Ambient air pollution concentration in Montreal and environmental equity: Are children at risk at school?

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A R T I C L E   I N F O

A B S T R A C T

The analysis of ambient air quality in the environments around elementary schools is an important issue, as children are at school for a large part of the day. This article has two objectives: first, to compare the proportion of major roads and NO_2 concentration levels in city blocks where there are schools with the situation in the rest of the Island of Montreal; and second, to see whether there are significant differences in these pollution indicators according to the levels of socioeconomic deprivation at these schools.

Montreal's 319 elementary schools were geocoded in a geographic information system (GIS). Two types of pollution indicators based on the types of roads and NO_2 concentrations were calculated within a 200-m radius of each city block centroid on the Island of Montreal and of the main building of each elementary school.

Elementary schools, regardless of their level of socioeconomic deprivation, are located in city blocks where there are fewer major roads than in, and generally similar concentrations of NO_2 to, the rest of the Island of Montreal. However, NO_2 concentrations near elementary schools are positively and significantly associated with levels of deprivation at these schools.

This study highlights an issue of environmental equity, in showing that students from socioeconomically disadvantaged backgrounds tend to attend elementary schools located in more polluted environments.

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1. Introduction

Pollutant emissions are one of the major pollutants in urban areas and affect people's quality of life on a number of levels (Briggs et al., 2008; Brunekreef and Holgate, 2002; Hoek et al., 2002). Air pollution also contributes to health inequalities, and the authorities must develop adequate social inclusion policies towards the most vulnerable populations to these pollutants. Vehicular exhaust is the main source of harmful particles that have a detrimental impact on health, especially nitrogen oxides (NO_x) (Cesaroni et al., 2008; Crouse et al., 2009a) and, to a lesser extent, carbon monoxide (CO) (Houston et al., 2004; Rioux et al., 2010). Recent observations in regard to NO_2 levels in the United Kingdom report that the spatial concentrations of this pollutant have stabilized in recent years. These observations could undermine the authorities' objective of reducing NO_2 concentrations in urban areas (Carslaw et al., 2011).

The highest concentrations of these pollutants are generally found within 200 m of highways and major roads (Brugge et al., 2007). Studies have shown that children are more vulnerable to the effects of high concentrations of various air pollutants due to the fact that their organs and nervous systems are not fully developed (Bolte et al., 2009) and that they inhale more air per unit of body mass (Landrigan et al., 2004), and because of their limited mobility, which tends to restrict them to their residential area (Day and Wager, 2010). A number of studies around the world have also shown that children who attend schools located less than 200 m from a major road, that is, in areas where traffic densities are high and where there are high levels of traffic-related pollutants, are more likely to develop problems associated with asthma and to have reduced lung function (Brunekreef et al., 1997; Clark et al., 2010; Gauderman et al., 2007; Jerrett et al., 2008; Kim et al., 2008). For example, Brunekreef et al. (1997) found that a residential location near major motorways in the Netherlands may lead to reduced lung function in children.

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The literature on environmental and social equity has focused on the health impacts of the spatial distribution of environmental burdens, and on the lack of amenities experienced by low-income households and ethnic or racial groups in different countries (Schweitzer and Stephenson, 2007; Walker, 2011). Numerous studies have shown that low-income households tend to be located in the most polluted areas in Canada (Buzzelli and Jerrett, 2007; Crouse et al., 2009b), the United States (Chakraborty, 2006, 2009; Pastor et al., 2001), the United Kingdom (Brainard et al., 2002; Mitchell and Dorling, 2003) and New Zealand (Kingham et al., 2007). In the same vein, other studies have looked at the social impacts of transportation infrastructure (Feitelson, 2002; Hodgson et al., 2013; Thomopolous and Grant-Muller, 2013). More recently, the literature on environmental and social equity has increasingly examined other population groups such as children and older people due to their physiological vulnerability to air pollution (Walker, 2009). Nevertheless, few studies on environmental and social equity and transportation have explored whether children are exposed to high concentrations of air pollutants (Brainard et al., 2002; Crouse et al., 2009b; Mitchell and Dorling, 2003).

This analysis focusing on Montreal has been inspired by these studies on air pollution and social impacts in transportation from the perspective of environmental and social equity. It concentrates, however, on an evaluation of air quality in the environments around elementary schools. Only a few studies in environmental and social equity have emphasized intra-group differences in terms of the exposure to air pollutants.

2. Schools, air pollution, environmental and social equity

Numerous studies have been conducted in order to evaluate the association between air quality around schools and various outcomes such as academic performance (Clark et al., 2010; Zahran et al., 2009), mental health (Evans, 2003) and respiratory problems (McConnell et al., 2010; Pastor et al., 2006). In that perspective, the characterization of the socioeconomic status of children attending schools located in areas that are most affected by traffic-related air pollution has become a topic of considerable interest in the literature on environmental and social equity because of the amount of time that children spend at school (Sampson, 2012).

A number of U.S. studies have shown that children from low-income backgrounds and Hispanic or African-American communities are more likely to attend schools that are located near major roads and in the most polluted areas. In California, Green et al. (2004) showed that public schools located within 150 m of a major road with daily traffic of over 50,000 vehicles were more frequently attended by ethnic minorities (Hispanics and Blacks) and students from low-income households. In other American cities, Chakraborty and Zandbergen (2007) and Stuart and Zeager (2011) in Tampa Bay, and Wu and Batterman (2006) in Detroit found that schools with a high level of deprivation were positively associated with a proximity to major roads and a higher concentration of nitrogen dioxide (NO_2). A recent study by Amram et al. (2011) on large Canadian urban areas notes that 22% of schools in the most deprived quintile at the census tract level are located less than 75 m from a major road, compared with 13% of schools in the least deprived quintile. Moreover, a study in Malmo, Sweden shows that children under 15 years of age from low-income households are more exposed to higher concentrations of NO_2 in their home and school environments (Chaix et al., 2006).

3. Research objectives

The literature has emphasized the finding that children from low-income households or of low socioeconomic status are more likely than those from more well-off households to attend schools that are located near major roads, where concentrations of pollutants are higher (Amram et al., 2011; Chakraborty and Zandbergen, 2007). This situation is an important issue for understanding health inequalities and developing appropriate social inclusion policies for transportation, as children are vulnerable to pollutants in their environment in two ways. On the one hand, the incomplete development of their organs and nervous systems increases their risks of developing various health problems if they are exposed to high concentrations of pollutants. On the other hand, because children—and especially children from low-income backgrounds—are less mobile, they are more likely to stay in their residential environments.

To our knowledge, no study on environmental and social equity has compared the levels of traffic-related pollutants in the environments around schools with the levels in a larger control area. The emphasis has often been placed on the differences in pollutant concentrations between schools according to their socioeconomic composition. This study has two objectives. It first attempts to determine whether Montreal elementary schools are located in city blocks that are more polluted than in the rest of the Island of Montreal. We then develop an assessment of environmental and social equity by establishing whether the most disadvantaged elementary schools show higher pollution indicators than schools in more well-off areas.

4. Methodology

A number of methodological issues have been raised in the literature in order to determine, with considerable precision, the existence of environmental inequities for a given population group. Among the important criteria for a rigorous evaluation of environmental and social equity, Walker (2010) emphasizes the issue of the choice of the scale of analysis. In concrete terms, this spatial division has to be as fine as possible in order to obtain a good degree of variability of the indicator of exposure to the environmental nuisance across the spatial units in the area under study. This concept of the modifiable areal unit problem (MAUP) has largely been addressed in the literature in environmental and social equity (Bowen, 2002; Schweitzer and Stephenson, 2007), and recently in the literature on transportation (Wang et al., 2011). An inadequate choice of the scale of analysis could lead to errors and misinterpretations, as reported in Bowen (2002). Walker (2010) also considers it appropriate to compare the levels of exposure to the nuisance examined in the target group with the levels for a control group, in order to establish whether these levels are in fact higher in the target group. Consequently, in the context of this study, it is important to select the appropriate spatial division and control groups in order to determine whether or not the elementary schools are located in more polluted environments.

4.1. Study area, targeted groups and scale of analysis

This study focuses on the Island of Montreal, which has 1.88 million inhabitants and covers 499 km². This territory is part of the Montreal census metropolitan area (CMA), which is the second most populous metropolis in Canada (with 3.92 million inhabitants). We have only considered the Island of Montreal because air pollution data were only available in that geographic area. More specifically, this study focuses on the environment around Montreal's 319 public elementary schools, excluding schools in Île-Bizard (with a population of 17,950 inhabitants), where no air pollution measurements had been taken (Fig. 1).

We selected two control groups—children between 5 and 12 years old, and the total population—the numbers of which were extracted by Statistics Canada from the 2011 census, at the
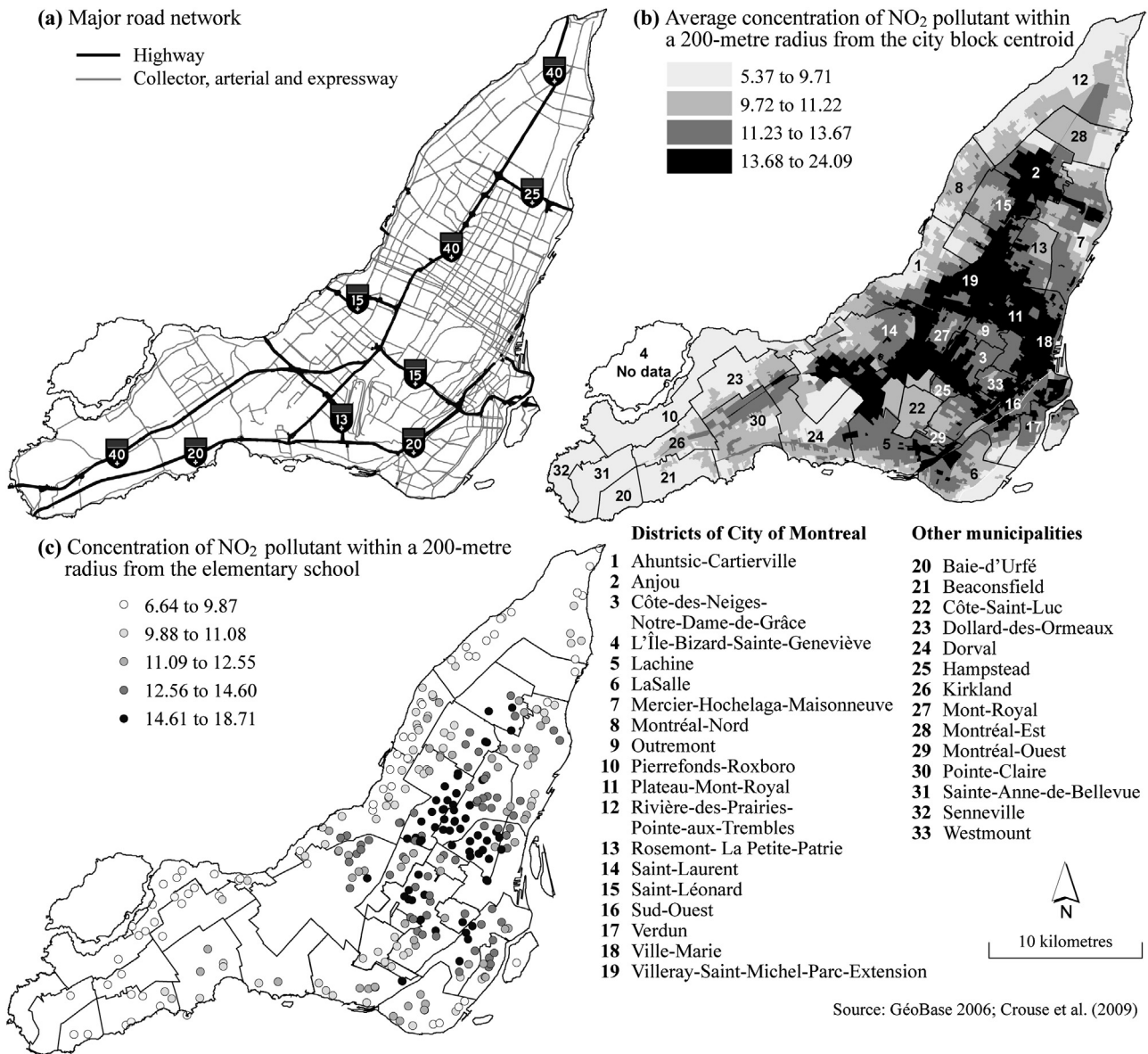
(a) Major road network

— Highway
— Collector, arterial and expressway

(b) Average concentration of NO$_2$ pollutant within a 200-metre radius from the city block centroid

▢	5.37 to 9.71
▨	9.72 to 11.22
▨	11.23 to 13.67
■	13.68 to 24.09

(c) Concentration of NO$_2$ pollutant within a 200-metre radius from the elementary school

○	6.64 to 9.87
○	9.88 to 11.08
◐	11.09 to 12.55
●	12.56 to 14.60
●	14.61 to 18.71

Districts of City of Montreal

1 Ahuntsic-Cartierville
2 Anjou
3 Côte-des-Neiges-Notre-Dame-de-Grâce
4 L'Île-Bizard-Sainte-Geneviève
5 Lachine
6 LaSalle
7 Mercier-Hochelaga-Maisonneuve
8 Montréal-Nord
9 Outremont
10 Pierrefonds-Roxboro
11 Plateau-Mont-Royal
12 Rivière-des-Prairies-Pointe-aux-Trembles
13 Rosemont- La Petite-Patrie
14 Saint-Laurent
15 Saint-Léonard
16 Sud-Ouest
17 Verdun
18 Ville-Marie
19 Villeray-Saint-Michel-Parc-Extension

Other municipalities

20 Baie-d'Urfé
21 Beaconsfield
22 Côte-Saint-Luc
23 Dollard-des-Ormeaux
24 Dorval
25 Hampstead
26 Kirkland
27 Mont-Royal
28 Montréal-Est
29 Montréal-Ouest
30 Pointe-Claire
31 Sainte-Anne-de-Bellevue
32 Senneville
33 Westmount

N

10 kilometres

Source: GéoBase 2006; Crouse et al. (2009)

Fig. 1. Study area: schools, major road networks and pollution indicators.

dissemination area (DA) level. The DA is the most accurate unit of analysis on which socioeconomic data are available. Generally, 400–700 people reside in a DA, and this spatial unit corresponds to a small area composed of one or more neighbouring blocks (Statistics Canada, 2011). Concretely, the selection of these two control populations allowed us to compare pollution indicator values between the environments around public elementary schools and residential areas across the entire Island of Montreal. The selection of the control population of children between 5 and 12 years old also enabled us to compare the spatial concentrations of air pollution indicators around the schools and around the residential areas. We were thus able to see whether pollution levels for children were higher at school than in their home environment. This also allowed us to determine the potential NO$_2$ exposure for children in this age group as they spent most of their day at school and in their residential area.

Checking for environmental and social inequities for a given population group requires that analyses be performed at a fine geographic scale, as pollution levels can vary greatly at the scales of a neighbourhood, a census tract or a dissemination area. We

therefore decided to use the city block, the finest spatial unit provided by Statistics Canada, as our basis for generating pollution indicators. It should be noted that Statistics Canada only provides data on the total population and the number of dwellings at the city block level. To address this issue, we estimated the numbers of 5–12 year-olds consistent with the approach recently put forward by Pham et al. (2012), as follows:

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

where t_i represents the estimated population of the 5–12 year-old group in the city block, t_a is the group's population in the dissemination area, and T_i and T_a are the total population in the block and the dissemination area respectively.

One of the main limitations of this method is related to the assumption of a homogenous distribution for a demographic group at the city block and dissemination area levels. To validate the robustness of the interpolation, we did the same exercise but with data interpolated from the census tract level to the DA level, as suggested by Maantay et al. (2007) and as also done by Pham et al.

(2012). The correlation between the interpolated values and those provided by Statistics Canada for the 5–12 year-old group at the DA level is 0.87, which is comparable to the results of Maantay et al. (2007) and Pham et al. (2012).

4.2. Geocoding of elementary schools

We developed our list of public elementary schools from the data available on the websites of the five school boards covering the territory of the Island of Montreal. We then validated this list with data from the Québec Ministry of Education, Recreation and Sports. After this, the schools were geocoded in a GIS (ArcGIS version 10.1) according to their postal codes, and a correction was finally effected to ensure that the points for the schools were placed in the centre of each main building by using the online high-resolution imagery basemaps of ArcGIS (ESRI, 2011). The Google Maps website was also used to validate this process for each of the 319 schools.

4.3. Determination of socioeconomic deprivation levels for elementary schools

The authority in charge of school tax on the Island of Montreal (Le comité de gestion de la taxe scolaire de l'île de Montréal, or CGTSIM) has established the socioeconomic deprivation levels (or "underprivileged status") of all elementary schools located on the Island of Montreal (CGTSIM, 2013). To set these levels, the CGTSIM first develops an "overall underprivileged index," by using four variables from the 2006 Canadian census data collected by Statistics Canada and establishing the respective weight of these variables in the index calculation as follows: low income (50%), mother's education (16.67%), female lone-parent families (16.67%) and parents' economic activity (16.67%). The index is applied to 470 zones determined by the CGTSIM and located on the Island of Montreal. Using the postal code for his or her home address, each student is assigned a value for the "index of underprivileged status" associated with one of the 470 zones where he or she lives. The overall underprivileged index can vary from 0 (absence of deprivation) to 100 (all of the students live in an area with a high level of socioeconomic deprivation). The CGTSIM then assigns an index of underprivileged status to each elementary school by adding all the values of the students' indices and dividing this by the total number of students in the school. This index ranges from 0.47 to 44.69 (mean = 15.58 and SD = 9.36), that is, from a low to a high level of deprivation.

4.4. Air pollution indicators

The operations involved in constructing the pollution indicators were carried out in ArcGIS (ESRI, 2011). All of the values for these indicators were calculated both for the areas around—and within 200 m of—elementary schools and all city block centroids on the Island of Montreal. Two types of pollution indicators were developed.

The first pollutant estimation measurements were created by using a spatial database from 2006 of all the streets on the Island of Montreal (Geobase) where various indicators of major road lengths were calculated in the areas within a 200-m radius of the elementary schools and city blocks. The distance of 200 m was chosen as the effects of air pollutants are rarely felt beyond this distance. Brugge et al. (2007) have reported that the spatial concentrations of air pollutants from highways rapidly decline from 0 to 200 m. These buffer zones were demarcated around the centroid of the area occupied for residential purposes in each city block on the Island of Montreal. These estimation measurements represent a proxy of air pollution following from the postulate that

pollution levels should be higher near major roads and highways. The length of major roads simply corresponds to the sum of the lengths of all road sections associated with their hierarchies (as secondary roads or highways) in each buffer zone. The indicators developed are related to: (1) the length of the highway network within the 200-m radius around schools and city block centroids; (2) the length of secondary roads—collector, arterial and express roads; and (3) the length of highways and secondary roads.

For the second type of pollution indicators, we used a series of data created by a team of McGill University researchers who had measured NO_2 concentrations during the months of May, August and December 2006 at 133 locations on the Island of Montreal (Crouse et al., 2009a). A pollution map for the entire island was then generated by using land-use regression at a fine spatial resolution (Crouse et al., 2009b). This technique consists in constructing a regression equation with the observations at the 133 points sampled for the concentration of a pollutant as the dependent variable, and a whole series of independent variables, especially the proximity to major roads and highways, the length of sections of road near the sampling location, traffic flows, residential density, and the presence of industrial facilities (Crouse et al., 2009a; Ryan and LeMasters, 2007). Once a robust regression model has been obtained (with a high R^2), the equation is applied to the entire territory. Using the map of pollutant emissions thus developed, we then calculated the average NO_2 value within a 200-m radius of each elementary school on the Island of Montreal and of each city block centroid. However, we also need to remember that the NO_2 concentrations are derived from the results of land-use regression modelling using data observed over a period of three different months. But this may mask considerable variations in such concentrations according to the day of the week and the time of day. In sum, it is important here to distinguish between the notions of the concentration of a pollutant and an individual's exposure to pollutants. The latter is related to the period of time spent in an environment and the quantity of pollutants to which the individual is exposed (Janssen and Mehta, 2006).

4.5. Statistical analyses

In order to determine whether there are environmental and social inequities affecting public elementary schools with higher levels of socioeconomic deprivation, we employed four types of statistical analyses widely used in studies on environmental and social equity (Apparicio et al., 2010; Briggs et al., 2008; Kingham et al., 2007). We also decided not to conduct regression modelling because we wanted to place the emphasis on comparing air pollutant concentration levels and the length of major roads between the students enrolled in the elementary schools and the two control groups.

In keeping with our first objective, the first two statistical analyses were designed to show whether the schools were located in city blocks that were more polluted than in the rest of the Island of Montreal through: (1) a comparison of the univariate statistics for the pollution indicators weighted by the number of students enrolled in elementary schools, the total population, and the number of 5–12 year-olds per city block and (2) a *t*-test to compare the mean values of the pollution indicators calculated within 200 m of city blocks that have an elementary school weighted by the number of enrolled students, and for city blocks without an elementary school weighted by the number of 5–12 year-olds.

Next, in line with our second objective, we performed two other statistical analyses to determine whether the most disadvantaged elementary schools showed higher pollution indicators than the more well-off elementary schools. Thirdly, we calculated Spearman correlation coefficients between the elementary schools' socioeconomic deprivation levels and the pollution indicators calculated within 200 m of these schools. Due to the fact that the

association between the level of deprivation index for elementary schools and the pollution indicators might not be linear, we conducted a fourth statistical analysis. We conducted a *t*-test analysis to compare the mean values of the pollution indicators for the extreme quintiles (first and last quintiles) of the school deprivation index, an exercise conducted, among others, by Kingham et al. (2007) and Briggs et al. (2008). These analyses were performed in SAS version 9.2 (SAS Institute Inc, 2009).

5. Results

5.1. Descriptive statistics for the pollution indicators on the Island of Montreal

The univariate statistics for the four pollution indicators weighted by the total population as reported in the 2011 Canadian census, the number of 5–12 year-olds and the number of students enrolled in public elementary schools at the city block level are presented in Table 1.

An analysis of these statistics shows that the level of NO_2 and the length of major roads are not as great when they are weighted by the number of students enrolled in elementary schools. The difference is even larger for all the pollution indicators when we compare the number of students enrolled in elementary schools and the total population. So we find that elementary-level students go to schools where there is a slightly lower concentration of NO_2 (mean = 11.99 parts per billion (ppb) and median = 11.57 ppb, compared with 12.29 ppb and 12.05 ppb for the total population) and where there are shorter major roads and highway sections (mean = 359 m and median = 300 m, compared with 466 m and 383 m for the total population). It was not however unexpected to find a much smaller gap between the statistics obtained for the number of 5–12 year-olds and the number of students enrolled in elementary schools. These first results show that elementary schools tend to be located in areas that are less polluted by NO_2, and with shorter lengths of major roads in comparison with the total population of the Island of Montreal.

Finally, it is worth noting that all the values of the air pollutants around elementary schools shown in Fig. 1 are below the threshold set by the World Health Organization (WHO) (Forastiere et al., 2006).

5.2. Comparison between the mean pollutant values for elementary schools and city blocks

We performed a *t*-test to compare the mean values for the four pollution indicators at the level of city blocks with or without an elementary school weighted by various count variables. For city blocks without a school, the pollution indicators are weighted by the number of 5–12 year-olds and the total population. For city blocks with a school, the pollution indicators are weighted by the number of students enrolled in elementary schools (Table 2).

At a 0.05 threshold of significance, city blocks with public elementary schools show shorter average lengths of nearby highways and collector, arterial and express roads and lower average NO_2 concentrations when compared with Montreal city blocks weighted by the number of 5–12 year-olds and the total population. However, the difference in the average NO_2 concentrations is not significant between city blocks with elementary schools and other city blocks weighted by the number of 5–12 year-olds. This indicates that, on average, elementary schools are located in city blocks showing levels of NO_2 pollution indicators that are slightly lower than those for the rest of the Island of Montreal, and where there are shorter lengths of major roads and highways nearby. Consequently, the results of this second analysis point in the same direction as the previous analysis, in showing an advantageous geographic location for the elementary schools in comparison with city blocks without such schools.

5.3. Correlation between the pollutants and the school deprivation index

Spearman correlation coefficients were calculated to see whether there were significant linear relationships between the Montreal elementary schools' socioeconomic deprivation index and the four pollution indicators weighted by the number of students (Table 3). First, only one correlation was found to be moderate—that is, the correlation between the elementary schools' socioeconomic deprivation index, weighted by the number of students, and the NO_2 concentration ($r = 0.410$; 95% CI: 0.314–0.497)—thus revealing an environmental and social inequity in terms of the schools that students from disadvantaged backgrounds attend. Next, an increase in the elementary schools' level of socioeconomic deprivation was also tied to an increase in the length of major roads in their immediate environment, but this relationship was relatively weak ($r = 0.118$; 95% CI: 0.008–0.224). The other correlations between the elementary schools' level of deprivation and the pollution indicators were found to be weak and not significant at a 0.05 threshold. In sum, socially deprived students are more likely to attend schools located in the most polluted areas, especially in terms of NO_2 concentrations.

Table 1

Univariate statistics for the pollution indicators within a distance of 200 m from the city block centroid weighted by the total population, the number of 5–12 year-olds, and the number of students enrolled in public elementary schools.

Indicator	Weighting	N	Mean	P5	P25	P50	P75	P95
Highw	Total population	12,979	50	0	0	0	0	389
	5–12 year-olds	12,979	**51**	0	0	0	0	**430**
	Elementary schools	319	*33*	0	0	0	0	*0*
CollExp	Total population	12,979	**416**	0	0	**374**	695	1101
	5–12 year-olds	12,979	375	0	0	333	656	1061
	Elementary schools	319	*327*	0	0	*287*	*551*	*1026*
HCE	Total population	12,979	**466**	0	0	**383**	723	1304
	5–12 year-olds	12,979	425	0	0	352	701	1236
	Elementary schools	319	*359*	0	0	*300*	*595*	*1127*
NO_2	Total population	12,979	**12.29**	8.35	10.25	12.05	**14.39**	**16.64**
	5–12 year-olds	12,979	12.01	8.17	*10.04*	11.66	*13.98*	16.42
	Elementary schools	319	*11.99*	*8.09*	10.15	*11.57*	14.08	*16.39*

Highw: length of highways by city block (m); CollExp: length of collector, arterial and express roads by city block; HCE: length of highways, collector, arterial and express roads by city block; NO_2: mean concentration of NO_2 by city block.
P5, 5th percentile; P25, first quartile; P50, median; P75, third quartile; P95, 95th percentile. Bold typeface indicates the strongest values for each statistical measurement; italics, the weakest.

Table 2

Comparison of the mean values of the pollution indicators within 200 m of city block centroids without a public elementary school weighted by the total population and the number of 5–12 year-olds, and of the pollution indicators for city blocks with a public elementary school weighted by the number of enrolled students.

City blocks without schools (G1)	City blocks with a school (G2)	Highways (m)				Collector, arterial and express roads (m)			
Weighting	Weighting	Mean		Difference		Mean		Difference	
		G1	G2	Diff	P	G1	G2	Diff	P
Total population	Enrolled students	50.6	32.5	18.1	0.053	417.9	326.8	91.1	0.000
5–12 year-olds	Enrolled students	51.9	32.5	19.4	0.052	376.1	326.8	49.3	0.012

City blocks without schools (G1)	City blocks with a school (G2)	Highways, collector, arterial and express roads (m)				NO$_2$ (ppb)			
Weighting	Weighting	Mean		Difference		Mean		Difference	
		G1	G2	Diff	P	G1	G2	Diff	P
Total population	Enrolled students	468.5	359.4	109.1	0.000	12.29	11.99	0.30	0.034
5–12 year-olds	Enrolled students	428.0	359.4	68.6	0.003	12.01	11.99	0.02	0.871

If the variances of the two groups are unequal (with $P < 0.05$), the Satterthwaite variance estimator is used for the *t*-test; otherwise, the pooled variance estimator is used.

5.4. Comparison of mean pollutant values between the first and fifth quintiles of the school deprivation index

The findings of the analysis shown in Table 4 indicate that the elementary schools in the most deprived quintile tend to be located in areas with longer lengths of highways and collector, arterial and express roads compared with schools in the least deprived quintile. However, these differences between the means are not statistically significant for highways at a threshold of 0.10. Moreover, the mean NO$_2$ concentration for the fifth quintile of socioeconomic deprivation of elementary schools is 13.00 ppb, compared with 10.02 ppb for the first quintile, which represents a difference of 2.98 ppb in the concentration of this pollutant. So this points to a situation of environmental and social inequity, in indicating that the students attending the schools that present the greatest deprivation are more exposed to air pollution. This finding is further confirmed by an analysis of the boxplots shown in Fig. 2.

6. Discussion

Two main findings have come out of our study in terms of the concentration of pollutants within a 200-m radius of elementary schools.

The first finding is encouraging, in that all the elementary schools, regardless of their level of socioeconomic deprivation, tend to be located in city blocks that are characterized by having shorter total lengths of major roads nearby than the city-wide average. Additionally, the average concentrations of NO$_2$ around elementary schools are lower than those around all city blocks on the Island of Montreal weighted by the total population.

This first finding is however tarnished by the existence of a situation of environmental and social inequity when we introduce the level of socioeconomic deprivation of the various elementary schools. A higher level of socioeconomic deprivation for elementary schools is associated with an increase in NO$_2$ levels in their

immediate environment, as indicated by the Spearman correlation coefficients. Moreover, schools in the last quintile of deprivation are located in areas where the NO$_2$ concentration (mean = 13.00 ppb) is higher than for schools located in more well-off areas (mean = 10.02 ppb). Moreover, the level of NO$_2$ in the last quintile of deprivation is higher than the mean concentration in the Island of Montreal (mean = 12.29 ppb).

The results of this study, showing that the most deprived schools are located in environments that are significantly more polluted, are in line with the findings of earlier studies on the same topic in Detroit (Wu and Batterman, 2006), Tampa Bay (Chakraborty and Zandbergen, 2007; Stuart and Zeager, 2011), and other Canadian cities (Amram et al., 2011). But just how important is this situation in terms of the health risks for students attending schools where the concentrations of pollutants are the highest? A further analysis allows us to evaluate the health risks for students going to schools where there are higher levels of air pollutants. The World Health Organization (WHO) has determined that annual concentrations of NO$_2$ should not exceed 40 $\mu g/m^{-3}$ (Forastiere et al., 2006). The mean concentration of this pollutant is 13.00 ppb in the environments around Montreal schools in the last quintile of deprivation, and the maximum value for all the schools is 18.7 ppb, which are respectively equivalent to 24.44 and 35.16 $\mu g/m^{-3}$, that is, a lower level than the threshold set by the WHO. It should however be noted that 11 elementary schools are located less than 200 m from a highway, as shown in Fig. 3, and that seven of them are in the fourth and fifth quintiles of deprivation.
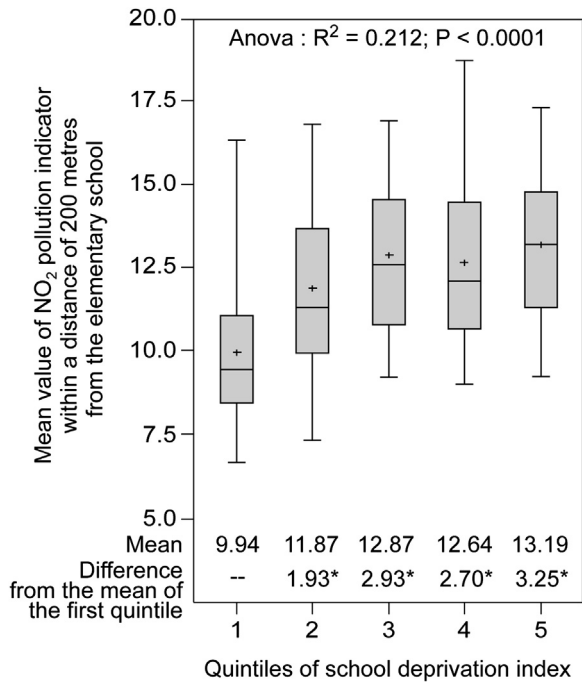
6.1. Potential solutions for tackling air pollution inequities at school

This section examines two possible avenues for solutions designed to ensure, on the one hand, that new elementary schools are not located in areas with the highest concentrations of

Table 3

Spearman correlation coefficients between the pollution indicators within 200 m and the level of deprivation of public elementary schools.

Length of major roads near the city block			Land-use regression
Highw	CollExp	HCE	NO$_2$
Level of deprivation of elementary schools			
0.027	0.118[**]	0.107[*]	0.410[***]

$N = 319$.
[*] $P < 0.10$.
[**] $P < 0.05$.
[***] $P < 0.01$.

Table 4

Comparison of the mean values of the pollution indicators within 200 m between the first and last quintiles of the school deprivation index weighted by the number of enrolled students.

Highways (m)				Collector, arterial and express roads (m)			
Q1	Q5	Diff	P	Q1	Q5	Diff	P
3.9	45.1	−41.2	0.156	206.9	316.6	−109.7	0.051
Highways, collector, arterial and express roads (m)				NO$_2$ (ppb)			
Q1	Q5	Diff	P	Q1	Q5	Diff	P
210.8	361.6	150.8	0.026	10.02	13.00	−2.98	0.001

Anova : R^2 = 0.212; P < 0.0001

	1	2	3	4	5
Mean	9.94	11.87	12.87	12.64	13.19
Difference from the mean of the first quintile	--	1.93*	2.93*	2.70*	3.25*

Quintiles of school deprivation index

Note: Tukey test for comparison of the mean values.
* Significant difference at P=0.01.

Fig. 2. Boxplot of the NO_2 pollution indicator according to the quintiles of deprivation of public elementary schools.

pollutant emissions, or, on the other, that mitigation measures are taken to reduce the disadvantages associated with the most problematic locations. The first potential solution is a normative approach prohibiting the building of new schools near major traffic arteries. The second approach, based on one of the conceptions of equity in transportation policies, consists in developing compensatory measures for elementary schools affected by the highest levels of environmental nuisances stemming from road transportation.

In light of these health risks, six American states have set tighter urban planning standards in regard to the development of sensitive-use facilities such as schools and playgrounds near major traffic arteries. Moreover, only six states require environmental assessments in school siting processes (Sampson, 2012).

The State of California has adopted the strictest planning norms. Since 2003, this state has prohibited the building of "*new school sites within 500 feet (166 metres) of the edge of the closest traffic lane of a freeway or busy traffic corridor*" (California, 2003).

To our knowledge, in Canadian provinces, unlike the situation in the U.S., no urban planning standards appear to have been set up governing the building of new elementary schools. The Canadian approach seems to instead emphasize the making of recommendations. For example, in British Columbia (Canada), the Ministry of Environment has recommended the keeping of a buffer zone of 150 m between major roads and sensitive-use facilities such as schools or hospitals (Environment, 2006). In the same vein, in line with current Québec provincial legislation on urban planning, Montreal's master plan must "*identify the thoroughfares whose present or planned presence in a place results in land occupation near this place being subject to major restrictions for reasons of public safety, public health or general welfare*" (Quebec, 2013). The council of a municipality may then adopt a zoning by-law to "*regulate or prohibit all or certain land uses, taking into account the proximity of a place where the present or planned presence or carrying out of an immovable or an activity results in land occupation being subject to special restrictions for reasons of public safety, public health or general welfare*" (Quebec, 2013).

A normative approach as in California—that is, the setting of a minimum distance of no less than 200 m—could be adopted in Québec's urban planning regulations to prohibit the location of sensitive-use facilities near major traffic arteries, given the potential risk to the health of local children. A ministerial decree could thus be issued in Québec to ensure that, in all municipalities, no sensitive-use facility could be built at a certain distance from a major traffic artery in view of the public health risks. These municipalities would then be obliged to include in their zoning by-laws the prohibition against targeted uses at a specific distance from a section of highway or major traffic artery in order to comply with the government's decision. Finally, the City of Montreal has recently conducted experiments aimed at reducing the speed limits on the arterial network. A speed reduction would considerably reduce air pollutant emissions and road traffic noise levels. This project could be specifically implemented at a certain distance from all elementary schools during class hours.

Consideration of the social impacts associated with road transportation projects has been a particular focus of attention in the recent literature in order to ensure that the benefits and costs linked to transport infrastructures are equitably distributed between population groups.
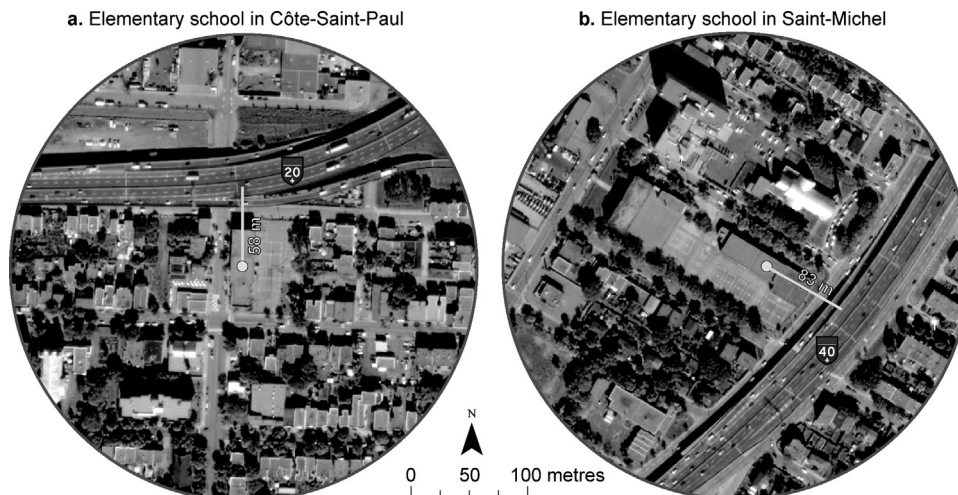

a. Elementary school in Côte-Saint-Paul

b. Elementary school in Saint-Michel

0   50   100 metres

Fig. 3. Examples of two public elementary schools located less than 200 m from a highway.

The notion of compensatory equity is increasingly being taken into account in methods of evaluating the social impacts of transportation projects (Geurs et al., 2009; Thomopolous et al., 2009). The overall idea is that individuals disproportionately affected by a transportation project should be compensated by those benefiting the most from the project (Thomopolous et al., 2009). An approach of this kind could be relevant in mitigating impacts related to road transportation around elementary schools. Putting this into practice could, for example, take the form of mitigation measures under the responsibility of public authorities in order to improve air quality near elementary schools associated with Island of Montreal school boards where the highest levels of pollutants are observed. These investments could be used to build noise barriers and plant trees and to carry out greening measures in schoolyards. These actions would be beneficial in, among other things, helping to reduce noise pollution, to absorb a portion of pollutant emissions and to lessen the heat-island effect (Akbari et al., 2001).

7. Conclusion and limitations

Finally, we want to emphasize the importance of performing this kind of analysis with different indicators of exposure to pollution prior to suggesting the existence of a situation of environmental and social inequity. If, for example, in the context of this study, we had only used indicators associated with the length of major roads and highways, we could have maintained that the situation of environmental and social inequity in regard to disadvantaged public elementary schools in Montreal was not very marked. But when we then performed further analyses using the NO_2 indicator, we were able to highlight more substantial inequities.

In order to further refine our results and to more systematically deal with the question of exposure, additional studies could be carried out. On the one hand, for a sample of schools, pollution monitors could be placed in schoolyards during class times. On the other hand, a sample of students could be equipped with monitors to determine their levels of exposure to pollutants throughout the day during a given time period. We could then establish whether the children's levels of exposure were higher in their home or school environments.

Finally, this study emphasizes two important elements in the assessment of transportation-related environmental and social equity for children. On the one hand, this study indicates the importance of comparing the situation of a particular group with that of a control population (i.e. children at school compared with children at home). On the other hand, the performing of intra-group comparisons according to the level of deprivation, as advocated by Collins et al. (2011), constitutes a recent advance in studies in environmental and social equity.

References

Akbari, H., Pomerantz, M., Taha, H., 2001. Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. Sol. Energ. 70 (3) 295–310.

Amram, O., Abernethy, R., Brauer, M., Davies, H., Allen, R., 2011. Proximity of public elementary schools to major roads in Canadian urban areas. Int. J. Health Geogr. 10 (68) 1–11.

Apparicio, P., Cloutier, M.-S., Séguin, A.-M., Ades, J., 2010. Accessibilité spatiale aux parcs urbains pour les enfants et injustice environnementale: exploration du cas montréalais. Rev. Int. Géomat. 20 (3) 363–389.

Bolte, G., Tamburlini, G., Kohlhuber, M., 2009. Environmental inequalities among children in Europe – evaluations of scientific evidence and policy implications. Eur. J. Public Health 20 (1) 14–20.

Bowen, W., 2002. An analytical review of environmental justice research: what do we really know? Environ. Manage. 29 (1) 3–15.

Brainard, J., Bateman, I., Lovett, A., Fallon, P., 2002. Modelling environmental equity: access to air quality in Birmingham, England. Environ. Plan. A 34 (4) 695–716.

Briggs, D., Abellan, J., Fecht, D., 2008. Environmental inequity in England: small area associations between socio-economic status and environmental pollution. Soc. Sci. Med. 67 (10) 1612–1629.

Brugge, D., Durant, J., Rioux, C., 2007. Near-highway pollutants in motor vehicle exhaust: a review of epidemiologic evidence of cardiac and pulmonary health risks. Environ. Health 6 (23) 1–12.

Brunekreef, B., Holgate, S., 2002. Air pollution and health. Lancet 360 (9341) 1233–1242.

Brunekreef, B., Janssen, N., Hartog, J., Harssema, H., Knape, M., van Vliet, P., 1997. Air pollution from truck traffic and lung function in children living near motorways. Epidemiology 8 (3) 298–303.

Buzzelli, M., Jerrett, M., 2007. Geographies of susceptibility and exposure in the city: environmental inequity of traffic-related air pollution in Toronto. Can. J. Reg. Sci. 30 (2) 195–210.

California, S.o., 2003. State Bill Number 352.

Carslaw, D., Beevers, S., Tate, J., Westmoreland, E., Williams, M., 2011. Recent evidence concerning higher NO_x emissions from passenger cars and light duty vehicles. Atmos. Environ. 45 (39) 7053–7063.

Cesaroni, G., Badaloni, C., Porta, D., Forastiere, F., Perucci, C.A., 2008. Comparison between various indices of exposure to traffic-related air pollution and their impact on respiratory health in adults. Occup. Environ. Med. 65 (10) 683–690.

CGTSIM, 2013. Classification des écoles primaires et classification des écoles secondaires selon leur indice de défavorisation.

Chaix, B., Gustafsson, S., Jerret, M., Kristerson, H., Lithman, T., Boalt, A., Merlo, J., 2006. Children's exposure to nitrogen dioxide in Sweden: investigating environmental injustice in an egalitarian country. J. Epidemiol. Community Health 60 (3) 234–241.

Chakraborty, J., 2006. Evaluating the environmental justice impacts of transportation improvement projects in the US. Transport. Res. D 11, 315–323.

Chakraborty, J., 2009. Automobiles, air toxics, and adverse health risks: environmental inequities in Tampa Bay, Florida. Ann. Assoc. Am. Geogr. 99 (4) 674–697.

Chakraborty, J., Zandbergen, P.A., 2007. Children at risk: measuring racial/ethnic disparities in potential exposure to air pollution at school and home. J. Epidemiol. Community Health 61 (12) 1974–1979.

Clark, N.A., Demers, P.A., Karr, C.J., Koehoorn, M., Lencar, C., Tamburic, L., Brauer, M., 2010. Effect of early life exposure to air pollution on development of childhood asthma. Environ. Health Perspect. 118 (2) 284–290.

Collins, T., Grineski, S.E., Chakraborty, J., McDonald, Y., 2011. Understanding environmental health inequalities through comparative intracategorical analysis: racial/ethnic disparities in cancer risks from air toxics in El Paso County, Texas. Health Place 17 (1) 335–344.

Crouse, D., Goldberg, M., Ross, N., 2009a. A prediction-based approach to modelling temporal and spatial variability of traffic-related air pollution in Montreal, Quebec. Atmos. Environ. 43 (32) 5075–5084.

Crouse, D., Ross, N., Goldberg, M., 2009b. Double burden of deprivation and high concentrations of ambient air pollution at the neighbourhood scale in Montreal, Canada. Soc. Sci. Med. 69 (6) 971–981.

Day, R., Wager, F., 2010. Parks, streets and "just empty space": the local environmental experiences of children and young people in a Scottish study. Local Environ.: Int. J. Justice Sustain. 15 (6) 509–523.

Environment, B.C.M.o., 2006. Environmental Best Management Practices for Urban and Rural Land Development in British Columbia.

ESRI, 2011. ArcGIS Desktop: Release 10. Environmental Systems Research Institute, Redlands, CA.

Evans, G., 2003. The built environment and mental health. J. Urban Health 80 (4) 536–555.

Feitelson, E., 2002. Introducing environmental equity dimensions into sustainable transport discourse: issues and pitfalls. Transport. Res. D 7, 99–118.

Forastiere, F., Peters, A., Kelly, F., Holgate, S.T., 2006. Nitrogen dioxide. In: Air Quality Guidelines: Global Update 2005. WHP, Copenhagen, Denmark.

Gauderman, J., Vora, H., McConnell, R., Berhane, K., Gilliand, F., et al., 2007. Effect of exposure to traffic on lung development from 10 to 18 years of age: a cohort study. Lancet 369 (9561) 571–577.

Geurs, K., Boone, V., Van Wee, B., 2009. Social impacts of transport: literature review and the state of the practice of transport appraisal in the Netherlands and the United Kingdom. Transport Rev. 29 (1) 69–90.

Green, R.S., Smorodinsky, S., Kim, J.J., McLaughlin, R., Ostro, B., 2004. Proximity of California public schools to busy roads. Environ. Health Perspect. 112 (1) 61–66.

Hodgson, S., Namdeo, A., Araujo-Soares, V., Pless-Mulloli, T., 2013. Towards an interdisciplinary science of transport and health: a case study on school travel. J. Transport Geogr. 2, 70–79.

Hoek, G., Brunekreef, B., Goldbohm, S., Fischer, P., Van Den Brandt, P.A., 2002. Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study. Lancet 360 (9341) 1203–1209.

Houston, D., Wu, J., Ong, P., Winer, A., 2004. Structural disparities of urban traffic in southern California: implications for vehicle-related air pollution exposure in minority and high-poverty neighborhoods. J. Urban Affairs 26 (5) 565–592.

Janssen, N., Mehta, S., 2006. Human Exposure to Air Pollution, Quality Guidelines: Global Update 2005. World Health Organization (WHO), Copenhague, Danemark.

Jerrett, M., Shankardass, K., Berhane, K., et al., 2008. Traffic-related air pollution and asthma onset in children: a prospective cohort study with individual exposure measurement. Environ. Health Perspect. 116 (10) 1433–1438.

Kim, J.J., Huen, K., Adams, S., et al., 2008. Residential traffic and children's respiratory health. Environ. Health Perspect. 116 (9) 1274–1279.

Kingham, S., Pearce, J., Peyman, Z., 2007. Driven to injustice? Environmental justice and vehicle pollution in Christchurch, New Zealand. Transport. Res. D 12 (4) 254–263.

Landrigan, P., Kimmel, C., Correa, A., 2004. Children's health and the environment: public health issues and challenges for risk assessment. Environ. Health Perspect. 112, 57–65.

Maantay, J.A., Maroko, A.R., Hermann, C., 2007. Mapping population distribution in the urban environment: the cadastral-based expert dasymetric system (CEDS). Cartogr. Geogr. Inf. Sci. 34 (2) 77–102.

McConnell, R., Islam, T., Shankardass, K., 2010. Childhood incident asthma and traffic-related air pollution at home and school. Environ. Health Perspect. 118 (7) 1021–1026.

Mitchell, G., Dorling, D., 2003. An environmental justice analysis of British air quality. Environ. Plan. A 35 (5) 909–929.

Pastor, M., Morello-Frosch, R., Sadd, J., 2006. Breathless: schools, air toxics, and environmental justice in California. Policy Stud. J. 34 (3) 337–362.

Pastor, M., Sadd, J., Hipp, J., 2001. Which came first? Toxic facilities, minority move-in and environmental justice. J. Urban Affairs 23 (1) 1–21.

Pham, T.-T.-H., Apparicio, P., Séguin, A.-M., Landry, S., Gagnon, M., 2012. Spatial distribution of vegetation in Montreal: an uneven distribution or environmental inequity? Landsc. Urban Plan. 107 (3) 214–224.

Quebec, 2013. Loi sur l'aménagement et l'urbanisme. Gazette officielle du Québec.

Rioux, C., Gute, D., Brugge, D., Peterson, S., Parmenter, B., 2010. Characterizing urban traffic exposures using transportation planning tools: an illustrated methodology for health researchers. J. Urban Health 87 (2) 167–188.

Ryan, P., LeMasters, G., 2007. A review of land-use regression models for characterizing intraurban air pollution exposure. Inhal. Toxicol. 19 (1) 127–133.

Sampson, N., 2012. Environmental justice at school: understanding research, policy, and practice to improve our children's health. J. Sch. Health 82 (5) 246–252.

SAS Institute Inc. 2009 SAS version 9.3. Cary, NC, USA.

Schweitzer, L., Stephenson, J., 2007. Right answers, wrong questions: environmental justice as urban research. Urban Stud. 44 (2) 319–337.

Statistics-Canada, 2011. 2011 Census Data.

Stuart, A., Zeager, M., 2011. An inequality study of ambient nitrogen dioxide and traffic levels near elementary schools in the Tampa area. J. Environ. Manage. 92 (8) 1923–1930.

Thomopolous, N., Grant-Muller, S., 2013. Incorporating equity as part of the wider impacts in transport infrastructure assessment: an application of the SUMINI approach. Transportation 40, 315–345.

Thomopolous, N., Grant-Muller, S., Tight, M.R., 2009. Incorporating equity considerations in transport infrastructure evaluation: current practice and a proposed methodology. Eval. Program Plann. 32 (4) 351–359.

Walker, G., 2009. Beyond distribution and proximity: exploring the multiple spatialities of environmental justice. Antipode 41 (4) 614–636.

Walker, G., 2010. Environmental justice, impact assessment and the politics of knowledge: the implications of assessing the social distribution of environmental outcomes. Environ. Impact Assess. Rev. 30, 312–318.

Walker, G., 2011. Environmental Justice: Concepts, Evidence and Politics. Routledge, New York.

Wang, C., Quddus, M., Ryley, T., Enoch, M., Davison, L., 2011. Spatial models in transport: a review and assessment of methodological issues. In: Transportation Research Board 91st Annual Meeting, Washington, DC.

Wu, Y.-C., Batterman, S.A., 2006. Proximity of schools in Detroit, Michigan to automobile and truck traffic. J. Expo. Sci. Environ. Epidemiol. 16 (5) 457–470.

Zahran, S., Mielke, H., Weiler, S., Berry, K., Gonzales, C., 2009. Children's blood lead and standardized test performance response as indicators of neurotoxicity in metropolitan New Orleans elementary schools. Neurotoxicology 30 (6) 888–897.