies that look at positive elements in the urban environment, green spaces, or vegetation, are often highlighted. In urban areas in particular, green spaces foster the sequestration of air pollution (Akbari 2002; Nowak, Crane, and Stevens 2006) and the reduction of ambient temperatures (Jensen and Gatrell 2009) and ambient noise. In terms of people's well-being and social benefits, various authors from a number of disciplines note that the presence of vegetation helps to lower stress levels and contributes to the social integration of the elderly, children and adolescents, especially in multiethnic urban areas (Cackowski and Nasar 2003; Castonguay and Jutras 2009; Seeland, Dübendorfer, and Hansmann 2009). Some North American studies have shown that low-income populations are more likely to live in environments where there is little vegetation (Landry and Chakraborty 2009; Pham et al. 2013; Pham et al. 2012; Tooke, Klinkenber, and Coops 2010).

Parks have been the focus of particular interest given the benefits that they offer for people's well-being and in terms of the practicing of physical activities (Maroko et al. 2009; Boone et al. 2009). Parks also have positive effects on the psychological and physiological level, especially in reducing stress and lowering blood pressure (Hartig et al. 2003; Mitchell and Popham 2008; Van den Berg, Hartig, and Staats 2007). Concerning the distribution of parks in urban environments, some studies have shown that low-income populations and visible minorities tend to be located in areas with few or no parks (Sister, Wolch, and Wilson 2010; Wolch, Wilson, and Fehrenbach 2005; Abercrombie et al. 2008).

The distributional analysis of the access to food is another component of the urban environment that has been considered in studies examining the quality of such environments. People's immediate access to food can have an impact on whether or not they adopt healthy eating habits (Cummins and Macintyre 2002; Morland et al. 2002; Wrigley, Warm, and Margetts 2003). Several authors have demonstrated the existence of food deserts in a number of North American cities: that is, areas with both relatively high concentrations of disadvantaged people and very little access to grocery stores where people can obtain fresh, healthy, and affordable food (Wrigley 2002; Zenk et al. 2005; Walker, Keane, and Burke 2010). On the other hand, one Montreal study found that there were no food deserts in that city (Apparicio, Cloutier, and Shearmur 2007).

2.3 The combination of several elements in the urban environment

Numerous studies have investigated associations between the spatial distribution of one particular element in the urban environment (pollution, noise, vegetation, etc.) and the distribution of population groups in a given area. The combined analysis of several elements of the urban environment has been attracting growing interest in the environmental equity field, as the combined action of various nuisances and the lack of certain urban resources in a given environment can have negative impacts on the residents' health and well-being (Evans and Kantrowitz 2002; Pearce et al. 2010; Walker 2011). This concern is also in line with some of the most recent topics of interest in environmental equity studies. The work of Pearce et al. (2010) has been especially influential in this regard, in terms of their development of a Multiple Environmental Deprivation Index ($MEDI_x$), set up on the level of wards in the United Kingdom and based on several environmental indicators (air pollution, climate, industrial facilities, UV radiation and greenspace). This approach has also been applied by Pearce et al. (2011) and Richardson et al. (2013) in New Zealand and Scotland respectively. In the Scottish case, Richardson et al. (2013) developed a similar indicator, the South Lanarkshire Index of Multiple Environmental Deprivation (SLIMED), which they calculated for the residential areas of people who had been admitted to hospital for respiratory problems. In New Zealand, the $MEDI_x$ was also statistically related to data on people who had died of breast cancer, cardiovascular disease and respiratory problems (Pearce et al. 2011).

3. Research objectives

The general objective of this research is to determine whether individuals under 15 years old, people aged 65 and over, visible minorities or low-income populations on the Island of Montreal are more likely to live in areas characterized by a combination of several nuisances (greater presence of NO_2, longer lengths of sections of major traffic arteries, and higher temperatures during heat waves) and fewer beneficial elements in the urban environment (presence of vegetation, parks and supermarkets). The first specific objective is to construct an environmental equity index comprised of seven components of the urban environment, both negative and positive, on a fine spatial scale: that is, on the scale of inhabited city blocks. The second specific objective is to arrive at an environmental equity assessment by considering each component on its own, as well as the global index of the quality of the urban environment resulting from the combination of these various components.

4. Methodology

4.1 Definition of the study area and population groups considered

The study area is the Island of Montreal, which, in 2006, had 1.62 million inhabitants and covered 499 km^2 (Figure 1). We selected four population groups: 1) people in low-income households, 2) persons stating that they are members of a visible minority, 3) young people under 15 years old, and 4) people aged 65 and over. We are thus interested in two groups that are often studied in the environmental equity field: that is, low-income individuals and members of visible minorities. The variable of visible minorities refers to all non-white individuals, except Aboriginal people: that is, the Canadian census categories of Chinese, South Asian, Filipino, Latin American, Black, Arab, Korean, Japanese, South East Asian, West Asian and South Sea Islander (Statistics Canada 2006). The categories of “African-

American or Hispanic populations" (properly exist in the Canadian census) / can be associated with the categories of "Black" and "Latin American" people in the Canadian census. However, the proportions of "Black" and "Latin American" people are fairly low in Montreal. Moreover, these proportions are significantly lower in Montreal (4.7% and 2.1%) in comparison with the United States (12.6% and 16.3%). In order to do this, we have considered that the "visible minority population" is more relevant in the Canadian context.

Our study also investigates two groups with particular vulnerabilities to negative elements in the urban environment, as we mentioned above: namely, the elderly and children. The numbers of these groups and of the total population were taken from the 2006 Statistics Canada census[1] on the level of the dissemination area: that is, the finest spatial unit of analysis, in which some 400 to 700 people live. Checking for variations in the urban environmental indicators requires that analyses be performed at a fine geographic scale, as pollution levels, for example, can vary greatly on the scales of a neighborhood, a census tract, or a dissemination area. We therefore decided to use the city block as the spatial division from which all the indicators and the variables relating to the four groups studied were generated. It should however be noted that Statistics Canada only provides data on the total population on the level of the city block. To deal with this issue, we estimated the numbers of each of the groups studied as follows, as recently proposed by Pham et al. (2012):

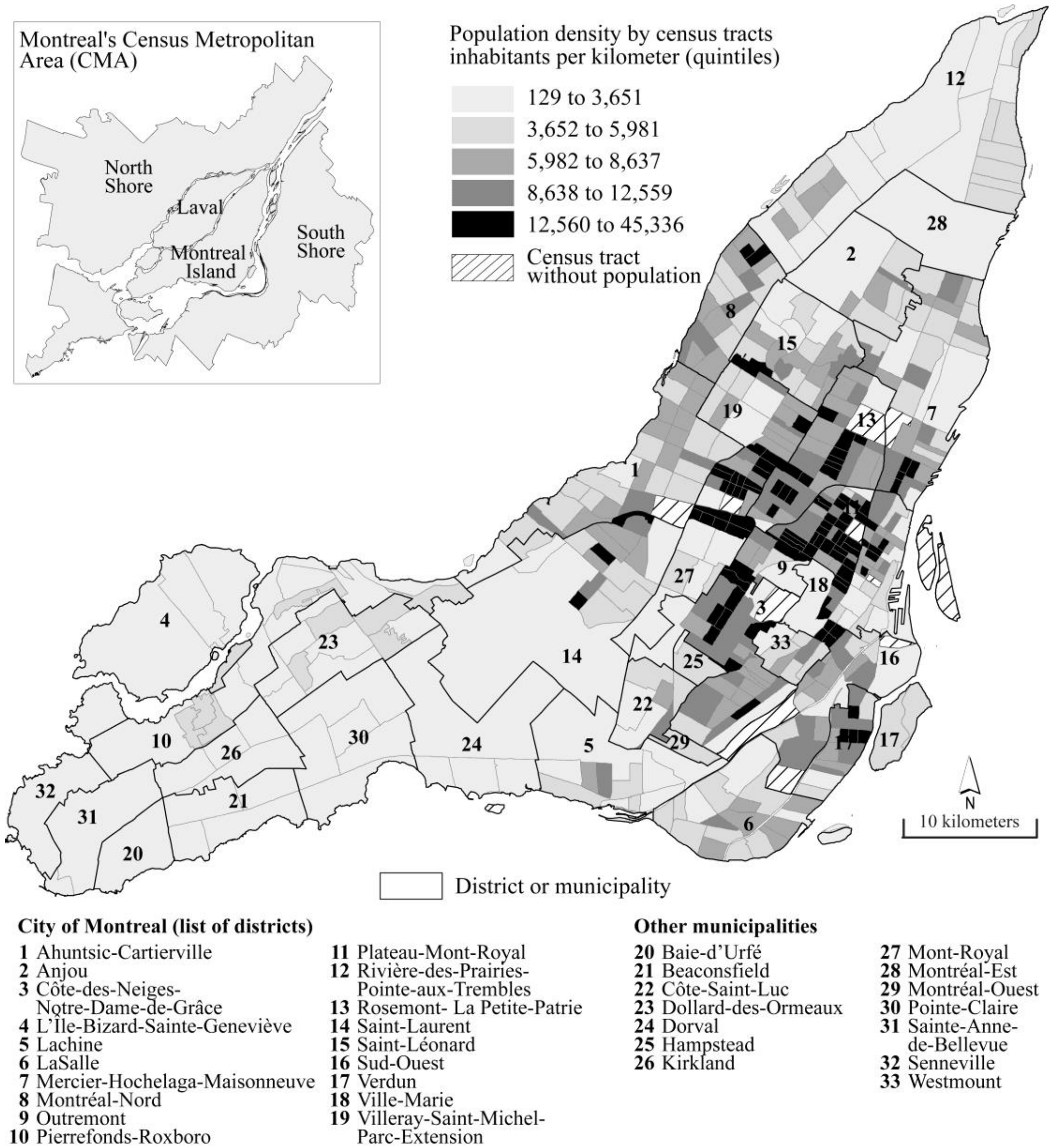
$$t_i = t_a \frac{T_i}{T_a}$$

where t_i represents the estimated population of the group (low-income individuals, for example) in the city block, t_a is the group's population in the dissemination area, and T_i and T_a are the total populations

[1]Data from the 2006 census were used given the lack of specific information on the numbers of these groups on the level of the dissemination area in the 2011 National Household Survey.

in the block and the dissemination area respectively. Descriptive statistics on the estimated percentages of the populations of each group are shown in Table 1.

< Figure 1 Location of the Island of Montreal within the metropolitan area >



<Table 1 Univariate statistics for the four groups studied at the city block level>

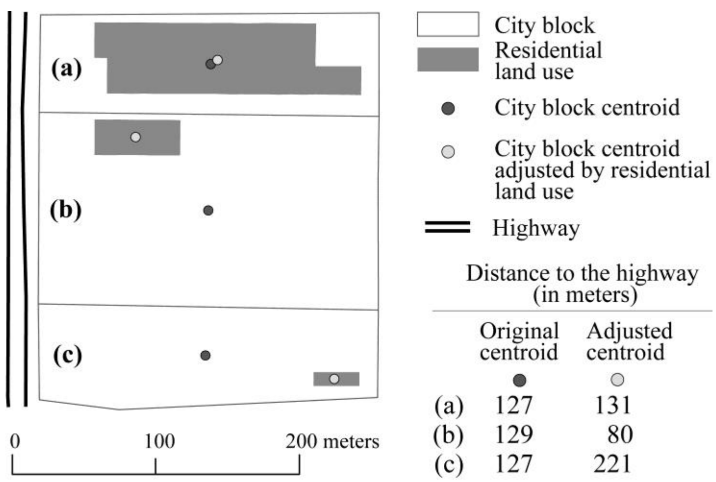
Group	N	Mean	S.D	Median	Max
0-14 years old (%)	10,290	15.86	5.34	15.91	41.38
65 years old and over (%)	10,290	14.98	8.35	13.95	95.15
Visible minorities (%)	10,290	21.20	16.51	17.44	96.60
Low-income population (%)	10,290	23.88	16.18	21.27	94.42

S.D : Standard Deviation

4.2 Calculation of the urban environmental indicators by city block

We then performed calculations for seven indicators to obtain a global measurement of the urban environment in the 10,290 inhabited city blocks in the study area. In each case, the values were calculated using the city block centroid adjusted by residential land use in order to arrive at the most accurate measurements possible. An example is given in Figure 2, which shows how the number of meters of sections of highway variation according to the utilization of the original centroid or the centroid adjusted by residential land use.

<Figure 2. Measurement of the number of meters of sections of highway using the city block centroid adjusted by residential land use >



4.2.1 NO_2 concentrations

For this indicator, we used a set of data developed by a team of McGill University researchers who had measured NO_2 concentrations during the months of December 2005, May 2006 and August 2006 at 133 locations on the Island of Montreal, sampled according to population density and proximity to major traffic arteries (Crouse, Goldberg, and Ross 2009). This technique involves constructing a regression equation by using the observations at the 133 points sampled, with the concentration of a pollutant (NO_2, for example) as the dependent variable and a series of independent variables, including the proximity to major traffic arteries, the length of sections of road near the monitoring location, traffic flows, residential density, the presence of industrial or commercial facilities or parks, etc. (Crouse, Goldberg, and Ross 2009; Ryan and LeMasters 2007). A pollution map for the entire Island of Montreal was then generated by using land-use regression (Crouse, Goldberg, and Ross 2009). This map was subsequently used to calculate mean NO_2 values for the 10,290 Montreal city blocks analyzed.

4.2.2 The length of sections of highway and of major traffic arteries

To construct this second indicator, we measured the lengths, in meters, of sections of major roads (except highways) in buffer zones within a 200-meter radius created around the city block centroids adjusted by residential land use, that is, the lengths of major traffic arteries—collector and arterial roads and expressways. We also repeated this exercise in order to measure the length of sections of highway within a 200-meter radius of all city blocks in the study area. The distance of 200 meters was chosen, as the effects of air pollutants are rarely felt beyond this distance (Brugge, Durant, and Rioux 2007). These operations were carried out in ArcGIS 10.1 (ESRI, 2011).

4.2.3 Temperature measurement during summer heat waves

We obtained ground temperature data for the territory of the Island of Montreal for the date of June 27, 2005 from a series of Landsat 5TM-type satellite images. Once the data had been collected, atmospheric corrections were made by using the dark object subtraction method to adjust the surface temperature. The following article can be consulted to obtain more information on the mathematical formulae used to calculate the temperature (Chander, Markham, and Helder 2009). Using the temperature matrix image we then estimated the mean ground temperature in all the inhabited city blocks.

4.2.4 The proportion of vegetation in the city block

Vegetation cover on the Island of Montreal was obtained from high-resolution QuickBird-type satellite images taken in September 2007, at a resolution of 60 centimeters. The object-oriented approach, applied in eCognition 8.1 software, was used to classify the different types of vegetation (Pham et al.

2012). A detailed description of the classification method can be found in Pham et al. (2011). The total proportion of the city block covered by vegetation was ultimately calculated for the entire study area.

4.2.5 Surface area of accessible parks and access to food

We then calculated the total surface area (in hectares) of accessible parks located less than 500 meters from each city block centroid adjusted by residential land use in the study area. The distance of 500 meters was selected in the context of the Island of Montreal to measure the accessibility of urban parks. This distance has already been used by other authors such as Apparicio et al. (2013), Apparicio et al. (2010) and Apparicio and Seguin (2006) in Montreal. In terms of the access to food, a database containing a total of 169 supermarkets from the main large grocery store chains was used. Although supermarkets do not make up the entirety of the food supply, it is noteworthy that, on the Island of Montreal, nearly 80% of all food-related transactions are conducted in this type of store (Bertrand 2002) and that the latter contain two to four times more “heart-healthy” foods compared with neighborhood grocery stores or convenience stores (Morland et al. 2002). A distance of 1,000 meters was considered to measure the number of supermarkets around each city block. We selected the distance of 1,000 meters since other studies on “food deserts” in the Canadian context have used the same distance (Apparicio et al. 2007; Smoyer-Tomic et al. 2006). We used network distance to calculate the accessibility of parks and supermarkets by applying the Network Analyst extension of ArcGIS 10.1 software. We thus obtained the number of supermarkets located less than 1,000 meters, via the network of streets, from all inhabited city blocks, as well as the total number of hectares of accessible parks less than 500 meters away.

4.2.6 Global environmental equity index

A z-score was calculated for each of the seven indicators. We then added up all the positive elements (vegetation, parks and supermarkets) and subtracted the nuisances (NO_2, highways, major roads and temperature) for the 10,290 city blocks in the study area. A similar weight was accorded to each component of the urban environment. The following equation shows how we ultimately calculated the global index at the level of city block *i* using the z-score values for each of the variables:

$$Index_i = \sum Vegetation_i + \text{Parks}_i + \text{Supermarkets.}_i - \text{NO2.}_i - \text{Highways}_i - \text{Major roads}_i - \text{Temperature}_i$$

4.3 Statistical tests used

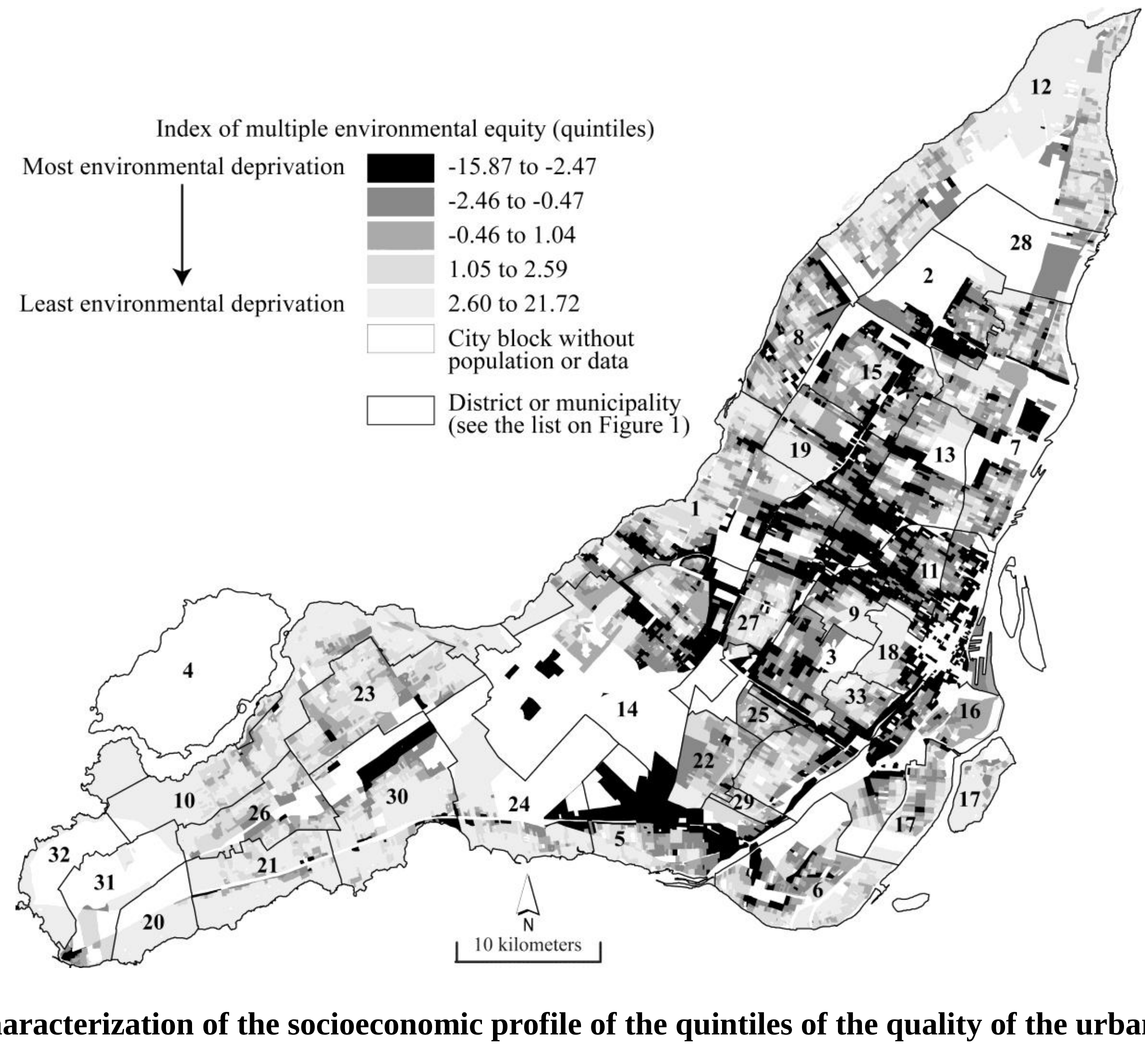
Once the indicators had been generated on the scale of city blocks, we used various statistical tests to check for the existence of environmental inequities on the level of each component of the urban environment for our four target groups (Briggs, Abellan, and Fecht 2008; Carrier et al. 2014; Pham et al. 2012). These statistical tests are as follows: 1) a T-test for the extreme quintiles (quintile 1 compared with quintile 5 of the percentage of low-income individuals, for example). These analyses were performed in SAS version 9.2 (SAS Institute Inc.). Finally, two spatial regressions (spatial lag and spatial error models) were carried out to control for spatial dependence (Anselin 2005). The dependent variables in this model refer to each of the indicators of the urban environment and to their cumulative effect, whereas the independent variables refer to the proportions of each of the four population groups studied. Spatial regression models are often used in environmental equity studies, especially in regard to air pollution (Carrier et al. 2014; Chakraborty 2009), road traffic noise (Carrier, Apparicio, and Séguin 2016; Nega et al. 2013), and vegetation (Pham et al. 2013; Pham et al. 2012). The spatial regression analyses were computed in R by using the *spdep* library (Bivand 2013).

5. Results

5.1 Global index of the quality of the urban environment, and the mapping of this index

The global index of the quality of the urban environment was first calculated for each of the 10,290 inhabited city blocks on the Island of Montreal. The index values range from -15.87 (the least advantageous situation) to 21.72 (the most advantageous situation). Figure 3 shows that the most advantaged areas are concentrated at the eastern and western ends of the Island of Montreal, on l'Îledes-Sœurs, and in certain areas around Mount Royal (Westmount, Outremont and part of the downtown sector). Conversely, the areas with the lowest index values, shown in black, are mostly located along highways, near the central business district (CBD), in central boroughs (Plateau Mont-Royal, Rosemont–La Petite-Patrie and Villeray–Saint-Michel–Parc-Extension) and in the Côte-des-Neiges district and part of the borough of Saint-Laurent.

< Figure 3 Classification of city blocks by quintiles based on the value of the global index of the urban environment >



5.2 Characterization of the socioeconomic profile of the quintiles of the quality of the urban environment

5.2.1 Comparison of the means between the extreme quintiles of the proportion of the groups

The aim of the second analysis was to compare the means of the extreme quintiles of the proportions of each of the groups in the city blocks in the study area by using a T-test, an exercise that had already been performed by Kingham et al. (2007) and Briggs et al. (2008), among others. Table 2 indicates that the environmental inequities previously observed for low-income populations and members of visible minorities are even more pronounced in this case. For example, city blocks in areas with high concentrations of poverty (Q_5) have a vegetation cover of only 21.88%, compared with 48.99% for blocks in the first quintile of poverty (Q_1), that is, a difference of 27.11 %. But we need to qualify our observations here, as there is a significantly greater access to food in areas with high poverty levels. We find the opposite situation for city blocks with high proportions of individuals under 15 years of age and people aged 65 and over in regard to all of the indicators examined, except for the lengths of sections of highway. Moreover, in areas with high concentrations of these two groups, there is also more limited access to supermarkets, with mean values of less than 1.

< Table 2 Comparison of the indicator values associated with the first and last quintiles of the groups studied >

		NO_2 (ppb)				**Highways (meters)**			
		Mean		Difference		Mean		Difference	
First quintile (Q1)	**Last quintile (Q5)**	**Q1**	**Q5**	**Diff**	**P**	**Q1**	**Q5**	**Diff**	**P**
0-14 years old	0-14 years old	13.08	10.92	2.16	0.000	39.99	39.62	0.38	0.948
65 years old and over	65 years old and over	12.41	11.68	0.74	0.000	47.96	51.21	-3.26	0.611
Visible minorities	Visible minorities	11.21	12.49	-1.27	0.000	21.90	70.83	-48.92	0.000
Low-income population	Low-income population	10.23	13.28	-3.05	0.000	25.37	56.26	-30.89	0.000
		Major roads (meters)				**Temperature (C^o)**			
0-14 years old	0-14 years old	708.6	368.1	340.5	0.000	32.46	31.28	1.18	0.000
65 years old and over	65 years old and over	580.5	489.9	90.52	0.000	32.48	31.47	1.01	0.000
Visible minorities	Visible minorities	423.9	587.3	-163.5	0.000	31.02	32.58	-1.55	0.000
Low-income population	Low-income population	308.7	687.9	-379.2	0.000	30.43	32.94	-2.51	0.000
		Park area (hectares)				**Vegetation cover (%)**			
0-14 years old	0-14 years old	6.16	5.32	0.84	0.000	24.29	41.08	-16.80	0.000
65 years old and over	65 years old and over	5.91	5.79	0.12	0.486	26.75	35.02	-8.28	0.000
Visible minorities	Visible minorities	5.73	4.98	0.76	0.000	38.61	28.97	9.64	0.000
Low-income population	Low-income population	5.64	5.27	0.37	0.025	48.99	21.88	27.11	0.000
		Supermarkets within one km				**Global index**			
0-14 years old	0-14 years old	1.48	0.55	0.92	0.000	-1.27	0.97	-2.24	0.000
65 years old and over	65 years old and over	1.13	0.89	0.24	0.000	-0.72	0.18	-0.91	0.000
Visible minorities	Visible minorities	0.81	1.18	-0.37	0.000	1.01	-1.19	2.20	0.000
Low-income population	Low-income population	0.33	1.47	-1.13	0.000	2.12	-1.91	4.03	0.000

5.2.2 Spatial regressions

The diagnostic of the spatial dependence of the ordinary least squares (OLS) models is shown in Table 3. The Moran's I values calculated on the residuals show a problem of spatial dependence in all the

OLS models. Consequently, and due to a lack of space, the coefficients of these models are not presented here. For each of the models, the values of the Lagrange Multiplier and Robust Lagrange Multiplier tests are compared in order to choose either a spatial lag model or a spatial error model, as recommended by Anselin (2005).

<Table 3. Diagnostic of the ordinary least squares regressions of the indicators>

	NO_2	Highways	Major roads	Temperature (C^{o})	Parks	Vegetation	Supermarkets	Global index
OLS diagnostic								
R^2	0.227	0.011	0.173	0.233	0.003	0.329	0.187	0.234
F statistic	756.4***	27.84***	536.1***	782.3***	8.8***	1,262.0***	593.1***	784.2***
AIC	47,369	136,475	151,247	42,197	-126,646	85,611	29,587	50,873
Diagnostic for spatial dependence of the OLS models								
Moran's I (error)[a]	0.819***	0.549***	0.533***	0.516***	0.804***	0.452***	0.796***	0.658***
LM (lag)	15,541***	7,547***	7,508***	3,620***	15,894 ***	5,868***	15,911***	10,923***
LM (error)	16,552***	7,536***	7,423***	7,014***	15,927***	5,027***	15,626***	10,660***
RLM (lag)	355.9***	15.6***	204.8***	37.9***	11.3**	850.5***	510.0***	455.1***
RLM (error)	1366.6***	5.0*	119.6***	3431.7**	44.4***	8.876**	224.9***	192.2***

[a] Moran's I is computed with a row standardized Queen matrix; P is obtained with a randomization procedure (999 permutations).
LM: Lagrange Multiplier. RLM: Robust Lagrange Multiplier. * $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

In general, the results of the spatial lag and spatial error models confirm the results of the bivariate analyses performed (Table 4). On the one hand, people under age 15 and individuals aged 65 and over are in a more favorable situation. We find significant negative coefficients for the indicators relating to air pollution, the presence of major traffic arteries and temperature, and a positive coefficient for the vegetation indicator. This means that when the proportion of each of these groups increases, the concentration of these pollutants decreases. However, these two groups are associated with a more limited number of supermarkets within a one-kilometer radius, but these coefficients, although clearly negative and significant, are nonetheless quite low. This means that, all other things being equal, the more the proportions of under-15-year-olds and people aged 65 and over increase in a city block, the less NO_2 and fewer major traffic arteries and supermarkets there are, and the more vegetation there is. On the other hand, we find positive and significant coefficients for NO_2, the presence of major roads and temperature associated with the proportions of low-income individuals and visible minorities, and negative coefficients for vegetation, whereas the coefficients for parks are not significant for either of these two groups. It is also noteworthy that, in most cases, the coefficients are higher for low-income populations than for visible minorities. These results show that the areas with high concentrations of low-income individuals or visible minorities do not always combine all the disadvantages. There are more supermarkets in these areas, and no, or only slight, disadvantages in terms of the surface areas of nearby parks. Regarding the coefficients associated with the global index, they are positive and significant for people under 15 or those aged 65 and over, whereas they are negative and significant for low-income populations and visible minorities. Overall, we can say that, aside from the nuances that we have highlighted in certain cases, the environments in areas with high concentrations of low-income individuals and visible minorities are less favorable for people's health and well-being.

<Table 4 Spatial lag and spatial error regressions of the indicators>

Dependent variable	NO_2	Highways	Major roads	Temperature	Parks	Vegetation	Supermarkets	Global index
Constant	12.332***	4.259	202.716***	32.528***	0.487***	6.43***	0.201***	-0.450***
	(93.44)	(0.70)	(14.76)	(62.57)	(18.38)	(10.60)	(9.41)	(-5.97)
0-14 years old (%)	-0.020***	-0.204	-6.964***	-0.043***	0.009	0.407***	-0.008***	0.039***
	(-8.98)	(-0.78)	(-12.37)	(-9.17)	(1.04)	(15.46)	(-8.89)	(10.55)
65 years old and over (%)	-0.001	0.068	-1.576***	-0.025***	0.004	0.161***	-0.002***	0.017***
	(-0.45)	(0.44)	(-4.83)	(-10.21)	(0.86)	(10.63)	(-4.24)	(8.15)
Visible minorities (%)	0.003***	0.355***	0.904***	0.010***	0.004	-0.038***	0.001*	-0.010***
	(3.19)	(4.10)	(5.02)	(5.99)	(0.12)	(-4.63)	(2.31)	(-8.38)
Low-income pop. (%)	0.002*	0.086	1.528***	0.009***	-0.003	-0.160***	0.001***	-0.012***
	(2.02)	(0.99)	(8.23)	(5.90)	(-1.07)	(-18.08)	(4.85)	(-9.51)
Lambda (error model)	0.941	-	-	0.777	0.890	-	-	-
Rho (lag model)	-	0.806	0.774	-	-	0.668	0.890	0.817
AIC	28,630	129,860	144,760	36,223	-140,670	80,858	13,433	41,467
AIC difference (from OLS model)	-18,739	-6,610	-6,490	-5,974	-14,020	-4,753	-16,154	-9,406
Moran's I (error)[a]	-0.061	-0.017	-0.015	-0.032	-0.030	-0.066	-0.072	-0.036

Note: coefficients with *z* values in parentheses.
[a] Moran's I is computed with a row standardized Queen matrix; P is obtained with a randomization procedure (999 permutations).
* $p < 0.05$. ** $p < 0.01$. *** $p < 0.001$.

6. Discussion

6.1 Overview of the results and identification of explanatory factors

The results of the univariate and bivariate analyses show that low-income populations are likely to live in city blocks where there are greater NO_2 concentrations, more highways and other major traffic arteries, and significantly higher temperatures in the summer. Low-income populations and visible minorities also tend to live in city blocks with less vegetation and slightly fewer hectares of parks. The results of the spatial regressions are in keeping with these findings. They confirm that low-income individuals and, to a lesser extent, visible minorities are more likely to live in urban environments combining a number of nuisances (high temperatures, presence of major traffic arteries, higher NO_2 concentrations) and with fewer beneficial elements, such as vegetation. This explains the fact that these two groups live in blocks where there is a lower global environmental equity index. It should however be reiterated that these two groups have more access to supermarkets. This latter aspect can be explained by the geography of central areas in Canadian metropolitan regions, where, unlike some of their American counterparts, relatively high densities of services and amenities are concentrated, which tempers the environmental inequities found in regard to other elements of the urban environment (Bunting, Filion, and Priston 2002).

These results can be explained in particular by the residential geography of each of the groups studied. Low-income populations have been concentrated in the central neighborhoods of Montreal for the past several decades (Séguin, Apparicio, and Riva 2012) as well as near many sections of highway (Carrier et al. 2014). The high residential density of the central boroughs along with the greater concentrations of major traffic arteries in these residential areas mean that there are more transportation infrastructures and higher NO_2 levels, and less space available for vegetation, which in turn leads to higher temperatures in the summer. The combination of a number of negative elements in the urban environment can also result in a decline in property values and lower rents in these areas. In their description of built-up areas near the Metropolitan and Décarie expressways, Sénécal et al. (2000) note that these areas are mostly characterized by lower-value residential dwellings such as “walk-ups” or low-income housing (social housing). In the case of the Town of Mount Royal and Notre-Dame-de-Grâce areas, larger, lower-prestige residential buildings form a visual and noise barrier along the Metropolitan and Décarie expressways to protect the higher-value residential areas behind them

(Sénécal, Archambault, and Hamel 2000). But this situation is mitigated by the fact that residents of central neighborhoods on the Island of Montreal have better access to services, which compensates for the concentration of various negative elements (Apparicio, Cloutier, and Shearmur 2007; Apparicio and Séguin 2006).

Moreover, relatively large differences are found between the wealthiest residential areas (Q_1) and those with high levels of poverty (Q_5) with regard to the NO_2 indicators, major traffic arteries, and vegetation, as well as the global index. Certain planned municipalities on the Island of Montreal that were developed in the early twentieth century, namely, Outremont, Westmount and the Town of Mount Royal, and, a few decades later, Hampstead, were designed to maximize the space allotted for vegetation and to minimize automobile traffic (Poitras 2012). The urban form planned for these areas also meant that there was a lower-density road network, as traffic arteries in these municipalities were laid out according to the local topography or were designed to discourage through traffic, in contrast to the orthogonal network of streets in the central boroughs (Poitras 2012; Bérubé 2008). These neighborhoods are still inhabited today by a population with an income level that is much higher than the Montreal average. These historical factors related to urban planning provide, at least in part, another explanation for the differences observed in the geography of the global index of the quality of the environment between areas with low and high levels of poverty.

Visible minorities are also affected by environmental inequities. The high concentrations of this group in the densely inhabited sectors of Côte-des-Neiges and the Villeray–Saint-Michel–Parc-Extension borough contribute to the environmental inequities experienced in terms of air pollution and lack of vegetation. However, the inequities measured for visible minorities are not as great as those observed for low-income populations. This corroborates the findings of a number of studies examining various urban environmental indicators in Canada (Apparicio et al. 2010; Buzzelli and Jerrett 2004, 2007; Carrier et al. 2014; Pham et al. 2013; Pham et al. 2012). The significant presence of visible minorities in some western Island of Montreal municipalities and other less densely inhabited boroughs in the first-ring suburbs, characterized by fewer major traffic arteries, in part helps to explain the lower environmental inequities found for this group.

As for young people under 15 years of age, they tend to live in city blocks where there are fewer major roads and thus lower NO_2 levels. The proportion of under-15-year-olds has been declining considerably in the central boroughs since the 1960s, whereas it has substantially increased in suburbs at the eastern and western ends of the Island of Montreal (Séguin, Apparicio, and Riva 2012). These areas are characterized by their low urban density and higher proportion of vegetation, but also by a lower entropy index, as seen by the smaller number of supermarkets in sectors with high concentrations of individuals aged 14 and under. Finally, people aged 65 and over living on the Island of Montreal also enjoy an advantageous situation in regard to several of the urban environmental indicators considered. This may also be in part explained by their residential geography. Since 1981, this group has increasingly been located in first-ring boroughs such as Ahuntsic-Cartierville, Anjou and Saint-Léonard, whereas it is less often found in the central boroughs (Séguin et al. 2015). These first-ring suburbs are generally marked by lower residential densities and fewer major traffic arteries than in the central boroughs, so that there is more room for vegetation and green spaces.

6.2 Implications of use of the equity index in future planning actions

There are several implications linked to the use of the equity index that may be relevant for other North American cities. Firstly, the index could be used to quickly pinpoint city blocks where the quality of the environment is significantly lower than in the territory of a given urban area as a whole. Secondly, an analysis of the components that form the equity index makes it easier to identify elements that public authorities should pay particular attention to in order to improve the residents' quality of life. This type of index could prove to be especially useful for municipal actors in the sphere of urban planning, given that municipal authorities must often meet certain objectives of equity in the allocation of urban resources (municipal parks and urban vegetation) and in the management of certain environmental nuisances. Through their public policies and urban planning tools (zoning regulations), municipal authorities could, for example, set thresholds for particular elements of the urban environment, while establishing systematic monitoring measures to estimate the concentrations of air pollutants and to evaluate the presence of a sufficient quantity of municipal services and amenities across the territory as a whole. These urban planning objectives would be accompanied by an operational framework, including minimum thresholds for urban resources and maximum thresholds for environmental nuisances, for all the elements of the urban environment, which would be supported by specific interventions in high-risk areas should these thresholds not be met.

7. Research limitations

In terms of the main limitations of this research, it is first important to note that equal weight was given to each of the variables considered in constructing the global index, as had been done in earlier studies (Pearce et al. 2010; Pearce et al. 2011; Richardson et al. 2013). But this can be criticized, as one or another of the urban environmental indicators might have a more substantial impact on the health and well-being of the urban populations examined. This is, however, difficult to determine. Moreover, the global index is the result of the combined z-scores of the seven dimensions selected. The fact that a city block is in the first quintile of the global index, that is, it is among the 20% of city blocks with the lowest index, does not necessarily mean that the populations living there are located in highly problematic urban living environments. We did not in fact develop a threshold approach in the context of this article. For example, we could have systematically identified blocks where NO_2 concentrations were higher than the threshold established by the WHO, and then have performed the same type of analysis for each of the variables. So it may well be that some city blocks in the first quintile of the global environmental equity index clearly do not exceed the thresholds established for the pollutants considered, and are not completely lacking the positive elements highlighted in our study (vegetation, supermarkets and parks). In short, the approach developed in this article does not enable us to conclude that the fact of living in a city block with a low value for overall quality of the environment is problematic from the point of view of public health, and that interventions are necessary. Other studies need to be conducted to explore this issue.

8. Conclusion

The results show, on the one hand, that low-income populations and, to a lesser extent, visible minorities are more likely to be found in residential areas with higher concentrations of air pollutants and more major traffic arteries compared with the situation for the rest of the population. Residential densities and the denser road network in the environments where these two groups are concentrated leave little room for vegetation and produce more mineralized surfaces, which lead to high temperatures. These results corroborate the findings of a number of other studies in the environmental equity field that were identified in section 2. On the other hand, individuals under the age of 15 enjoy an advantageous situation in regard to most of the dimensions considered, while the situation is more or less the same, although slightly less positive, for people aged 65 and over.

Next, there are currently no specific thresholds established in municipal or provincial public policies for the elements of the urban environment that were considered in this study. It would thus be very pertinent for municipal and provincial authorities to take steps to systematically monitor air pollutant concentrations and the level of municipal services and amenities provided throughout the territory. Municipal authorities could thus develop an operational framework based on minimum thresholds (urban resources) or maximum thresholds (environmental nuisances) for all the elements of the urban environment in order to ensure that specific interventions could be carried out should these thresholds not be respected.

One future research avenue that could be explored would be to statistically relate each of the seven dimensions discussed in this study and the global environmental quality index to health data for people in the same study area. After controlling for individual socioeconomic variables and lifestyle choices associated with smoking or alcohol use, among other things, it would be a question of establishing the contribution of the characteristics of the urban environment to the incidence of various types of health problems. This type of analysis could be especially helpful in enabling us to accurately measure the influence of the environment on the development of socio-spatial inequalities in health.

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