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Spatial distribution of vegetation in and around city blocks on the Island of Montreal: a double environmental inequity?

Abstract

Recent studies have shown that urban vegetation is unevenly distributed across numerous North American cities: neighbourhoods predominantly inhabited by low-income populations and/or by certain ethnic groups have less vegetation cover. The goal of this paper is to examine the existence of environmental inequities related to access to urban vegetation on the Island of Montreal for four population groups (low-income people, visible minorities, individuals 0-14 years old and persons 65 years old and over). Six indicators of vegetation in and around residential city blocks (within 250 m and 500 m) are computed by using QuickBird satellite images. These indicators are then related to socioeconomic data by using different statistical analyses (T-test, seemingly unrelated regression and multinomial logistic regression). The results show that low-income people and, to a lesser degree, visible minorities reside in areas where vegetation is less abundant. On the other hand, the opposite situation is found for children and the elderly. The use of indicators computed in and around city blocks leads to the finding of a double inequity in certain neighbourhoods. This points to the need to target vegetation-deprived areas for urgent greening in order to improve vegetation cover within city blocks (in residential yards or through alternatives such as green walls and green roofs) and around these blocks (along streets and in parks).

Keywords: urban vegetation; environmental equity; environmental justice; spatial analysis; remote sensing; seemingly unrelated regression; Montreal.

1. Introduction

Most large cities around the world have acknowledged the crucial role of nature in the city. North American cities are no exception: they have recognized the important part that urban vegetation plays in the quality of life by implementing tree preservation and tree planting measures in both the United States (Hubacek & Kronenberg, 2013) and Canada (City of Montréal, 2011; City of Toronto, 2013). Moreover, the many benefits of urban vegetation have recently been documented, on the biophysical, health, social and economic levels. Numerous studies have shown that vegetation helps to improve the quality of the urban environment by reducing air and noise pollution, capturing a portion of the carbon in the air, helping to save energy, and, more vitally, minimizing the negative impacts that heat islands have on the health of populations (Mullaney, Lucke, & Trueman, 2015; Roy, Byrne, & Pickering, 2012). In terms of people's well-being and social benefits, a number of authors from various disciplines note that the presence of vegetation helps to lower stress levels and contributes to the social integration of the elderly, children and adolescents, especially in multiethnic urban areas (de Vries, van Dillen, Groenewegen, & Spreeuwenberg, 2013; Taylor, Wheeler, White, Economou, & Osborne, 2015). Finally, on the economic level, other scholars emphasize that vegetation can be profitable for cities (Mullaney, et al., 2015), for example by reducing electricity consumption and increasing property values (Donovan & Butry, 2010).

Several recent studies have however shown that urban vegetation is not equitably distributed across North American cities, to the detriment of certain population groups such as low-income households and visible minorities (e.g. Landry & Chakraborty, 2009; Pham, Apparicio, Séguin, Landry, & Gagnon, 2012; Schwarz, et al., 2015; Tooke, Klinkenberg, & Coops, 2010). These studies frequently use high resolution satellite images (e.g. QuickBird, Ikonos imagery, etc.) to build vegetation indicators, spatial census data integrated into Geographical Information Systems (GIS) and statistical methods to explore the associations between vegetation indicators and socioeconomic variables. The approach taken here is in line with this type of studies: its objective is to verify the existence of environmental inequities regarding access to urban vegetation on the territory of the Island of Montreal for the four population groups most often examined in studies on environmental equity: that is, low-income populations, visible minorities, children and the elderly. The article focuses in particular on access to vegetation within residential city blocks, as well as around these blocks, in order to determine whether some groups are more likely to be affected by a double inequity than others.

The study attempts to answer three research questions. The first question is: Where are the areas located that have little vegetation both in and around the city block, and, conversely, that have a large amount of vegetation in and around the city block? The second question is: Do children, seniors, low-income populations and visible minorities live in areas with little vegetation in and around their city block? The third question is: After controlling for the characteristics of the built environment (population density and age of the neighbourhoods), do the four population groups studied live in residential areas with proportionately more or less vegetation?

The paper is organized as follows. It begins by discussing the notion of environmental equity as applied to urban vegetation, in emphasizing the use of vegetation indicators on a number of scales. It then describes the methodological approach taken in this study, which combines multisource data (satellite images, GIS data from the City of Montreal and census data) and various methods from the fields of GIS, remote sensing, and spatial analysis. After this, a concise presentation of the results is followed by a discussion of the findings.

2. Literature review

Walker (2012) identifies and defines three dimensions of environmental justice: distributive justice, procedural justice and justice as recognition. The first is understood in terms of the distribution or sharing of beneficial elements (resources) and negative elements (sources of risk). The second dimension refers to the ways that decisions are made, who is involved, and who has the power to influence such decisions. The third is based on the idea of respect for all individuals in a given society and rejects the manifestation of disrespect toward particular social groups. Environmental justice thus recognizes that all individuals in a given society, regardless of their status, have the right: 1) to live in a healthy environment with access to basic territorial resources; and 2) to participate in the process of formulating laws, policies and environmental regulations.

This study is interested in the first dimension: that is, environmental equity or distributive justice. Several studies carried out in North America and based on different methodologies have demonstrated the existence of environmental inequities in terms of access to vegetation for low-income populations (Heynen, 2006; Landry & Chakraborty, 2009; Pham, et al., 2012; Tooke, et al., 2010). In Canada, Tooke, et al. (2010) find that the amount of vegetation is negatively associated with the percentage of low-income persons per census tract, whereas it is positively associated with median and average incomes for both individuals and households, in Montreal, Toronto and Vancouver. However, the correlation between the percentage of immigrants and the amount of vegetation is only negatively significant in Toronto. In Montreal, Pham, et al. (2012) conclude that low-income populations and, to a lesser degree, visible minorities, live in city blocks where there is less vegetation on average. In the United States, the results are however less conclusive for racial minorities. In Tampa, Landry and Chakraborty (2009) show that, the percentage of tree cover on streets declines as the proportions of African-American and Hispanic residents rise. In Baltimore and Milwaukee, on the other hand, African Americans do not seem to have more limited access to vegetation, unlike the case for Hispanic residents (Heynen, 2006; Troy, Grove, O'Neil-Dunne, Pickett, & Cadenasso, 2007).

Many studies on environmental equity and vegetation look at vegetation within city blocks or census block groups (Landry & Pu, 2010; Pham, Apparicio, Landry, Séguin, & Gagnon, 2013; Pham, et al., 2012; Troy, et al., 2007). This spatial approach, although interesting, leaves room for improvement. An individual may in fact live in a block with largely impervious surfaces—in other words, in a block with little vegetation—whereas there is a large amount of vegetation cover around that block, and vice versa. For example, a person may live in a block with very little vegetation, primarily consisting of high-density housing, but that faces a large park. On the other hand, little vegetation in the immediate environment around the residential block would represent a double disadvantage. In other words, evaluating the existence of vegetation cover should not be spatially limited to the block where the person lives, but should also include the immediate environment around the block. Indeed, if, compared with the rest of the population, a population group is overrepresented in spaces with little or no vegetation both in and around the residential city block, this constitutes a double environmental inequity. Because some authors (Bowen, 2002; Cutter, Holm, & Clark, 1996) have emphasized the relevance of examining exposure to nuisances or access to benefits on a number of spatial scales (e.g. census tracts, block groups, census blocks, buffer zones), this study uses a method of evaluating distributional inequity that involves measuring the access to vegetation on several scales: within the city block, and within 250 and 500 metres around the residential block.

In environmental equity studies related to the distribution of vegetation, it has been shown that the presence of vegetation is negatively associated with residential density and the age of the built environment (Grove, et al., 2006; Landry & Chakraborty, 2009; Mennis, 2006; Pham, et al., 2013; Pham, et al., 2012). In the case of the Island of Montreal, low-income populations and visible minorities are concentrated in central City of Montreal neighbourhoods that often have the highest residential densities and an older built environment (Séguin, Apparicio, & Riva, 2012). Conversely, young children are more often found in suburban municipalities with a recent built environment and low residential density. The elderly, on the other hand, are concentrated both in central neighbourhoods and in the first-ring suburbs of the Island of Montreal (Séguin, Apparicio, & Riva, 2015). It is therefore appropriate to control for these two characteristics of the built environment in order to arrive at an accurate environmental equity assessment.

3. Study area and methodology

The study covers the territory of the municipalities on the Island of Montreal, which extends over roughly 500 km^2 and included 1.85 million inhabitants in 2006. This territory is the central part of the Montreal census metropolitan area (CMA), which is the second most populous metropolis in Canada (with 3.92 million inhabitants).

3.1. Data processing

To answer the research questions, two sets of data were employed. QuickBird images (acquired in September 2007, 60 cm resolution) were used to map two types of vegetation, that is, trees/shrubs and grass/lawn, based on an object-oriented classification performed in e-Cognition (Pham, Apparicio, Séguin, & Gagnon, 2011); and socioeconomic data were extracted from the 2006 census on the level of the dissemination area.

It was then a matter of defining the spatial entities in which the socioeconomic and vegetation indicators would be calculated. As several other authors had done (Pham, et al., 2013; Pham, et al., 2012), we selected the finest spatial division, that is, the city block. Two buffer zones were defined around the block within a radius of 250 and 500 metres, excluding the block itself. The second step was to build the six vegetation indicators: the proportions of the surface area of the block that were completely covered by total vegetation (trees/shrubs and grass/lawn) and by trees/shrubs alone; the proportions of the surface area of the buffer zones of 250 and 500 metres around the block that were covered by total vegetation and by trees/shrubs. These two distances were chosen in order to define immediate environments that can easily be reached on foot. These two distances have moreover already been used in Montreal in studies on the accessibility of services (Apparicio, Abdelmajid, Riva, & Shearmur, 2008; Apparicio, Séguin, & Naud, 2008).

The third step was to bring the numbers of the four groups studied —children under age 15, people aged 65 and over, the population with low income before tax, and visible minorities[1]—extracted from the 2006 census down to the level of city blocks. It should be noted that the only three variables available from Statistics Canada on the scale of the dissemination block (i.e. city block) were the total population, the number of households and the number of occupied dwellings. To bring the data available on the level of the dissemination area (DA, i.e. city block group in the United States), that is, a spatial area larger than that of the city block, down to the city block level, a population-based weighting technique, as proposed by Pham et al. (2012), was used. For example, to bring the number of children under age 15 from the DA level down to the city block level, the number of children in the DA in which the block was located was multiplied by the total population of the block divided by the total population of the DA:

$$Pop014_{Block} = Pop014_{DA} \frac{TotalPop_{Block}}{TotalPop_{DA}} \quad [1]$$

3.2. Measuring environmental inequity: Mapping and statistical analyses

To answer the first research question—locating areas with little vegetation both in and around the city block—a mapping technique is used based on a cross tabulation composed of the quintiles of two vegetation indicators (the percentage of vegetation in the block and within 250 metres around the block). A typology of the blocks can then be developed according to the various possible combinations between the quintiles of the two variables. For

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[1] According to Statistics Canada, "Visible minority refers to whether a person belongs to a visible minority group as defined by the Employment Equity Act and, if so, the visible minority group to which the person belongs. The Employment Equity Act defines visible minorities as 'persons, other than Aboriginal peoples, who are non-Caucasian in race or non-white in colour.' The visible minority population consists mainly of the following groups: Chinese, South Asian, Black, Arab, West Asian, Filipino, Southeast Asian, Latin American, Japanese and Korean" (Statistics Canada, 2010: 104-105).

example, blocks in the fifth quintile for the two indicators are characterized by the highest level of vegetation in and around the city blocks. Conversely, blocks in the first quintile for the two indicators have little vegetation both in and around the city block. With this technique, it is thus possible to identify sectors with a large amount of vegetation within the blocks, but little around the blocks, and vice versa.

Three types of statistical analyses are used to answer questions 2 and 3, and, more specifically, to evaluate the statistical relationships between the variables pertaining to the four groups studied and the six vegetation indicators (the univariate statistics for these can be found in Table 1). To answer the second question, we compare the means of the vegetation indicators for the 10,210 blocks weighted by the numbers of the population of each group with the rest of the population (for example, the population under age 15 compared with the population aged 15 and over). The Student's T-test, widely used in environmental equity studies (Briggs, Abellan, & Fecht, 2008; Carrier, et al., 2016; Carrier, Apparicio, Séguin, & Crouse, 2014a, 2014b), makes it possible to determine whether the four groups studied live in environments with significantly less vegetation than is the case for the rest of the population.

To answer question 3, regression models are used. As mentioned above, the population density and age of the neighbourhoods should be taken into account in equity analyses related to vegetation. Once these two characteristics have been controlled for in a regression model, this will show whether there are still significant associations between the vegetation indicators and the proportions of the four groups studied. It should be noted that the median age of the residential buildings in the blocks is also introduced in a squared form, as several authors (Grove, et al., 2006; Mennis, 2006; Pham, et al., 2012) have shown that this variable has a curvilinear relationship with the vegetation indicators. Also, for reasons of normality, the population density variable (inhabitants per hectare in the block) has been introduced in logarithmic form.

The first type of regression used is a seemingly unrelated regression (SUR). Four models in R (version 3.1.2) are built with the *systemfit* library (Henningsen & Hamann, 2015). A particularity of this model is the fact that the two equations are estimated simultaneously in order to express: the percentage of the surface area of the block covered by total vegetation or by trees/shrubs (y_1); and the percentage of total vegetation or trees/shrubs in buffer zones of 250 and 500 metres around the block, excluding the block itself (y_{250} or y_{500}), where y is a dependent variable vector of dimension (N × 1), with N being the total number of blocks analyzed (10,210). The model assumes that the two dependent variables (y_1 and y_{250} or y_{500}) are related to two distinct sets of explanatory variables: one set of variables describing the built environment in the block ($\boldsymbol{X}_1$) and the built environment within a 250 or 500 metre radius ($\boldsymbol{X}_{250}$ or $\boldsymbol{X}_{500}$); and another set of variables relating to the proportion of the four groups studied in the total population living in the block ($\mathbf{X}_2$) (equations 2 and 3).

$$y_1 = \alpha_1 + X_1\beta_1 + X_2\theta_1 + \varepsilon_1 \qquad [2]$$

$$y_{250} = \alpha_2 + X_{250}\beta_{250} + X_2\theta_2 + \varepsilon_2 \text{ or } y_{500} = \alpha_2 + X_{500}\beta_{500} + X_2\theta_2 + \varepsilon_2 \qquad [3]$$

Where the matrices of the explanatory variables, $\boldsymbol{X_1}$, $\boldsymbol{X_{250}}$ or $\boldsymbol{X_{500}}$ and $\boldsymbol{X_2}$, are, respectively, of dimensions (N × 3), (N × 3) and (N × 4) and where the parameters of interest (to be estimated) of the built environment $\boldsymbol{\beta_1}$, $\boldsymbol{\beta_{250}}$ and $\boldsymbol{\beta_{500}}$ are of dimensions (3 × 1) and those of population groups $\boldsymbol{\theta_1}$, $\boldsymbol{\theta_2}$ are of the dimensions (4 × 1). The parameters α_1 and α_2 represent the intercepts and $\boldsymbol{\varepsilon_1}$ and $\boldsymbol{\varepsilon_2}$ represent the vectors of the error terms of the dimensions (N × 1). A system of equations was chosen since authors such as Zellner (1962, 1963) have shown that when the equations are interrelated via the correlation of the error terms and the explanatory variables in the two equations are different, the coefficients estimated by means of independent equations are biased and the estimated variance-covariance matrix is inaccurate, which thereby invalidates the tests of significance of the parameters. For this reason, and especially to take into account the fact that the relationships are implicitly interlinked, the model is estimated by using seemingly unrelated regression (SUR).

Finally, another type of regression is used: that is, multinomial logistic regression with, as the dependent variable, the different types of blocks qualified according to the abundance of vegetation in the block and around the block (as identified by the mapping technique mentioned above). The percentages of each of the four population groups and the variables relating to the built environment in and around the block are introduced as independent variables. This will make it possible to see whether the percentages of each of the four population groups increase the probability of residing in a particular type of block.

Table 1. Univariate statistics for the vegetation indicators, two control variables and the four groups studied.

Variables	Mean	STD	P10	Q1	Q2	Q3	P90
Indicators within the block							
Vegetation (%)	35.1	18.6	11.5	20.3	33.8	49.0	60.5
Trees/shrubs (%)	16.0	11.6	3.2	6.8	13.2	23.6	33.0
Density (inhabitants/ha)	87.8	74.0	22.4	36.9	68.4	120.5	173.1
Median age of residential buildings	52.1	25.2	21.0	37.0	49.0	61.0	91.0
0-14 years old (%)	15.9	5.3	9.5	12.5	15.9	19.3	22.2
65 years old and over (%)	14.9	8.3	6.4	9.6	13.9	18.2	23.2
Visible minorities (%)	21.0	16.4	3.9	8.3	17.2	29.6	43.0
Low-income population (%)	23.6	16.0	4.8	11.1	21.3	33.7	45.9
Indicators within 250 metres							
Vegetation (%)	37.6	15.1	18.1	25.8	36.9	48.2	57.8
Trees/shrubs (%)	16.1	9.6	5.8	8.4	13.9	22.3	29.5
Density (inhabitants/ha)	87.8	74.0	22.4	36.9	68.4	120.5	173.1
Median age of residential buildings	53.2	22.9	25.0	40.0	50.0	62.0	91.0
Indicators within 500 metres							
Vegetation (%)	38.0	14.2	20.2	26.7	37.5	47.6	56.8
Trees/shrubs (%)	16.0	9.2	6.2	8.7	13.8	21.8	28.6
Density (inhabitants/ha)	83.3	71.0	20.8	34.7	64.8	114.8	165.4
Median age of residential buildings	53.1	22.3	25.0	39.0	50.0	61.0	91.0

N = 10,210. STD: standard deviation; P10: 10th percentile; Q1: lower quartile; Q2: median; Q3: upper quartile; P90: 90th percentile.

4. Results

4.1. Spatial distribution of the vegetation indicators

To simplify matters, and also due to lack of space, the vegetation indicators in the block and within 250 metres around the block are only being presented, for a total of four indicators (Figure 1). It should however be noted that the results mapped within 500 metres around the block are very similar to those within 250 metres. Moreover, the indicators are only mapped for blocks on the Island of Montreal with a resident population. It should also be noted that the choropleth maps in Figure 1 are built by using the quantiles classification with five classes (i.e quintiles). That means each category contains 20% of 10210 blocks which makes it possible to easily compare the four maps.

Figure 1 shows that the vegetation indicators clearly vary considerably across the Island of Montreal's territory. For boroughs within the City of Montreal, there is a fairly clear gradient from the centre to the periphery for the four indicators overall: blocks in more densely-populated central boroughs of the Island of Montreal (Ville-Marie and Plateau-Mont-Royal) often show less vegetation compared with blocks in more outlying boroughs (Rivière-des-Prairies-Pointe-aux-Trembles, Ahuntsic-Cartierville and Pierrefonds-Roxboro). And it is no surprise that blocks in suburban municipalities at the western end of the island, as well as in wealthier municipalities in the centre of the island (Mont-Royal, Westmount, Côte-Saint-Luc, Hampstead and Montréal-Ouest with high median household income and low proportion of low-income households) (Apparicio, Cloutier, & Shearmur, 2007; Séguin, et al., 2012), show higher levels of vegetation.

The cross tabulation of the quintiles of two vegetation indicators—the percentages of vegetation in the block and within 250 metres around the block (Figure 1a and 1c)—is mapped in Figure 2. Nine categories of blocks are thus obtained. The two categories in grey are characterized by little vegetation both in the block and within a 250-metre radius. Blocks in dark grey (the first quintile for the two indicators) cover 6.5% of the surface area of the Island of Montreal, compared with 11.5% for blocks in light grey. These two types of blocks are mostly found in central boroughs of the City of Montreal: that is, in Ville-Marie, Plateau-Mont-Royal and Mercier-Hochelaga-Maisonneuve (Figure 2). At the opposite extreme, the two types of blocks in green consist of blocks in the last quintiles of the two vegetation indicators: that is, those with the highest levels of vegetation in and around the city block. They are very often found in municipalities in the West Island and in wealthy municipalities in the centre of the island such as Mont-Royal and Westmount. Blocks in dark green (the fifth quintile for both indicators) in fact cover 31% of the total surface area of residential blocks, compared with 16.6% for blocks in light green. Blocks in red (6.6%) and blue (10.9%) present distinct particularities in terms of vegetation cover. In red are areas with low or medium levels of vegetation within the block (Q1 to Q3), but high levels of vegetation around the block (Q4 and Q5). These are mainly blocks with generally impervious surfaces situated next to a large city park. Areas in blue have high levels of vegetation within the block (Q4 and Q5), but low or medium levels of vegetation around the block (Q1 to Q3). These may for example include very green residential blocks typically found in suburbs adjacent to industrial or commercial areas. Finally, blocks in yellow (16.6%) have medium levels of vegetation.

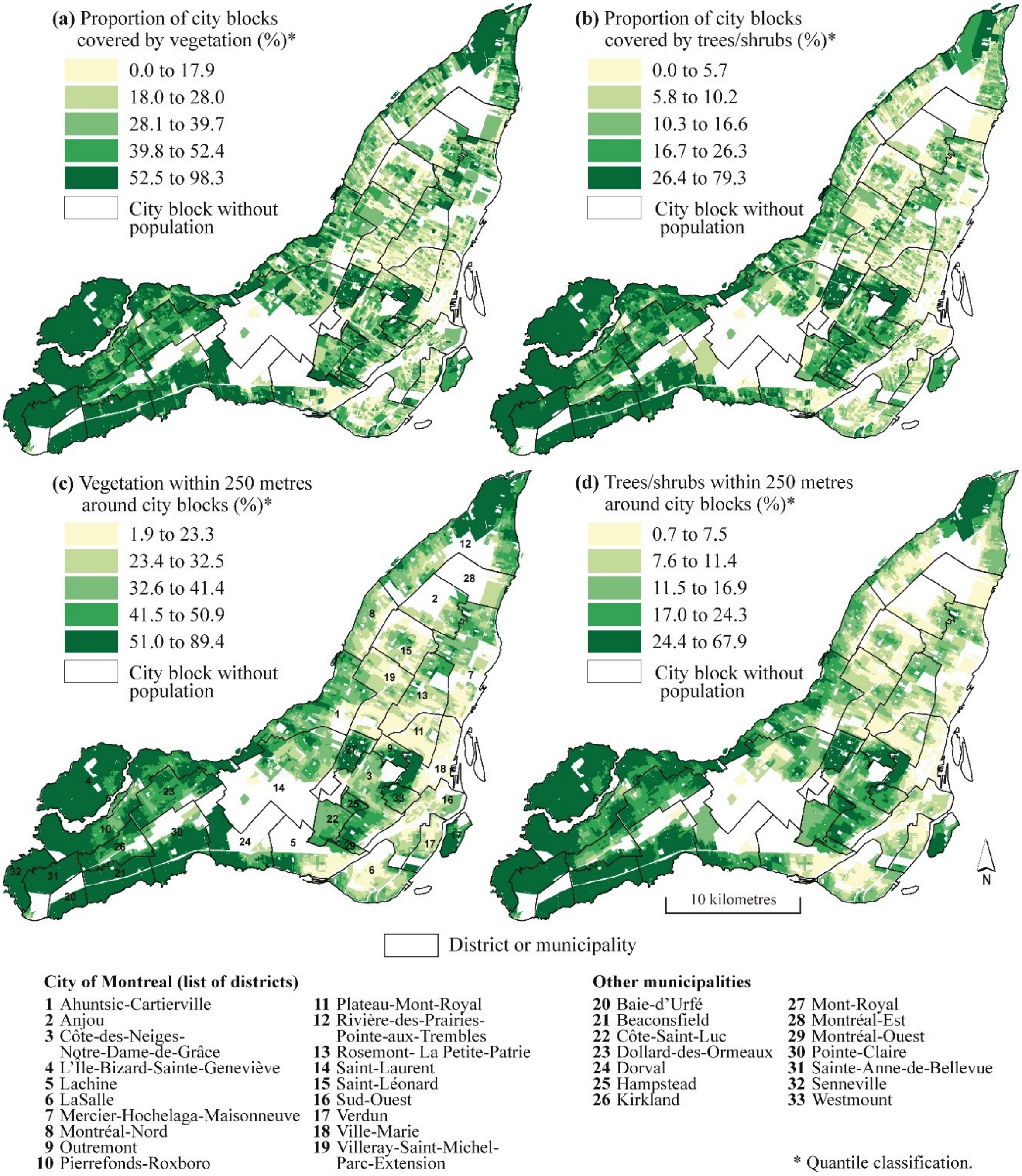

Figure 1. Vegetation indicators at the city block level

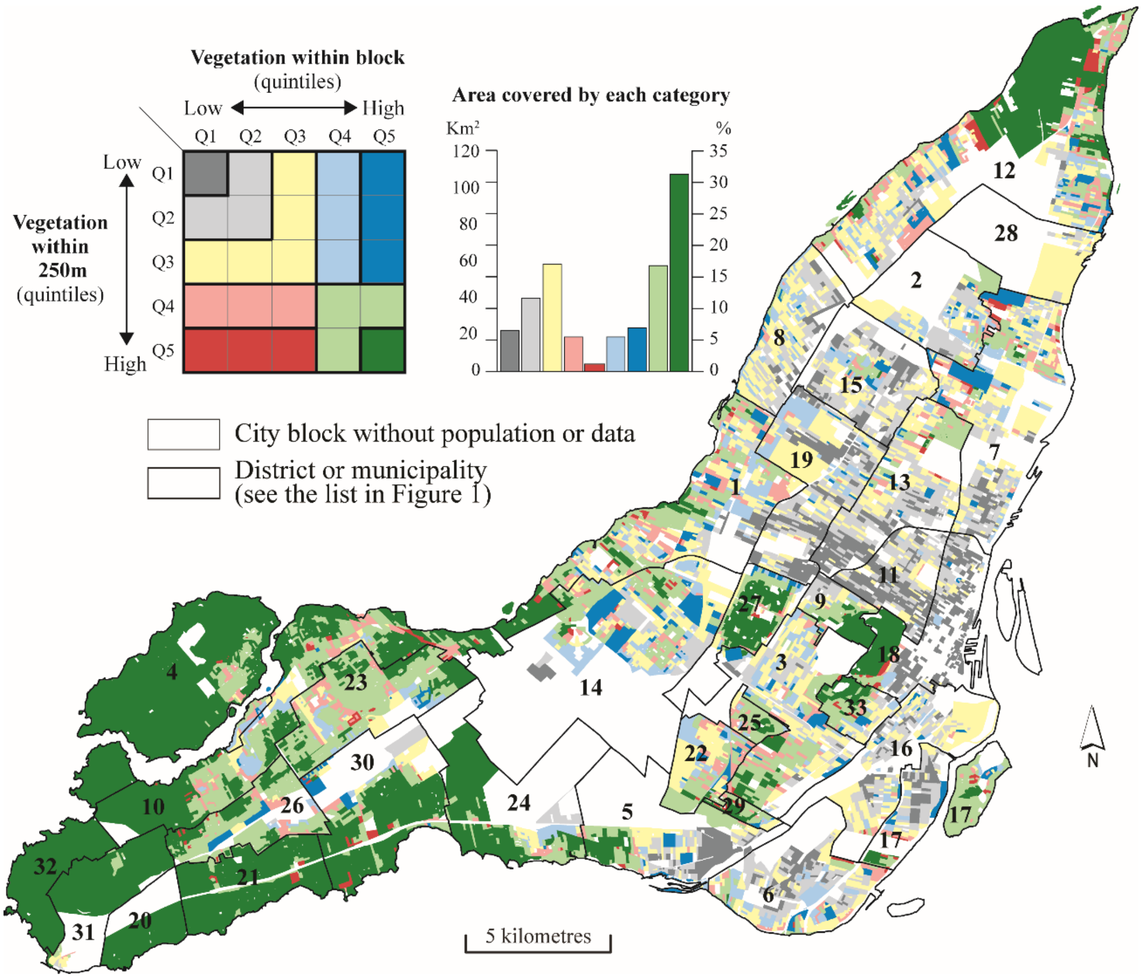

Figure 2. Typology of city blocks according to the two vegetation indicators

4.2. Environmental inequity assessment without controlling for the built environment: T-test analysis

The results of the T-tests presented in Table 2 are used to compare the mean values of the four vegetation indicators when they are weighted by the numbers of each of the groups studied compared with the rest of the population. They clearly show that low-income people live in environments with proportionately less vegetation in and around their residential city block: a difference of -6.5 percentage points for the total vegetation in the block, and of -5.4 and -4.9 percentage points within 250 and 500 metres around the block ($p<0.001$); and differences of -3.5, -2.8 and -2.5 respectively for the indicators of the percentage of trees in the block, and within 250 and 500 metres ($p<0.001$). The same finding applies for visible minorities, but to a lesser extent, as the differences are smaller: -3.2, -2.2 and -1.9 percentage points respectively for the total vegetation indicators ($p<0.001$). On the other hand, the situation is more favourable for young people under 15 years old and for seniors aged 65 and over, as they tend to live in environments with more vegetation and more trees in and around their residential city blocks.

Table 2. Means of vegetation indicators from the T-test for the four groups studied and the rest of the population.

		Vegetation within block				Trees/shrubs within block			
		Mean		Difference		Mean		Difference	
Group 1 (G1)	Group 2 (G2)	G1	G2	Diff	P	G1	G2	Diff	P
0–14 years old	>15 years old	32.5	30.9	1.6	<.0001	14.3	13.4	0.9	<.0001
>=65 years old	<65 years old	32.5	30.9	1.6	<.0001	14.0	13.5	0.5	0.0001
Low-income pop.	No low-income pop.	26.5	33.0	-6.5	<.0001	11.1	14.5	-3.5	<.0001
Visible minorities	No visible minorities	28.8	31.9	-3.2	<.0001	12.4	13.9	-1.6	<.0001
		Vegetation within 250 m				Trees/shrubs within 250 m			
0–14 years old	>15 years old	35.6	34.2	1.5	<.0001	15.0	14.1	0.9	<.0001
>=65 years old	<65 years old	35.2	34.2	1.0	<.0001	14.5	14.2	0.3	<.0001
Low-income pop.	No low-income pop.	30.6	35.9	-5.4	<.0001	12.2	15.0	-2.8	<.0001
Visible minorities	No visible minorities	32.7	34.9	-2.2	<.0001	13.6	14.4	-0.8	<.0001
		Vegetation within 500 m				Trees/shrubs within 500 m			
0–14 years old	>15 years old	36.3	34.9	1.4	<.0001	15.0	14.2	0.9	<.0001
>=65 years old	<65 years old	36.0	35.0	0.9	<.0001	14.6	14.3	0.3	0.0024
Low-income pop.	No low-income pop.	31.7	36.6	-4.9	<.0001	12.5	15.0	-2.5	<.0001
Visible minorities	No visible minorities	33.7	35.6	-1.9	<.0001	13.8	14.5	-0.6	<.0001

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.

4.3. Environmental inequity assessment when controlling for the built environment

4.3.1. Results of the seemingly unrelated regression models

Prior to an analysis of the coefficients of the SUR models, it should be emphasized that the correlations between the residuals of the two equations for models A to D are all highly positive (Table 3). This justifies the use of SUR models (Grene, 2011), as the coefficients of the ordinary least squares (OLS) models would have been biased. It should point out straight away that for all the equations in the four SUR models, the population density and median age of residential buildings have a significant effect on the amount of vegetation. It is not surprising that the logarithm of population density (inhabitants per hectare) is negatively associated with the proportion of vegetation in the block. Furthermore, the relationship between the age of the residential buildings and the vegetation indicators is not linear, but rather curvilinear, which is in keeping with the results of earlier studies (Grove, et al., 2006; Landry & Chakraborty, 2009; Mennis, 2006; Pham, et al., 2013; Pham, et al., 2012).

Once the three independent variables of the built environment have been controlled for (population density and median age of residential buildings and its squared form), an examination of the coefficients of the SUR models for the variables of the four groups studied reveals several interesting findings regarding the distributional equity of vegetation in Montreal.

In all the SUR models (A to D, Table 3), the coefficients of the percentages of children under 15 years old and of the elderly are positive and significant ($p<0.001$). The coefficients are in fact much higher for young people than for seniors: for example, in model A, they are 0.979 and 0.330 respectively for equation 1, and 0.797 and 0.173

for equation 2. This means that, all other things being equal, these two groups are in an advantageous situation in terms of the amount of vegetation and trees in and around the block where they live, especially in the case of children under age 15. The opposite situation is found for the low-income population, with negative and significant coefficients ($p<0.001$) for all the equations in the four SUR models ranging from -0.285 to -0.327 for models A and B (total vegetation indicators) and from -0.195 to -0.223 for models C and D (trees/shrubs indicators).

Table 3. Seemingly unrelated regression models.

	Model A: Eq. 1. (DV: vegetation within block) Eq. 2. (DV: vegetation within 250 m)				**Model B:** Eq. 1. (DV: vegetation within block) Eq. 2. (DV: vegetation within 500 m)			
	Equation 1		Equation 2		Equation 1		Equation 2	
	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Intercept	30.689***	33.82	41.342***	45.90	30.723***	33.61	43.621***	50.65
Inhab./ha (log)	-1.824***	-42.18	-3.132***	-24.17	-1.864***	-42.75	-2.902***	-24.47
MedAgeBuild	0.288***	18.24	0.217***	11.94	0.308***	19.03	0.161***	8.47
MedAgeBuild^2	-0.002***	-17.52	-0.002***	-16.37	-0.002***	-18.36	-0.002***	-14.07
0-14 years old (%)	0.979***	31.78	0.797***	31.87	0.968***	31.37	0.717***	30.28
65 years old and over (%)	0.330***	18.12	0.173***	11.59	0.324***	17.73	0.135***	9.59
Visible minorities (%)	-0.021*	-2.14	-0.086***	-10.73	-0.020*	-2.05	-0.087***	-11.72
Low-income population (%)	-0.325***	-29.37	-0.327***	-36.77	-0.322***	-28.97	-0.285***	-34.08
R^2	0.470		0.483		0.471		0.488	
Correlation of the residuals	0.597				0.527			
AIC for the two models	155,377				155,157			
	Model C: Eq. 1. (DV: trees/shrubs within block) Eq. 2. (DV: trees/shrubs within 250 m)				**Model D:** Eq. 1. (DV: trees/shrubs within block) Eq. 2. (DV: trees/shrubs within 500 m)			
	Equation 1		Equation 2		Equation 1		Equation 2	
	Coef.	T	Coef.	T	Coef.	T	Coef.	T
Intercept	7.681***	13.00	13.010***	21.79	7.049***	11.81	13.671***	23.08
Inhab./ha (log)	-0.914***	-32.64	-2.217***	-25.83	-0.937***	-32.99	-2.097***	-25.69
MedAgeBuild	0.274***	27.81	0.245***	21.10	0.306***	29.97	0.208***	16.40
MedAgeBuild^2	-0.002***	-23.00	-0.002***	-19.73	-0.002***	-24.89	-0.002***	-15.79
0-14 years old (%)	0.608***	30.00	0.571***	33.92	0.605***	29.74	0.544***	33.01
65 years old and over (%)	0.206***	17.22	0.114***	11.40	0.203***	16.83	0.098***	9.96
Visible minorities (%)	0.013*	1.99	-0.014**	-2.59	0.015*	2.35	-0.014**	-2.71
Low-income population (%)	-0.222***	-30.54	-0.214***	-35.81	-0.223***	-30.58	-0.195***	-33.47
R^2	0.400		0.413		0.402		0.399	
Correlation of the residuals	0.685				0.610			
AIC for the two equations	137,051				138,009			

DV: dependent variable.
Signif. codes: *** 0.001, ** 0.01, * 0.05.
For equation 2, the three independent variables relating to the built environment (Inhab./ha (log), MedAgeBuild and MedAgeBuild^2) are calculated within a radius of 250 m or 500 m, excluding the block.

Again, as seen in the T-test analyses, there is less distributional inequity for visible minorities. Indeed, although the coefficients are significantly negative, they are much weaker than for the percentage of low-income individuals for models A and B (varying from -0.020 to -0.087). Moreover, for equation 1 in models A and B, the coefficients are only significant at a threshold of 0.05. Finally, models C and D show that the percentage of visible minorities is weakly but positively associated (p=0.05) with the indicator of trees/shrubs within the block, but negatively associated with the same indicator within 250 metres around the block (p<0.01).

4.3.2. Results of the multinomial logistic regression model

The multinomial logistic regression model is built with the *dark green* category (the greenest blocks both within and around their boundaries) as the reference category (Figure 2). This model is used to determine whether the proportion of each of the four population groups increases the probability that the block belongs to one of the categories in the cross tabulation of vegetation, compared with the *dark green* category in the tabulation. It should be noted that the odds ratios shown in Table 4 were obtained after controlling for the characteristics of the built environment (population density, median age of residential buildings and its squared form) within the block and within a 250-metre radius of the block, excluding the block itself. However, for purposes of simplification, the coefficients and odds ratios for the variables relating to the built environment are not shown.

The results indicate that young people under 15 years old are in a favourable situation, as the odds ratios are all less than 1 and significant (p<0.0001). This means that, all other things being equal, an increase in the percentage of young people lowers the probability of their block belonging to the *dark grey* to *green* categories (blocks that are the least green to blocks that are moderately green both within and around their boundaries) compared with the *dark green* reference category. The lowest odds ratios are in fact found for categories covering areas with the least vegetation in and around the block (*dark grey*: 0.736; *light grey*: 0.792).

The situation is more complex for older people, as several of the coefficients are not significant at a threshold of 5%. Compared with the greenest blocks, an increase in the percentage of people aged 65 and over decreases the probability of their block being in areas with the least vegetation (*dark grey*: 0.943; *light grey*: 0.974), but to a lesser extent than for young people under 15 years of age. Moreover, an increase in the percentage of seniors increases the probability of their block being in areas characterized by a large amount of vegetation within the block but little vegetation within a 250-metre radius (*light blue*: 1.019; *dark blue*: 1.036). In sum, people aged 65 and over nonetheless enjoy a favourable situation overall.

The situation is very different for low-income individuals, as all the odds ratios are greater than 1 and significant (p<0.0001). The highest odds ratios are indeed associated with the least green categories (*dark grey*: 1.135; *light grey*: 1.129). Similar results are obtained for people stating that they are members of visible minorities, although their odds ratios, despite being positive, are nevertheless closer to 1 (for example: *dark grey*: 1.026; *light grey*: 1.012).

Table 4. Multinomial logistic regression (dependent variable: classification of two vegetation indicators)

Category [a]	Coef.	OR[b]	OR (95%[c])		Pr.	Coef.	OR[b]	OR (95%[c])		Pr.
	0-14 years old (%)					65 years old and over (%)				
Dark grey	-0.307	0.736	0.715	0.757	<.0001	-0.040	0.961	0.943	0.978	<.0001
Light grey	-0.234	0.792	0.771	0.812	<.0001	-0.027	0.974	0.957	0.991	0.003
Yellow	-0.205	0.815	0.795	0.836	<.0001	-0.005	0.995	0.979	1.012	0.557
Light red	-0.176	0.839	0.816	0.863	<.0001	-0.009	0.991	0.973	1.010	0.354
Dark red	-0.177	0.837	0.803	0.873	<.0001	-0.015	0.985	0.960	1.010	0.243
Light blue	-0.149	0.861	0.837	0.886	<.0001	0.019	1.019	1.001	1.037	0.041
Dark blue	-0.155	0.856	0.823	0.891	<.0001	0.036	1.036	1.015	1.058	0.001
Light green	-0.091	0.913	0.893	0.933	<.0001	0.000	1.000	0.984	1.017	0.963
	Visible minorities (%)					Low-income population (%)				
Dark grey	0.034	1.034	1.026	1.043	<.0001	0.127	1.135	1.123	1.148	<.0001
Light grey	0.012	1.012	1.004	1.020	0.003	0.122	1.129	1.118	1.142	<.0001
Yellow	0.015	1.015	1.007	1.022	0.000	0.108	1.114	1.102	1.125	<.0001
Light red	0.005	1.005	0.996	1.013	0.306	0.086	1.090	1.077	1.103	<.0001
Dark red	0.004	1.004	0.990	1.017	0.609	0.050	1.052	1.033	1.071	<.0001
Light blue	0.022	1.022	1.013	1.030	<.0001	0.095	1.100	1.087	1.112	<.0001
Dark blue	0.028	1.028	1.017	1.039	<.0001	0.096	1.101	1.085	1.116	<.0001
Light green	0.019	1.019	1.012	1.026	<.0001	0.044	1.045	1.035	1.055	<.0001
AIC	31722									
R2 (Cox & Snell)	0.598									
R2 (Nagelkerke)	0.608									

[a] See the categories in Figure 2. Reference category: Dark green. [b] Odds ratio. [c] 95% Wald confidence limits. The reported values were obtained after controlling for population density (logarithm of inhabitants/ha), median age of residential buildings and squared median age of residential buildings.

5. Discussion and conclusion

The different types of analyses used in this study show that in Montreal, children and, to a lesser degree, older people enjoy quite an advantageous situation: they more often live in areas with high levels of vegetation in and around their city blocks. Environmental inequities, on the other hand, are more strongly associated with people's income levels than with their belonging to an ethnocultural or racial group, which corroborates the findings of several earlier studies on urban vegetation in Baltimore (Troy, et al., 2007), Tampa (Landry & Chakraborty, 2009), Vancouver and Toronto (Tooke, et al., 2010). The use of vegetation indicators in and around the block makes it possible to demonstrate the existence of a double inequity in some areas of the city for these two groups, which previous studies had not shown. A double inequity of this kind is worrisome, given the negative impacts of a lack of vegetation on the public health of these populations.

This double inequity in terms of access to vegetation can in fact affect different population groups differently, depending on their level of income. Well-off households living in an area with little greenery—in a downtown residential tower, for example—can more easily remedy the lack of vegetation: with air conditioning, by staying at their secondary residence in the country on weekends or while on vacation, etc. Low-income households, on the other hand, tend to be more confined to their neighbourhoods all year long, as they often have less access to a motor vehicle. The lack of vegetation in neighbourhoods with high residential densities contributes to the heat island effect during the heat waves that sometimes strike Montreal in the summer, which can have disastrous consequences for some population groups, particularly the elderly (Smargiassi, et al., 2009). So, because all citizens are not equally able to cope with a lack of vegetation, it might be better to think in terms, not of distributional equity, but rather of compensatory equity (Apparicio & Séguin, 2006; Talen, 1998) in order to ensure that disadvantaged neighbourhoods have their fair share of vegetation.

Several possible reasons can be advanced to explain the higher proportion of low-income households in vegetation-deprived areas. For example, it may be due to the lower cost of both rental housing and home ownership in areas with less vegetation (Donovan & Butry, 2010). Also, Heynen (2006) mentions that households with limited financial means tend to place less emphasis, for various reasons, on the importance of vegetation. In regard to disparities affecting visible minorities, it is possible that they are being discriminated against in terms of their access to green living environments.

The approach developed here, which combines multisource data and remote sensing, GIS and spatial analysis methods, would seem to be an especially interesting technique for planning urban greening interventions. Mapping the different types of blocks according to the level of abundance of vegetation—both in and around these blocks—(in the cross tabulation of two vegetation indicators) could represent a very useful tool for urban planners. It can in fact be used to target areas that could benefit from greening campaigns. Nonetheless, Wolch, Byrne, and Newell (2014, p. 235) note that greening projects in disadvantaged neighbourhoods "can, however, create an urban green space paradox" by making these areas also more attractive to wealthier households, thus contributing to their gentrification and prompting disadvantaged households to leave the area. Greening projects should therefore be implemented on a local scale and involve the communities living in these neighbourhoods. In this sense, the results of this paper could help urban planners to design greening interventions. For example, in vegetation-deprived areas within the block, measures to foster the greening of private gardens, urban agriculture, or green walls and roofs are some of the initiatives that could be emphasized. In vegetation-deprived areas around the block, priority could be given to planting trees along the streets or to developing a new urban park. Interventions of this kind would help to reduce the environmental inequities that low-income people and visible minorities face.

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