Transport Policy 81 (2019) 302–310

Contents lists available at ScienceDirect

Transport Policy

journal homepage: www.elsevier.com/locate/tranpol

School locations and road transportation nuisances in Montreal: An environmental equity diagnosis

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A B S T R A C T

The analysis of the concentration of the traffic-related pollutants in the environments around elementary schools constitutes an important issue, as children are at school for a large part of the day and are physiologically vulnerable to these nuisances. The study has three main objectives. These are, respectively, to compare the levels of NO_2 concentrations and road traffic noise in parcels of land that include a school with the levels for the rest of the Island of Montreal, to determine whether there are significant differences in the values obtained for the air and noise pollution indicators according to the schools' socioeconomic deprivation levels, and to identify, among these schools, those showing the highest levels of pollutants. The methodology was carried out in two stages. The parcels of land that include the 234 elementary schools and the 7,765 inhabited city blocks in the study area were first geocoded, and two air and road traffic noise pollution indicators were then calculated in all of the city blocks in the study area and in all of the parcels that include an elementary school. Our results show that elementary schools, regardless of their level of socioeconomic deprivation, are located in parcels where there is a lower level of road traffic noise but a similar level of NO_2 concentration compared with city blocks without schools. However, the NO_2 concentration in the parcels that include elementary schools is significantly and positively associated with the schools' socioeconomic deprivation level.

1. Introduction

Pollutant emissions emanating from road transportation are one of the most important nuisances in the urban environment and affect people's quality of life and health on a number of levels (WHO, 2010, 2011). In recent years, increased traffic flows on the road networks of many cities around the world have sparked growing interest in the study of the effects of pollutant emissions on the most vulnerable population groups. Young people have been found to be especially vulnerable to the effects of high concentrations of various road traffic-related pollutant emissions (Mejia et al., 2011) due to the fact that their nervous systems and organs are not fully developed (Bolte et al., 2010) and because they breathe in more air per unit of body mass (Landrigan et al., 2004). A few studies have put their attention on traffic-related pollutants concentrations in elementary schools classrooms, where children spend most of the time during a normal school day (McCarthy et al., 2013; Stranger et al., 2008). Other studies have also shown that young people who attend schools located less than 150 m from a major traffic artery are more likely to develop problems with asthma and reduced lung function (Brunekreef et al., 1997; Clark et al., 2010; Gauderman et al., 2007; Jerrett et al., 2008; Kim et al., 2008; McConnell et al., 2006; van Vliet et al., 1997). It has also been found that road traffic noise in the school environment affects children's cognitive development (Clark et al., 2010; Söderlund et al., 2007). Cognitive impairment is defined as the delayed development of psychomotor skills, language, coordination and motor capacities (Lopez et al., 2006). A number of authors have also reported that a high enough level of road traffic noise affects reading skills and memory in children (Evans and Lepore, 1993; Evans et al., 2001; Evans and Maxwell, 1997).

2. Literature review

Research in environmental justice initially concentrated on the presence of environmental hazards in neighbourhoods dominated by poor populations or specific racial groups in United States. Today, researchers are introducing new social categories (Walker, 2009, 2011) defined by age, level of disability, or gender (Buckinham and Kulcur, 2009). Walker (2009) suggests that different categories of people be taken into account, especially owing to differentiated vulnerabilities that vary from one group to another. In this sense a few authors have put their

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https://doi.org/10.1016/j.tranpol.2017.09.010
Received 23 August 2016; Received in revised form 30 May 2017; Accepted 18 September 2017
Available online 2 October 2017
0967-070X/

attention on the exposure of young people under 15 years of age to air pollution (Chaix et al., 2006; Gunier et al., 2003) and road traffic noise (Nega et al., 2013; Brainard et al., 2004). The analysis of the associations between pollutant levels and schools' differing socioeconomic status has moreover become a topic of interest in the environmental equity literature given the number of hours that children spend at school (Sampson, 2012). Studies have shown that, in the United States, elementary schools located in disadvantaged areas or with a high proportion of students from socioeconomically deprived neighbourhoods are more likely to be located near major traffic arteries (Chakraborty and Zandbergen, 2007; Green et al., 2004; Wu and Batterman, 2006). In Canada, a study by Amram et al. (2011) on the ten most populous cities reports that nearly a quarter of the elementary schools in the most socioeconomically deprived quintile are located less than 75 m from a major road, compared with 13% of schools in the most well-off quintile.

3. Research objective

Earlier studies carried out in the North American context have thus indicated that young people from low-income households are more likely to be overrepresented in the numbers of students attending schools located less than 150 m from a major traffic artery (Amram et al., 2011; Green et al., 2004) and where road traffic-related NO_2 concentrations are higher than in more affluent areas (Chakraborty and Zandbergen, 2007; Stuart and Zeager, 2011; Wu and Batterman, 2006). Other authors have reported that students attending a school showing a high level of socioeconomic deprivation are more likely to be exposed to significantly higher NO_2 levels (Carrier et al., 2014). This situation illustrates an important environmental equity issue, as children are more vulnerable to nuisances in their environment. The incomplete development of their organs and nervous systems makes them more likely to develop various health problems associated with a high concentration of pollutants (Clark

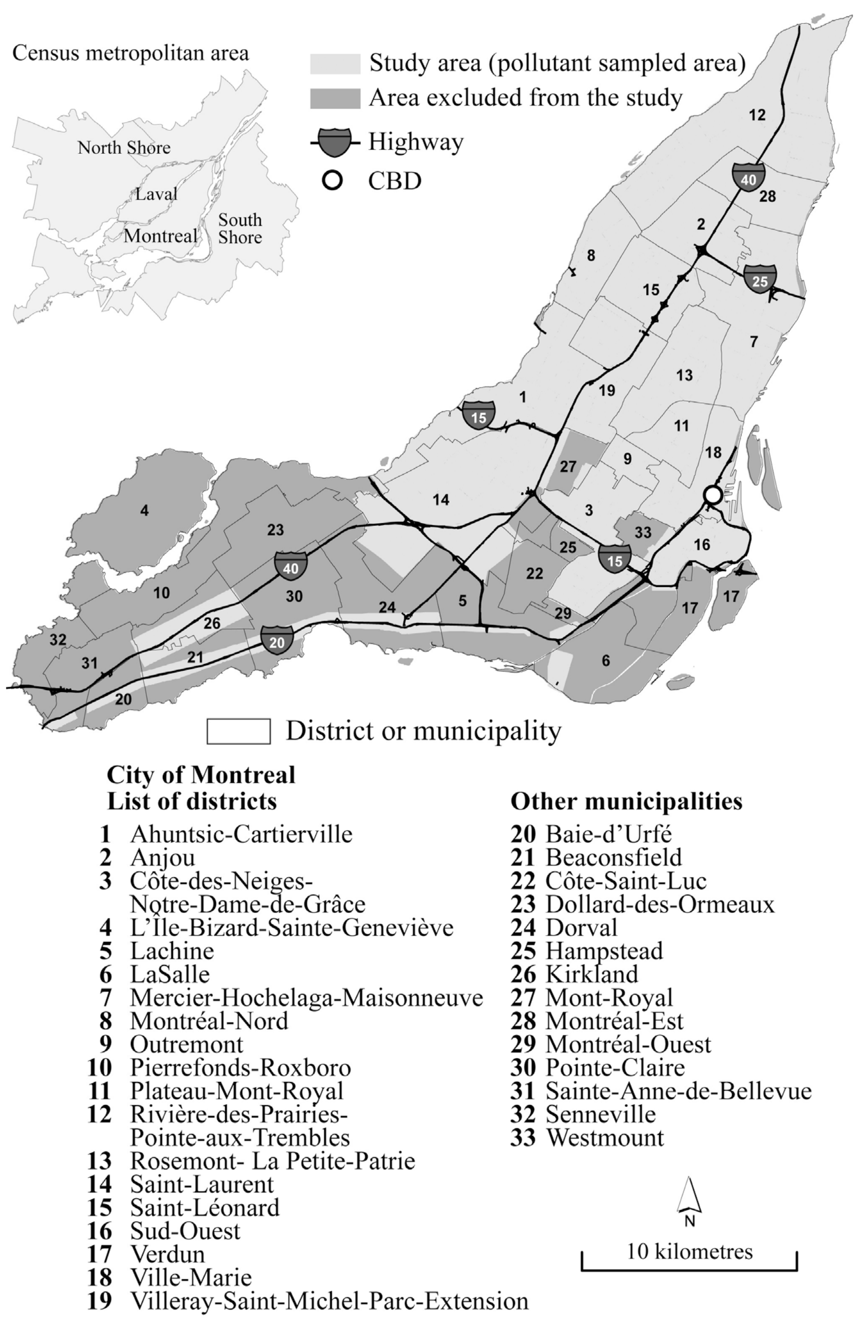

Fig. 1. Study area.

et al., 2012). Nor do children have the physiological mechanisms to adequately protect them from nuisances in their environment (Clark et al., 2012).

This study is guided by three main objectives. It is first a matter of determining whether the parcels of land in the study area that include elementary schools are located in environments where the levels of air pollutants (NO_2) and road traffic noise (dB(A)) are significantly higher than in the inhabited city blocks in the study area. We next attempt to develop an environmental equity assessment in order to determine whether the most disadvantaged Montreal elementary schools show higher air and road traffic noise pollution indicators than less deprived schools. Finally, we identify different practices in terms of land-use policies, transportation policies and other strategies related to building design to reduce the concentrations of traffic-related pollutants around schools.

4. Methodology

4.1. Study area

Our study focuses on 14 of the 19 boroughs on the territory of the Island of Montreal (Canada). Due to the lack of data on traffic flows for the collector and arterial road networks in the autonomous municipalities on the Island of Montreal, we were unable to conduct our research over the entire island. According to the most recent data from the 2011 Canadian census, there are 1.65 million inhabitants in the study area. There are also 234 elementary schools within this study area. For these schools, we measured the mean concentrations of air pollutants and road traffic noise levels in the parcel of land where the elementary school was located. Fig. 1 shows the territory covered by the study.

4.2. Scale of analysis and population groups considered

In order to evaluate the situation in terms of air and noise pollution near the schools, we used various statistical tools to compare the values obtained for the pollution indicators between, on the one hand, the parcels that include an elementary school and, on the other hand, the rest of the inhabited study area, in considering two population groups. The first group was children aged 5 to 12 given that this is the appropriate age category for students attending elementary school. 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 and road traffic noise indicators around the schools and the residential areas of the study area. We were thus able to see whether air pollution and road traffic noise levels for children in the study area were higher at school than in their home environment. We then looked at the total population per city block. For city blocks with an elementary school, the air pollution and road traffic noise levels are weighted by the number of students enrolled in each of them.

The data relating to these populations were taken from the 2011 Statistics Canada census on the scale of the dissemination area, which is the finest unit of analysis for which socioeconomic data are available. A dissemination area generally contains between 400 and 700 people. Several city blocks are entirely included within this spatial unit (Statistics Canada, 2011). For this study, we selected the city block as a spatial division, which is an even finer geographical unit than the dissemination area. Working at this spatial scale is essential in studies on the spatial dispersion of air pollutants and road traffic noise, as their respective concentrations can vary considerably on the scale of a neighbourhood or even of a dissemination area. However, for reasons of data confidentiality, Statistics Canada only releases figures for the total population on the scale of the city block. To overcome this problem, we estimated the number of individuals aged 5 to 12, for example, on the level of the city block through a proportional allocation technique previously used by Maantay et al. (2007).

$$t_b = t_d \frac{T_b}{T_d}$$

where t_b is the estimated number of 5–12 year-olds on the scale of the city block, td is this group's population on the level of the dissemination area, and T_b and T_d are the total populations in the city block and the dissemination area respectively.

4.3. Geocoding of elementary schools

We developed our list of Montreal elementary schools from the data available on the websites of the five school boards covering the study area. We then validated this list with data from the Québec Ministry of Education, Recreation and Sports. After this, the elementary schools were geocoded in a GIS (ArcGIS version 10.1) based on their postal codes. In Montreal, a unique postal code is associated to all the buildings located in a city block, a spatial unit which contains 100 to 300 persons. A final validation was done to ensure that the points for the schools were properly positioned within the parcel by using the online high-resolution imagery basemaps of ArcGIS (ESRI, 2011). The parcels that include the schools were derived from cadastral data available from the City of Montreal.

4.4. Determination of the elementary schools' socioeconomic deprivation levels

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 of all elementary schools located on the Island of Montreal (CGTSIM, 2015). To set these levels, the CGTSIM first develops an "overall underprivileged index" by using four variables from the 2006 Statistics Canada census and establishing their respective weight: namely, low household income (50%), mother's level of education (16.67%), lone-parent families (16.67%), and the percentage of families where neither parent works full-time among families with children under 18 years of age (16.67%). This index is applied to 470 homogenous zones determined by the CGTSIM and located on the Island of Montreal. Based on the postal code of the home address of the students associated with each of the 470 zones, the CGSTIM then assigns an "index of underprivileged status" to each elementary school. This index ranges from 0.47 to 44.69 (mean = 17.67 and SD = 9.04), that is, from a low to a high level of deprivation.

4.5. Air and road traffic pollution indicators

The operations involved in developing the pollution indicators were carried out in ArcGIS. To create the two types of pollution indicators, all of the indicator values were calculated both in the inhabited city blocks in the study area and in the parcels of land that include elementary schools. For the first type of pollution indicators, we used a series 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 (Crouse et al., 2009a). A map showing the concentrations of air pollutants for the entire Island of Montreal was then generated by using land-use regression (Crouse et al., 2009a). This technique involves constructing a regression equation by using the observations at the 133 points sampled, with the concentration of a pollutant 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 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, the equation is applied to the entire study area. Using the map of pollutant emissions thus produced, we then calculated the mean NO_2 values in all the inhabited city blocks in the study area and in each parcel of land that includes an elementary school. This air pollutant is generally recognized to be an adequate indicator of traffic-related pollutants due to its to its spatial association with NO_x, O_3 and $PM_{2,5}$ (Beckerman et al., 2008).

The second type of indicator is related to road traffic noise. This indicator includes two measurements, that is, the estimated minimal and maximal values, given that road traffic noise is calculated in the form of intervals. Road traffic noise levels were calculated by using the LiMA 5.0 software developed by the firm Bruël & Kjaer. This software, which is compatible with ArcGIS, has already been used in other environmental equity studies, notably those of Lam and Chan (2006), Brainard et al. (2004) and Carrier et al. (2016a). The XPS-31-133 calculation method and the Lden-day indicator were used to estimate road traffic noise levels during the weekday period (Monday to Friday, 7 a.m. to 6 p.m.) with the help of the 9.3.1 prediction module. This calculation method was recently employed in European Union countries to implement the environmental noise directive relating to road traffic noise (King et al., 2011). The parameters used to model road traffic noise are connected with traffic flows, the road geometry (road surface materials and number of traffic lanes), building heights, land elevation, the topography and the presence of noise barriers. The average summertime meteorological conditions were considered since that is the time of year when people are most likely to open their windows and thus be most affected by this nuisance (Belojevic et al., 2008). The summertime conditions represent the mean characteristics of air temperature and humidity for the months of September, October, May and June. These weather conditions also represent the time of the year where children are more susceptible to practice activities in the school parcel. Once the modelling of road traffic noise levels had been carried out, the mean levels of this nuisance were calculated in the inhabited city blocks and in the parcels with elementary schools. As is the case in Europe, Canadian authorities recommend that mean daily road traffic noise levels not exceed the 65 dB(A) threshold in residential areas and near sensitive-use facilities.

4.6. Statistical analyses

To determine whether there were environmental inequities affecting Montreal elementary schools showing higher levels of socioeconomic deprivation, we opted for four types of statistical analyses that are often used in making environmental equity assessments in regard to air pollutants (Briggs et al., 2008; Kingham et al., 2007) and road traffic noise (Brainard et al., 2004). In keeping with the first objective, the first two statistical analyses were used to determine whether the parcels with elementary schools were more polluted than were all the city blocks in the rest of the study area. They involved: 1) a comparison of the univariate statistics for the air and road traffic noise pollution indicators weighted by the number of students in Montreal elementary schools, the total population and the number of 5–12 year-olds per city block on the Island of Montreal; and 2) a T-test to compare the values obtained for the pollution indicators in the parcels with elementary schools and in city blocks weighted by the total population and the number of 5–12 year-olds. Next, in line with the second objective, two other statistical analyses were performed to determine whether the most disadvantaged Montreal elementary schools showed higher air and road traffic noise pollution indicators than were found with better-off schools, namely: 3) Spearman correlation coefficients between the elementary schools' socioeconomic deprivation levels and air and road traffic noise pollution indicators calculated in the parcel of land with the school; and 4) a T-test to compare the values of the pollution indicators between the extreme quintiles of the schools' level of socioeconomic deprivation. All of these analyses were conducted in SAS version 9.2.

5. Results

5.1. Univariate statistics

First, univariate statistics were calculated for the indicators measuring the levels of NO_2 and road traffic noise. These indicators were measured on the scale of the parcels in blocks that include a school and weighted by the number of students enrolled in Montreal elementary schools, and in the rest of the study area on the scale of city blocks and weighted by the total population according to the 2011 Canadian census and the number of 5–12 year-olds. The results are shown in Table 1. These statistics indicate that the NO_2 pollutant level is lower in the parcels with elementary schools compared with all the city blocks when weighted by the total population. So students at the elementary level go to schools where there is a slightly lower concentration of NO_2 (mean = 12.78 ppb, median = 12.65 ppb compared with 12.86 ppb and 12.65 ppb for the total population). However, the NO_2 concentrations are slightly lower in city blocks weighted by the number of 5–12 year-olds than in the parcels with elementary schools. In terms of road traffic noise, the mean level of this nuisance during the day is lower in school environments than in the rest of the study area whether weighted by the total population or the number of children aged 5 to 12. The differences are slightly greater when comparing the parcels with elementary schools and city blocks weighted by the total population in terms of the maximal values for road traffic noise (mean = 54.41 dB(A), median = 53.56 dB(A) compared with 56.90 dB(A) and 56.28 dB(A) for the total population).

5.2. Comparison of the means between parcels with elementary schools and Montreal city blocks weighted by the total population and the number of 5–12 year-olds

We then performed a T-test to compare the means for the two pollution indicators in the parcels with schools and in city blocks in the rest of the study area. Here again, in city blocks without a school, the pollution indicators are weighted by the number of 5–12 year-olds and then by the total population. For parcels with an elementary school, the indicators are weighted by the number of students enrolled in the

Table 1
Univariate statistics for the pollution indicators.

Indicator	Weighting	N	Mean	P5	P25	P50	P75	P95
NO_2	Total population	7785	**12.86**	8.95	**10.72**	12.65	**14.88**	**17.33**
	5-12 year-olds	7785	*12.62*	*8.84*	*10.54*	*12.37*	*14.51*	17.10
	Elementary schools	234	12.78	**9.31**	10.75	12.65	14.66	*16.88*
dB(A)-Min	Total population	7785	**51.83**	**45.06**	**48.42**	**51.26**	**54.91**	**60.39**
	5-12 year-olds	7785	51.65	45.01	48.19	50.93	54.79	60.45
	Elementary schools	234	*49.39*	*42.83*	*45.79*	*48.56*	*51.47*	*59.46*
dB(A)-Max	Total population	7785	**56.90**	**50.08**	**53.43**	**56.28**	**59.95**	65.86
	5-12 year-olds	7785	56.72	50.04	53.20	55.93	59.82	**65.93**
	Elementary schools	234	*54.41*	*47.83*	*50.79*	*53.56*	*56.47*	*64.46*

NO_2: mean concentration of NO_2 by city block, dB(A) – Min: minimal value of road traffic noise in the city block; dB(A) – Max; maximal value of road traffic noise in the 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.
The pollutant indicators have been calculated for all the city blocks weighted by the total population and the number of 5–12 year-olds. The pollutant indicators have been calculated for all the parcels that include a school weighted by the number of students enrolled in public elementary schools.

Table 2
Comparison of the mean values of the pollution indicators.

City blocks without schools (G1)	Parcelles avec des écoles primaires (G2)	NO2 (ppb)				Road traffic noise –Min. (dB(A))			
		Mean		Difference		Mean		Difference	
Weighting	Weighting	G1	G2	Diff	P	G1	G2	Diff	P
Total population	Enrolled students	12.86	12.78	0.08	0.63	51.83	49.39	2.44	0.000
5-12 year-olds	Enrolled students	12.62	12.78	−0.16	0.32	51.65	49.39	2.26	0.000
		Road traffic noise – Max. (dB(A))							
Total population	Enrolled students	56.90	54.41	2.59	0.000				
5-12 year-olds	Enrolled students	56.72	54.41	2.31	0.000				

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.
The pollution indicators have been calculated for all the city blocks without a public elementary school weighted by the total population and the number of 5–12 year-olds. The pollutant indicators have been calculated for all the parcels that include a school weighted by the number of students enrolled in public elementary schools.

associated elementary school (Table 2).

The parcels that include an elementary school show significantly (at a level of 0.05) lower means for minimal and maximal road traffic noise levels than found in Montreal city blocks weighted by the number of 5–12 year-olds and the total population. On the other hand, for NO_2 concentrations, no significant difference is found between the parcels with an elementary school and the rest of the city blocks in the area under study, whether weighted by the number of 5–12 year-olds or the total population. This indicates that, on average, Montreal elementary schools are located in parcels showing levels of NO_2 pollution comparable to those found in city blocks in the rest of the Island of Montreal, but that are characterized by a significantly lower level of road traffic noise.

5.3. Correlation between the pollutants and the proportions of the groups

Spearman correlation coefficients were calculated to see whether there were significant linear relationships between the Montreal elementary schools' socioeconomic deprivation levels and the NO_2 and road traffic noise indicators. Only one correlation was in fact significant although deemed to be relatively weak, namely, the correlation between the Montreal elementary schools' levels of socioeconomic deprivation, weighted by the number of students and the NO_2 concentration (0.185; $P = 0.005$), thus showing a slight environmental inequity for the most disadvantaged schools. Moreover, an increase in the elementary schools' level of socioeconomic deprivation is associated with a slight increase in the minimal and maximal level of road traffic noise in their immediate environment (0.084; $P = 0.203$), although this relationship is not significant.

5.4. Comparison of the means between the extreme quintiles of the schools' socioeconomic deprivation

A final statistical analysis was performed to compare the mean values of the pollution indicators between the extreme quintiles of the elementary schools' socioeconomic deprivation. The results of this analysis, shown in Table 3, indicate that the parcels with Montreal elementary schools in the most deprived quintile (Q_5) are more likely to be located in environments where the NO_2 concentrations are significantly higher. The noise level is also slightly higher in parcels with the most disadvantaged schools compared with parcels with less deprived schools, but this difference is not seen to be significant.

Table 3
Comparison of the mean values of the pollution indicators between the first and last quintiles of the school deprivation index weighted by the number of enrolled students.

NO_2 (ppb)				Road traffic noise (dB(A)) Min.			
Q1	Q5	Diff	P	Q1	Q5	Diff	P
11.80	12.92	−1.12	0.02	48.57	48.99	−0.42	0.68
Road traffic noise (dB(A)) Max.							
Q1	Q5	Diff	P				
53.60	54.00	−0.40	0.70				

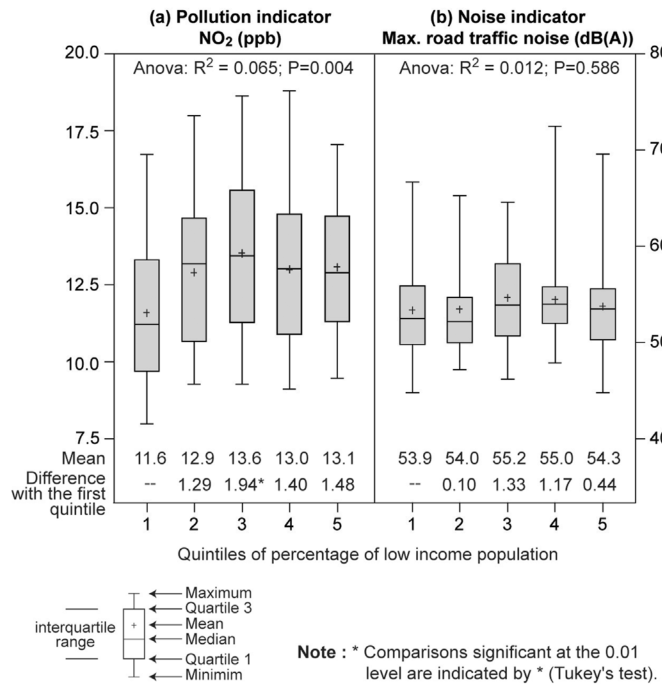

Fig. 2. Boxplots of NO_2 and road traffic noise according to the quintiles of deprivation of elementary schools.

An ANOVA-type statistical test was also used to determine the mean differences in the pollution indicators between all the quintiles of the elementary schools' deprivation. The objective here is to observe any potential discontinuities that may be found between these quintiles. So an additional finding emerges from an examination of the boxplots in Fig. 2. Schools in the middle quintile of deprivation (Q_3) show the highest mean concentrations of NO_2 and road traffic noise. Moreover, the mean concentrations of noise are relatively similar in schools in the first, second and fifth quintiles of deprivation, although the noise levels are slightly higher in this fifth quintile. These findings thus provide some interesting information that may be helpful in making an environmental equity assessment, and, in particular, the fact that it is not the schools in the most deprived quintile that show the highest values for the pollution indicators.

5.5. Identification of the elementary schools in the highest quintiles for the pollutants

We then grouped together schools characterized by NO_2 concentrations and road traffic noise levels that put them in the highest quintile for each of these nuisances. A concentration of 15.25 ppb for air pollution and a maximum road traffic noise level of 58.13 dB(A) are the respective minimum thresholds in the highest quintile for these nuisances. Overall, parcels with 19 schools show pollutant values that situate them in the highest quintiles for both air pollution and road traffic noise. Eight of these schools are located less than 500 m from a section of highway, and the others are situated next to a major road. The majority of these schools (that is, 16 of them) are located in the boroughs of Plateau Mont-Royal, Villeray-Saint-Michel-Parc-Extension and Rosemont-La Petite-Patrie. These boroughs are characterized by both high population densities and the presence of several major traffic arteries.

6. Discussion

6.1. Overview of the results

The results of the study show that the elementary schools are not located in environments that are more polluted when compared with the rest of the inhabited portion of the study area. There are however significant differences in the level of road traffic noise, which is lower in elementary school settings. The maximal level of road traffic noise is 54.41 dB(A) in parcels that include elementary schools, compared with 56.94 dB(A) in the rest of the inhabited portion of the study area. On the other hand, no significant differences were observed in NO_2 levels, in terms of the mean concentrations measured in the parcels with elementary schools compared with the rest of the inhabited study area. A positive but relatively weak correlation (0.185) was however found between the elementary schools' levels of deprivation and the NO_2 concentrations measured around these schools. A weak, positive correlation was also observed for road traffic noise (0.082), but it was not deemed to be significant. These results raise potential environmental equity issues for children from disadvantaged backgrounds, despite the fact that our findings do not point to any marked inequities for these children. Indeed, the overrepresentation of low-income individuals in the environments most polluted by road transportation has been reported in the context of various studies in the United Kingdom (Brainard et al., 2002; Briggs et al., 2008; Mitchell, 2005; Namdeo and Stringer, 2008; Wheeler et al., 2008), New Zealand (Kingham et al., 2007) and the United States (Grineski, 2007; Morello-Frosch et al., 2001; Sheppard et al., 1999). It is however important to remember that, in our study, NO_2 and road traffic noise levels (dB(A)) are highest in schools in the middle range of socioeconomic deprivation (Q_3) and that are mainly located in the boroughs of Plateau-Mont-Royal, Rosemont-La Petite-Patrie, and the Villeray sector, which are not considered to be high-poverty areas (Seguin et al., 2012a, b). Similar findings were also obtained by Bocquier et al. (2012) and Havard et al. (2011) in their studies on road traffic noise, conducted in Marseille and Paris respectively.

We believe that our results related to the environmental equity assessment could be partially explained by the fact that we remove a small portion of the territory of the Island of Montreal. Data on traffic flows on arterial and collector networks were not available for 3000 city blocks located in some autonomous municipalities and certain boroughs in the south-western part of the island, so we were unable to model road traffic noise in those areas. The socio-economic profile of these areas differs considerably from that of the study area that we examined. These areas in fact show a much lower concentration of low-income individuals (14.44%, compared with 32.02%) (Carrier et al., 2016b). This portion of territory also includes 75 elementary schools where the mean socioeconomic deprivation level is 9.83 (S.D 7.59) in comparison to 17.67 for our study area. Moreover, these generally less densely inhabited areas, which are predominantly residential, are characterized by a lower-density road network, so that traffic flows are lighter than those in our study area (Carrier et al., 2016b). Consequently, it is very probable that we would have concluded that there were greater environmental inequities for low-income children aged between 5 and 12 years old in comparison to those who attend school where the level of deprivation is lower.

This exclusion has helped to reduce the differences observed in the levels of air pollutants, and possibly of road traffic noise, between the extreme quintiles of the elementary schools' socioeconomic deprivation. The study by Carrier et al. (2014) on air pollution, for example, showed that there was a 2.98 ppm difference in NO_2 concentrations between the extreme quintiles of the elementary schools' deprivation when all the elementary schools on the Island of Montreal were taken into account (Carrier et al., 2014). In our study, the difference in NO_2 levels between the extreme quintiles of deprivation was only 1.12 ppm. A number of studies in the environmental equity stream have in fact documented the way that the choice of parameters can influence the results obtained (Anderton et al., 1994; Most et al., 2004; Walker, 2011).

6.2. Identification of problematic schools and associated risks

The values of the pollution indicators measured in the parcels of land that include the 234 elementary schools in the study area vary considerably from one sector to another. For example, NO_2 levels are, on average, less than 10 ppb in the least densely inhabited boroughs in the study area which are also characterized by a lower-density road network. In general, the elementary schools are located in parcels of land where air pollution and road traffic noise levels are lower than the average for the study area. However, 19 schools show pollution indicators approaching the tolerance thresholds set by transportation and public health authorities. Ten of these schools are located in parcels where road traffic noise levels surpass the 65 dB(A) noise threshold. On the other hand, none of the parcels with elementary schools show a NO_2 value greater than 21 ppb, the maximum daily threshold of acceptability that the WHO has established for this pollutant. Fig. 3 illustrates these two types of cases. In the first two examples (3a and 3b), the parcels with these schools are located in environments with some of the highest levels of air pollution and road traffic noise. In the third case (3c), this elementary school is located in a parcel where the NO_2 level is less than 10 ppb and the maximum noise level is 45 dB(A).

6.3. Potential solutions to reduce traffic-related pollutants around elementary schools

In light of health risks associated to the high levels of traffic-related pollutants along major roads and highways, several possible solutions are available to authorities wishing to reduce the concentrations of road transportation-related pollutants around schools. In a summary on the topic, the United States Environmental Protection Agency (EPA) recommends a strategy that simultaneously combines aspects associated with urban planning in order to minimize usage conflicts, the promotion of active transportation, and the consideration of characteristics linked to the design of schools and school ventilation systems (EPA, 2015). Each of these aspects is examined in greater detail below.

Firstly, in terms of land-use policies, a few American states and some Canadian provinces have set tighter urban planning standards in regard to the establishment of sensitive-use facilities such as schools near these major traffic arteries. Among the potential interventions, the urban authorities could, when is possible, promote the setting of industrial, commercial or institutional functions along these major traffic arteries because these functions permit to capture a large part of the traffic-related pollutants that comes from the highways or other major roads (FHWA, 2002). Also, through the zoning by-law, the municipalities in North America could regulate or prohibit certain land uses (for example elementary schools), taking into account a certain distance from highways or other major roads for reasons of public health and general welfare. Moreover, the municipalities could identify standards to meet

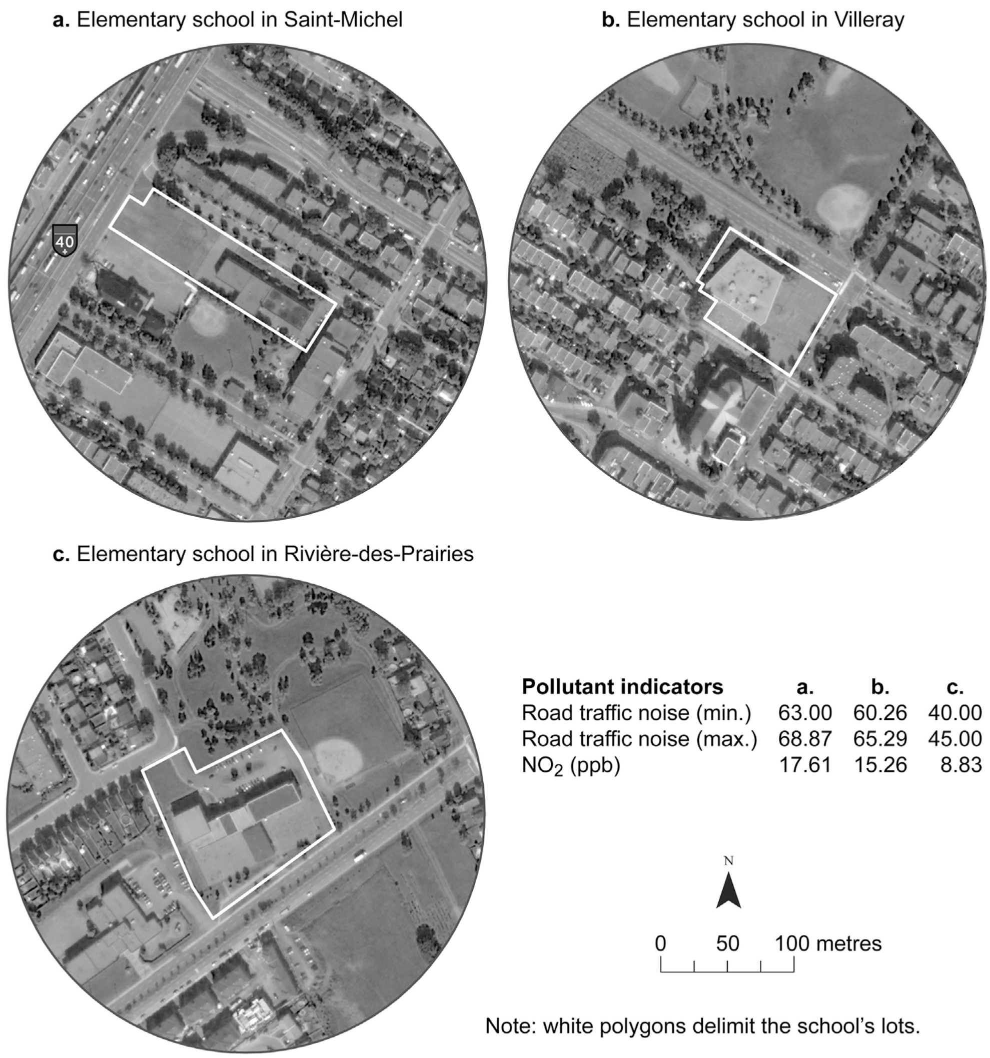

Fig. 3. Examples of public elementary school with low and high level of pollutants.

for the development of new sensitive-use facilities through their zoning by-law. For example, in the case of new schools, these standards could specify the distance and the orientation of the main building and their schoolyard from the road to ensure their optimal implantation. For the schools already constructed, a few interventions have been recently proposed to reduce traffic-related pollutants in urban areas. The City of Montreal, the second largest in Canada, has recently conducted an experiment to reduce the speed limits on his arterial network. That kind of project could be implanted around 1 km from all elementary schools to reduce road traffic noise and air pollution.

Secondly, in terms of transportation policies, the Québec Ministry of Transportation has recently decided to develop a new operational framework which includes an adequate budget allocation to protect the sensitive-use facilities that are located at less than 150 m from a highway section on the Island of Montreal. For example, the Québec Ministry of Transportation is actually rebuilding some parts of an important highway on the Island of Montreal where the annual average daily traffic volumes is more than 150,000 vehicles per day. The redevelopment of this road infrastructure provides a unique occasion to the Québec Ministry of Transportation to propose the adequate mitigation measures to minimize the levels of traffic related pollutants along the sensitive-use facilities located at less than 150 m from these highway sections during the construction period and once the project has been completed. In regard to municipal transportation policies, school boards, in partnership with City of Montreal authorities, could foster the building of safe walking and cycling paths for students in areas around primary schools. Setting up physical facilities, widening sidewalks, and adding pavement markings would enhance users' feelings of safety and encourage children's practicing of physical activity. This type of measure would be doubly effective in that, on the one hand, motorists would have to reduce their speeds on the road network, and, on the other hand, there would be fewer buses and other motor vehicles around primary schools during the morning and evening rush hours, as children would walk more. This would then be greatly beneficial in both reducing pollutant emissions and improving the soundscape (Woodcock et al., 2009; Giles-Corti et al., 2010).

Thirdly, although it is vital to act on the characteristics of the urban environment around the school, one can also intervene on the level of building design and, more particularly, in regard to the school's ventilation system. Most of the schools considered in the study area were built during the first part of the twentieth century. Some of them have very old ventilation systems, so that they have to open their windows during the hottest months of the year. This means that students are exposed to both air pollutants from outside the school and noise pollution. Given the positive impacts of indoor air quality on student success (Mendell and Heath, 2005), the EPA (2012) has recommended that central heating, ventilation and air-conditioning (HVAC) systems be used as much as possible in schools. Improving indoor air quality in primary schools also involves using a filtration system (McCarthy et al., 2013). From a perspective where public funding may soon be allocated to renovate the oldest Island of Montreal schools, most of which are located in central districts, the setting up of high-quality ventilation systems seems to be one potential solution designed to reduce, at least in part, children's potential exposure to traffic-related pollutants.

Finally, the concept of compensatory equity could be put in practice to minimize traffic-related pollutants near elementary schools associated with the highest levels of air pollution and road traffic noise. Putting into practice, mitigation measures could be fund by the transportation authorities and might build noise barriers along the schools and plant threes in the schoolyards (Carrier et al., 2014). These mitigation measures could be applied by the different schools boards by targeting the most underprivileged schools in their own territory in order to reduce the potential environmental inequities.

7. Conclusion and limitations

The continual increase in traffic flows along cities' main road networks has meant a rise in the levels of the associated environmental nuisances. It is vital that the authorities acquire the necessary tools to effectively evaluate the intensity of the nuisances related to increased traffic flows on the Island of Montreal's main road network and consider the associated health risks. Our study has shown that the elementary schools that we examined are not located in environments that are significantly more polluted than the rest of the study area. Moreover, we found only a weak significant correlation between the schools' level of deprivation and the NO_2 concentration measured in the parcels in question. This result is probably attributable, at least in part, to the fact that the area covered by the study did not encompass the entire island, as some of the data were unavailable. We did however identify 10 elementary schools showing road traffic noise levels exceeding the tolerance thresholds set by the Québec Ministry of Transportation. These schools could be monitored by public health authorities to ensure that road traffic noise levels not exceed the 65 dB(A) threshold and that corrective measures be taken should this prove to be the case.

In conclusion, one of the main limitations of this study resides in the fact that we have only considered one traffic-related pollutant (NO_2) although children are exposed to others in their school environment. One more main limitations of this study is related to the fact that we measured the spatial concentration of air pollutants and road traffic noise in the school environment using geostatistical methods and modelling techniques. We are consequently unable to establish the children's actual exposure to these pollutant emissions. It would therefore be interesting, in future studies, to measure the children's exposure to traffic-related pollutants as $PM_{2.5}$, PM_{10} and NO_2 and road traffic noise by using personal monitors to determine whether these children are in fact exposed to levels that could negatively affect their health and well-being.

Acknowledgements

We thank Mark Goldberg (department of medicine, McGill University) for the provision of the NO_2 data pollution. We thank the anonymous reviewers for their careful reading of our manuscript and their many insightful comments and suggestions.

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