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ABSTRACT

Background

Residential greenness has been associated with health benefits, such as lower risk of mortality, cardiovascular disease, obesity, adverse birth outcomes and asthma and better psychological health. However, the variation in greenness across socioeconomic and demographic characteristics in urban areas of Canada has not been well documented.

Data and methods

Respondents to the 2016 Census long-form questionnaire were assigned estimates of exposure to residential greenness based on the mean Normalized Difference Vegetation Index (NDVI) (from 2012 or the most recent year available) within a 500 m buffer around their home, based on postal code. Census weights were used to determine differences in average exposure to greenness according to selected demographic and socioeconomic characteristics.

Results

Mean residential greenness among the 5.3 million census respondents in urban Canada was 0.44 units of the NDVI (standard deviation = 0.18 units). Greenness was lower among immigrants (particularly recent immigrants), some groups designated as visible minorities (particularly people of Filipino ancestry), lower-income households and tenants (i.e., NDVI values ranging from 0.40 to 0.43 units). Greenness values were highest among White non-immigrants and higher-income households (i.e., NDVI values ranging from 0.46 to 0.47 units).

Interpretation

Given the potentially multifaceted role that greenness plays in health outcomes, the inequalities in residential greenness described here may contribute to producing or exacerbating existing health inequalities in the Canadian population.

Keywords

greenness, green space, environment, environmental justice

AUTHORS

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What is already known on this subject?

- Residential greenness is associated with better health, including lower risk of mortality.
- In other countries, greenness is lower in neighbourhoods of greater socioeconomic deprivation and for specific populations designated as visible minorities.
- In Canada, greenness is negatively correlated with income.

What does this study add?

- Residential greenness is distributed unequally among urban Canadians.
- Lower residential greenness was found for lower-income households; recent immigrants; young adults; tenants; and people belonging to groups designated as visible minorities, particularly those who self-identified as Filipino.
- Higher residential greenness was found for higher-income households, White populations and non-immigrants.

Living in a home surrounded by trees, gardens and natural vegetation (i.e., greenspace, or greenness) may confer numerous health benefits. Notably, studies in Canada, the United States and Europe have found inverse associations between residential greenness and all-cause or non-accidental,[1-5] respiratory[2,3] and cardiovascular mortality,[4] after adjusting for socioeconomic and demographic confounders. Associations with mortality are stronger among certain groups: in Canada, among women and people with higher income and education,[4] and, in England, among the lowest income group.[1] In addition to mortality outcomes, a Dutch study found that better self-assessed general health was associated with exposure to greenness within both 1 km and 3 km of a person's home,[6] and a Toronto study found better perceived health was associated with higher street tree density.[7]

Proximity and access to residential greenness may act upon health outcomes in several ways. For example, greener environments may directly promote improvements in psychological health by reducing psychological stress,[8] severity of distress and poor self-perceived mental health.[9] In addition, greenness may provide an aesthetic experience, and it may also provide an opportunity to receive ample daylight by encouraging outdoor activity, thereby nurturing circadian rhythms.[8] Greener environments may also act on health indirectly, by promoting outdoor physical activity through physical spaces for recreation and community activities, thereby improving cardiovascular health and reducing obesity.[10-13] However, this benefit may depend on the type of greenspace available, as one study in Montréal and the city of Québec noted that cardiovascular benefits from greenspace were observed only if sports and recreational facilities were also present.[14]

Despite the benefits of living in a greener environment, these environments are not evenly dispersed across the landscape. Several studies have highlighted inequalities in the physical area, vegetation density (e.g., local Normalized Difference Vegetation Index [NDVI] value), quality and characteristics (e.g., manicured garden vs. open field), and accessibility of residential greenspace. One study of the three largest cities in Canada found an association between family income and vegetation cover.[15] In England, greater greenness was observed in the least economically deprived regions,[1] and another study noted that usable greenspace was least accessible for those of Indian ancestry.[16] In urban areas of the United States, greenness values were associated with higher concentrations of White residents,[17] and lower greenness values were associated with higher concentrations of low-income, Black and Hispanic populations.[18,19]

Environmental justice is a broad field of study that focuses on describing exposures that disparately affect specific socioeconomic and ethnocultural groups.[20,21] Inequalities in access to greenness have not been well documented in Canada. One study in Montréal found results similar to those of international studies, reporting that city blocks with higher proportions of low-income residents and, to a lesser extent, populations designated as visible minorities had lower greenness values and access.[22] An earlier study that focused on respondents to the 2001 Census of Canada[4] reported that more affluent and more highly educated adults living in the 30 largest census metropolitan areas of the country had greater exposure to residential greenness than those who were less affluent and less well educated. This study builds on that work by using data from the more recent 2016 Census, including respondents of all ages, and by considering differences in exposure according not only to age, education and income, but also to immigrant status, time since immigration, self-reported ethnicity and neighbourhood deprivation indexes.

Data and methods

Study cohort

Exposure to greenness by demographic and socioeconomic characteristics was explored using the 2016 Census of Canada long-form questionnaire. The long-form questionnaire was distributed to about one in four households in private dwellings, excluding collective dwellings.[23] It had a response rate of

96.7%.[23] Census weights were used to derive estimates that were reweighted to more approximately represent the full population distribution of Canada. Individual and household variables extracted for the study included respondent age, Indigenous identity, self-identified population group (White, South Asian, Chinese, Black, Filipino, Latin American, Arab, Southeast Asian, West Asian, Korean, Japanese, or other or multiple identities), immigrant status and year of immigration to Canada, educational attainment (for those aged 25 or older), labour force status (for those aged 25 or older), household income, housing tenure (owner vs. tenant), and low-income status. Regarding self-identified population groups, the authors acknowledge the limitations of these disaggregated categories and are relying on available census data. The census defines visible minority based on the Employment Equity Act, as "persons, other than Aboriginal peoples, who are non-Caucasian in race or non-white in colour". The low-income status threshold is defined as half the median of the adjusted after-tax income, multiplied by the square root of household size.[24]

Geographic location of residence was estimated using the six-character postal code reported on the census questionnaire. The Postal Code Conversion File Plus (PCCF+) version 7C was used to determine an approximate latitude and longitude, as well as census geography characteristics. The PCCF+ is most accurate for geocoding within urban centres, with representative points assigned a median of 100 m to 200 m from the actual home, usually along the block face of the same street.[25]

In addition to individual and household characteristics, neighbourhood deprivation indexes were assigned by attaching the Canadian Index of Multiple Deprivation (CIMD) based on the 2016 Census to the individuals in the dataset. The CIMD considers four dimensions of deprivation: residential instability,

Figure 1
Description and line drawing examples of residential urban areas within four quartiles of greenness (Normalized Difference Vegetation Index)

Lowest quartile	Range: 0.06 to 0.39	Few trees, few parks, heavily built-up or newly developed lands	
Mid-lowest quartile	Range: 0.39 to 0.45	Sparse tree growth, small grassy areas and parks	
Mid-highest quartile	Range: 0.45 to 0.51	Larger trees, large grassy areas or parks	
Highest quartile	Range: 0.51 to 0.81	Mature trees forming canopy, close proximity or adjacent to forested areas or greenbelt	

Sources: 2016 Census of Canada; Crouse DL, Pinault L, Balram A, et al. Urban greenness and mortality in Canada's largest cities: a national cohort study. *The Lancet Planetary Health* 2017; 1: e289-97.

economic dependency, ethnocultural composition and situational vulnerability. It is derived at the dissemination area (DA) level, which is a small, relatively stable area of census geography composed of about 400 to 700 people.[26]

All of urban Canada was included in this study. To focus on the urban population of Canada, people who did not reside in census metropolitan areas (CMAs) or census agglomerations (CAs) were excluded from analyses. CMAs are defined as having a total population of at least 100,000 people, of whom at least half must live in the core, while CAs must have a core population of at least 10,000 people.[27] Urban form was further considered to distinguish those who may reside within the rural portions of CMAs or CAs.[28] Those living in a rural or exurban urban census tract (i.e., fewer than 150 people per km^2) were also excluded from analyses. Approximately 3.0 million respondents were excluded because they lived outside a CMA or CA or in an area with low population density. This left a total study population of 5,306,800 respondents, representing 21,925,200 people after applying census weights (counts are rounded for confidentiality).

Exposure assessment

Greenness estimates were derived from the remotely sensed NDVI, which is an index of vegetation ranging from -1 (water) to 0 (bare soil) to 1 (thick vegetation). NDVI values between 0.01 and 1.00 were used to estimate the residential mean NDVI

Table 1
Percentage distribution and mean residential greenness score among those living in active cores or suburban regions of census metropolitan areas and census agglomerations, household population, Canada, 2016

Characteristics	Population distribution by characteristic	Greenness: 500 m buffer	
	percent	mean	standard deviation
Total	**100.0**	**0.44**	**0.18**
Age group			
Younger than 5	5.4	0.48	0.21
5 to 17	14.7	0.45	0.17
18 to 39	30.4	0.43	0.19
40 to 65	35.7	0.45	0.18
Older than 65	13.8	0.45	0.18
Visible minority or Indigenous status			
White	66.1	0.46	0.18
Indigenous status	2.6	0.43	0.17
South Asian	7.9	0.42	0.16
Chinese	6.5	0.42	0.17
Black	4.9	0.42	0.17
Other Asian	3.5	0.42	0.18
Filipino	3.0	0.41	0.15
Arab	2.2	0.42	0.17
Latin American	1.8	0.42	0.17
Multiple visible minorities	1.0	0.42	0.17
Other visible minority	0.5	0.43	0.16
Immigrant status			
Not immigrant	68.7	0.45	0.18
Immigrant	31.3	0.43	0.17
Housing tenure (excluding those in band housing)			
Owner	69.5	0.46	0.17
Tenant	30.5	0.42	0.18
Education (older than 25)			
Less than secondary school graduation	9.5	0.43	0.17
Secondary school graduation	16.4	0.44	0.17
Non-university diploma or certificate	22.6	0.45	0.18
University degree	22.0	0.44	0.19
Labour force status (older than 25)			
Employed	44.5	0.44	0.19
Unemployed	2.9	0.43	0.18
Not in labour force	23.0	0.45	0.18
Household income (quintile)			
Highest	19.9	0.47	0.19
2nd	19.9	0.45	0.20
3rd	20.0	0.45	0.17
4th	20.1	0.44	0.16
Lowest	20.1	0.41	0.15

‡ After-tax low-income measure

Note: NA = not applicable. CIMD = Canadian Index of Multiple Deprivation.

Sources: 2016 Census of Canada; Crouse DL, Pinault L, Balram A, et al. Urban greenness and mortality in Canada's largest cities: a national cohort study. *The Lancet Planetary Health* 2017; 1: e289-97.

Table 1
Percentage distribution and mean residential greenness score among those living in active cores or suburban regions of census metropolitan areas and census agglomerations, household population, Canada, 2016 (continued)

Characteristics	Population distribution by characteristic	Greenness: 500 m buffer	
	percent	mean	standard deviation
Low-income status (excluding those NA)[‡]			
Low income	14.5	0.42	0.18
Not low income	85.3	0.45	0.18
CIMD: Residential instability			
Quintile 1—lowest	17.1	0.49	0.16
Quintile 2	17.4	0.47	0.17
Quintile 3	17.8	0.46	0.17
Quintile 4	19.6	0.44	0.16
Quintile 5—highest	28.0	0.40	0.18
CIMD: Economic dependency			
Quintile 1—lowest	28.8	0.43	0.20
Quintile 2	22.9	0.45	0.17
Quintile 3	20.1	0.45	0.17
Quintile 4	16.4	0.45	0.17
Quintile 5—highest	11.8	0.45	0.17
CIMD: Ethnocultural composition			
Quintile 1—lowest	5.2	0.50	0.17
Quintile 2	9.5	0.50	0.17
Quintile 3	19.0	0.47	0.17
Quintile 4	28.2	0.44	0.18
Quintile 5—highest	38.1	0.41	0.16
CIMD: Situational vulnerability			
Quintile 1—lowest	31.7	0.45	0.20
Quintile 2	22.5	0.46	0.18
Quintile 3	18.1	0.45	0.17
Quintile 4	15.6	0.43	0.16
Quintile 5—highest	12.1	0.41	0.16

[‡] After-tax low-income measure

Note: NA = not applicable. CIMD = Canadian Index of Multiple Deprivation.

Sources: 2016 Census of Canada; Crouse DL, Pinault L, Balram A, et al. Urban greenness and mortality in Canada's largest cities: a national cohort study. *The Lancet Planetary Health* 2017; 1: e289-97.

within a 500 m buffer around a representative point of the respondent's postal code. Other buffer sizes were considered in preliminary analyses, with similar results (results not shown). Annual maximum greenness values were taken from images at 30 m resolution from the United States Geological Survey's Landsat satellites during the growing season for vegetation (May 1 to August 31).[4,29] Data were derived from the most recent year available (2012 or an older year if 2012 was missing). Of the original 8.65 million respondents to the census long-form questionnaire, 253,700 were excluded because they were not successfully linked to greenness estimates. Further context for the concept of greenness is provided in Figure 1, which describes the four quartiles of greenness estimates within urban Canada and provides examples.

Statistical analyses

Descriptive statistics were used to determine differences in average exposure to greenness by selected individual and neighbourhood characteristics, using census weighting. To compare differences in greenness values among groups, Student's t-tests were used for significance testing, and Cohen's *d* effect size was used to interpret the magnitude of the difference between groups, since it provides a measure independent of sample size.[30] In addition to the full population across urban Canada, the same analyses were conducted within the three largest cities in Canada: Toronto, Montréal and Vancouver. Effect size estimates can be interpreted as small (d = 0.2), medium (d = 0.5) or large (d = 0.8). Analyses were conducted in SAS 9.4 software.

Results

Descriptive statistics of the study population are provided in Table 1. Approximately 31% of the 5.3 million respondents were immigrants, 34% self-identified as Indigenous or as belonging to a group designated as a visible minority, 31% rented their homes, and 15% were identified as being of low-income status. Across urban Canada, the mean residential greenness value within 500 m of the home was 0.44 (standard deviation [SD] = 0.18). Descriptively, greater greenness was observed for children younger than 5 or older adults, White populations, non-immigrants, homeowners, higher income quintiles, and people not of low-income status. At the neighbourhood level, residential greenness was incrementally greater among DAs with increasingly lower levels of residential

instability, lower ethnocultural composition and lower situational vulnerability.

When the analysis focused on the three largest cities in Canada, similar trends were observed between individual-level covariates and exposure to greenness (Table 2). However, the magnitude of inequalities was greater in Montréal than in Toronto or Vancouver, with residents reporting White or Indigenous ancestry having mean greenness values 0.05 higher than residents reporting Arab or Latin American ancestry ($p < 0.001$; $d = 0.25$), and non-immigrants having mean values 0.04 higher than immigrants ($p < 0.001$; $d = 0.23$). Notably, homeowners in Montréal reported mean values 0.08 higher than tenants ($p < 0.001$; $d = 0.44$), and, similarly, the mean NDVI of the highest income quintile was 0.08 higher than that of the lowest ($p < 0.001$; $d = 0.41$).

Increases across deciles of median household income were associated with marginal but nearly consistent increases in exposure to residential greenness across all age categories examined (Figure 2). However, greenness was lower for those aged 18 to 39 across all income deciles, except the highest. Outside the highest and lowest deciles, seniors had the highest residential greenness compared with those in other age groups.

A positive relationship was observed between median household income and residential greenness in all ethnocultural groups examined (Figure 3). However, across all income deciles, White populations had markedly higher greenness than any other population group. Indigenous populations also had greater greenness than every other group, except among those in the lowest household income decile. People of Filipino ancestry had lower greenness than any other population group, across all income deciles. The lowest exposure to greenness was among the lowest-income Filipino group (mean = 0.40; SD = 0.16), and the highest exposure to greenness was among the highest-income White group (mean = 0.48; SD = 0.18; difference: $p < 0.001$; $d = 0.46$).

Table 2

Percentage distribution and mean residential greenness score among those living in active cores or suburban regions of Toronto, Montréal or Vancouver, household population, Canada, 2016

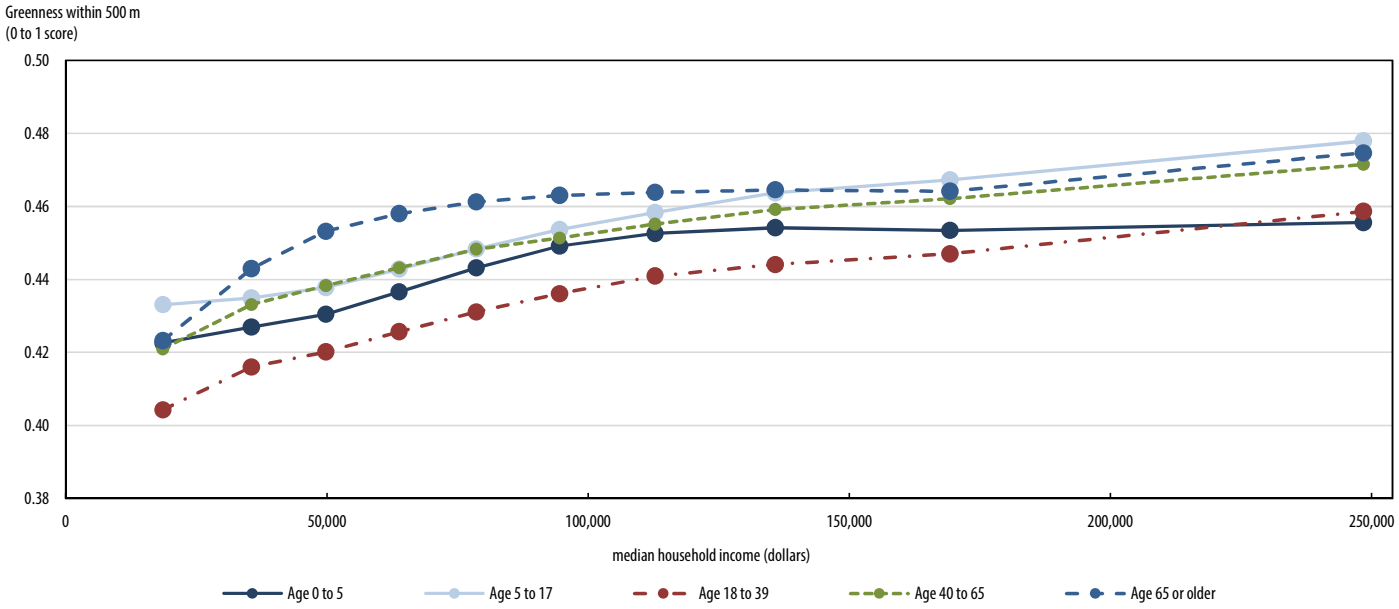
Characteristics	Toronto			Montréal			Vancouver		
	Population distribution	Greenness: 500 m buffer		Population distribution	Greenness: 500 m buffer		Population distribution	Greenness: 500 m buffer	
	percent	mean	standard deviation	percent	mean	standard deviation	percent	mean	standard deviation
Total	100.0	0.44	0.20	100.0	0.44	0.17	100.0	0.43	0.19
Age group									
Younger than 5	5.2	0.43	0.16	5.7	0.44	0.20	4.8	0.43	0.18
5 to 17	15.4	0.44	0.16	15.2	0.46	0.19	14.2	0.45	0.17
18 to 39	29.6	0.42	0.18	29.0	0.43	0.20	29.7	0.41	0.19
40 to 65	36.5	0.44	0.17	36.1	0.45	0.20	37.3	0.43	0.18
Older than 65	13.4	0.45	0.16	14.0	0.44	0.19	14.1	0.43	0.18
Visible minority or Indigenous status									
White	48.8	0.45	0.18	77.7	0.45	0.20	49.2	0.44	0.20
Indigenous status	0.8	0.44	0.18	0.9	0.45	0.20	2.5	0.43	0.19
South Asian	16.0	0.42	0.15	2.0	0.40	0.19	12.5	0.43	0.15
Chinese	10.5	0.43	0.17	2.1	0.41	0.19	19.0	0.41	0.17
Black	7.6	0.43	0.16	6.5	0.41	0.17	1.2	0.42	0.17
Other Asian	5.0	0.43	0.17	2.3	0.41	0.19	7.0	0.42	0.20
Filipino	4.4	0.43	0.15	0.8	0.42	0.15	4.9	0.40	0.15
Arab	1.7	0.42	0.16	4.5	0.40	0.17	0.7	0.41	0.19
Latin American	2.2	0.42	0.16	2.6	0.40	0.18	1.4	0.41	0.19
Multiple or other visible minority	3.0	0.43	0.16	0.7	0.42	0.18	1.7	0.41	0.17
Immigrant status									
Not immigrant	51.9	0.44	0.18	76.0	0.45	0.20	56.7	0.44	0.19
Immigrant	48.1	0.43	0.16	24.0	0.41	0.18	43.3	0.42	0.18
Housing tenure (excluding those in band housing)									
Owner	73.3	0.44	0.17	66.0	0.47	0.19	71.5	0.44	0.18
Tenant	26.7	0.42	0.18	34.0	0.39	0.17	28.5	0.40	0.19
Household income (quintile)									
Highest	24.0	0.46	0.17	15.4	0.48	0.19	22.3	0.46	0.18
2nd	19.8	0.44	0.17	18.8	0.47	0.19	20.5	0.44	0.18
3rd	18.9	0.43	0.17	21.0	0.45	0.19	19.2	0.43	0.18
4th	18.6	0.43	0.16	22.9	0.43	0.19	18.3	0.42	0.18
Lowest	18.7	0.42	0.17	21.9	0.40	0.19	19.7	0.40	0.19
Low-income status (exclude those NA)[‡]									
Low income	15.3	0.43	0.17	14.1	0.40	0.19	15.7	0.41	0.19
Not low income	84.7	0.44	0.17	85.9	0.45	0.20	83.9	0.43	0.18

[‡] After-tax low-income measure

Note: NA = not applicable.

Sources: 2016 Census of Canada; Crouse DL, Pinault L, Balram A, et al. Urban greenness and mortality in Canada's largest cities: a national cohort study. *The Lancet Planetary Health* 2017; 1: e289-97.

Figure 2
Mean (± standard error bars) residential greenness within 500 m buffer, by age group and median household income, household population in active core or suburban portions of census metropolitan areas and census agglomerations, Canada, 2016



Sources: 2016 Census of Canada; Crouse DL, Pinault L, Balram A, et al. Urban greenness and mortality in Canada's largest cities: a national cohort study. *The Lancet Planetary Health* 2017; 1: e289-97.

Figure 4 examines population groups by immigrant status and period of immigration to Canada. For most population groups who were also immigrants (except those of Chinese ancestry), residential greenness increased with longer residence in Canada, sometimes reaching and surpassing the estimated exposure of Canadian-born populations after a few decades. For Chinese immigrants, by contrast, greenness was greatest for those who had recently immigrated to Canada and was lowest among those who had been in Canada longer than 50 years. Non-immigrant White populations had higher greenness values (mean = 0.46; SD = 0.18) than any immigrant group, including White immigrants. The lowest greenness values were observed among people of Filipino ancestry who had immigrated to Canada in the past 10 years (mean = 0.40; SD = 0.14; difference between highest and lowest groups: $p < 0.001$; $d = 0.35$).

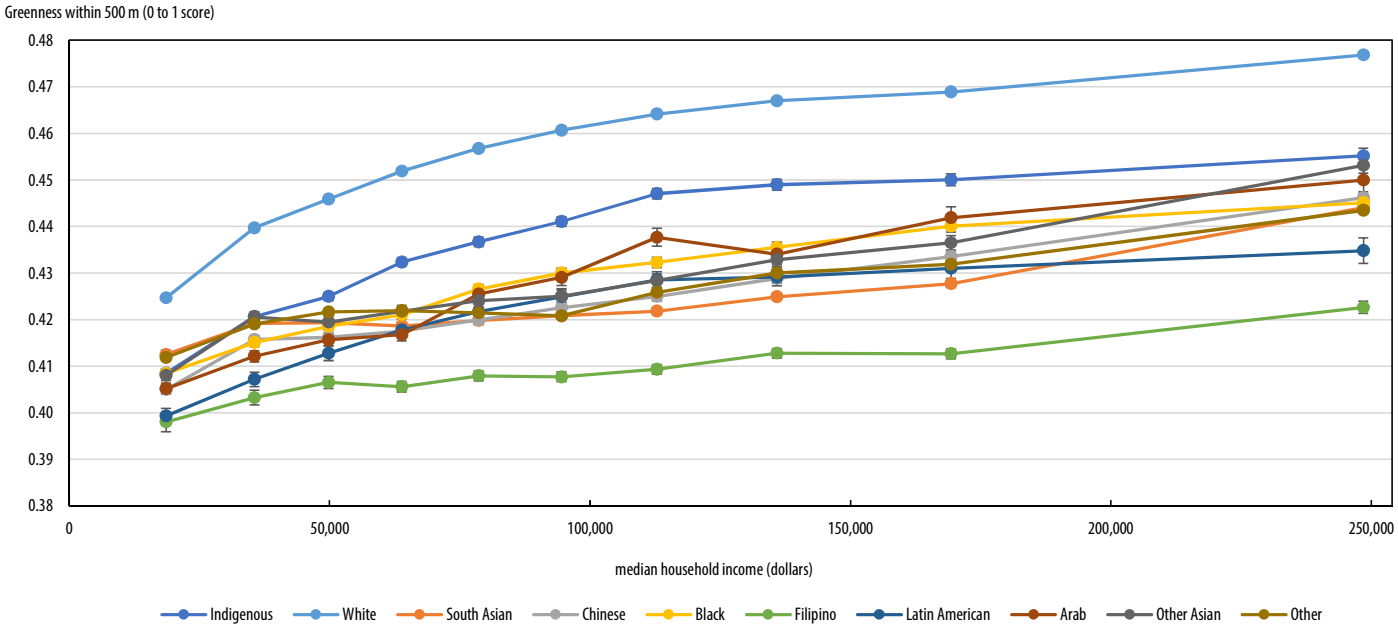
The association between homeownership, immigrant status and greenness was examined across household income deciles in Figure 5. Non-immigrant homeowners had greater greenness than any other group, at all income levels. Among homeowners who were not recent immigrants, greenness rose with increasing income. Tenants at all income levels had lower greenness, especially among recent immigrants. Among tenants and recent immigrant homeowners, there was no clear association between income and greenness.

Discussion

Residential greenness was distributed unequally among the 5.3 million urban residents of Canada included in this study, with inequalities observed across dimensions of income, immigrant status, ethnocultural identity, housing tenure and neighbourhood socioeconomic characteristics. In general, lower residential greenness was observed for people with lower income, immigrants (especially recent immigrants), young adults, populations designated as visible minorities (especially those of Filipino ancestry) and tenants. These trends were observed in the three largest cities in Canada to a greater or lesser degree. Particular strengths of this study were the large population sample (i.e., the weighted census) and the use of a wider variety of variables that cross social, ethnocultural and economic dimensions, as well as neighbourhood-level covariates.

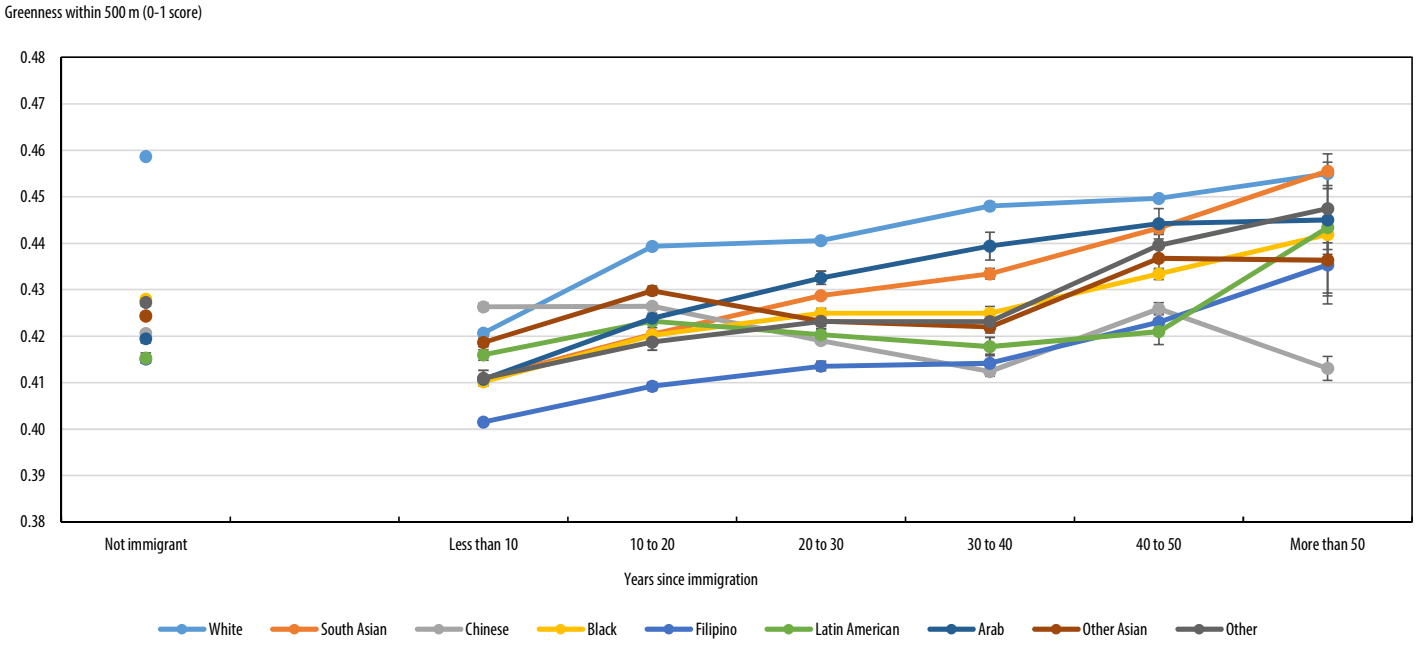
Particularly high or low greenness values were observed for some combinations of these population characteristics. For example, some of the lowest greenness was observed for people of Filipino ancestry who were either recent immigrants to Canada (in the country for less than 10 years) or in the lowest income decile. Low-income young adults (aged 18 to 39) and tenants who were recent immigrants also had notably low greenness around their place of residence. Conversely, greater greenness was observed among non-immigrant homeowners, White non-immigrants and White populations with higher

Figure 3
Mean (± standard error bars) residential greenness within 500 m buffer, by self-identified population group and median household income, household population in active core or suburban portions of census metropolitan areas and census agglomeration, Canada, 2016



Sources: 2016 Census of Canada; Crouse DL, Pinault L, Balram A, et al. Urban greenness and mortality in Canada's largest cities: a national cohort study. *The Lancet Planetary Health* 2017; 1: e289-97.

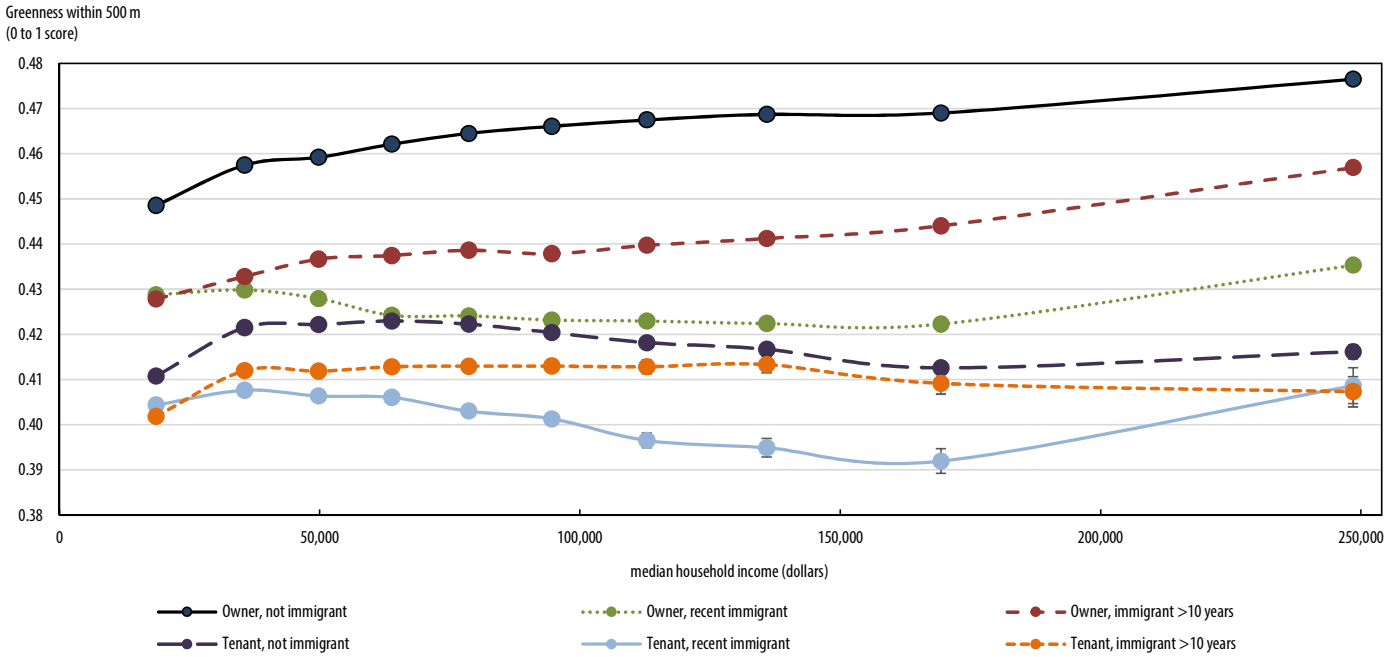
Figure 4
Mean (± standard error bars) residential greenness within a 500 m buffer, by self-identified population group and immigrant status or immigration period, household population in active core or suburban portions of census metropolitan areas and census agglomeration, Canada, 2016



Sources: 2016 Census of Canada; Crouse DL, Pinault L, Balram A, et al. Urban greenness and mortality in Canada's largest cities: a national cohort study. *The Lancet Planetary Health* 2017; 1: e289-97.

income. In some of these comparisons, Cohen's *d* (which measures the effect size for the difference between the mean NDVI) was estimated between 0.40 and 0.48, indicating a nearly "medium" effect size. The finding that immigrants had lower greenness levels was consistent with those of a study in urban Montréal, which found a negative association between

Figure 5
Mean (± standard error bars) residential greenness within a 500 m buffer, by homeownership vs. tenancy, immigrant status and period, and median household income, household population in active core or suburban portions of census metropolitan areas, Canada, 2016



Sources: 2016 Census of Canada; Crouse DL, Pinault L, Balram A, et al. Urban greenness and mortality in Canada's largest cities: a national cohort study. *The Lancet Planetary Health* 2017; 1: e289-97.

immigrants and street trees,[31] and a study across the United States, where immigrant status was negatively correlated with NDVI greenness.[32]

Generally, these findings were consistent with those of previous studies in Canada and elsewhere, which observed greater greenness among more socially and economically advantaged populations. Most city-scale studies, particularly in the United States, have noted that greenspace, parks and tree cover are more likely to be concentrated near populations with higher income and less likely to be located in regions with lower-income populations, tenants and specific groups designated as visible minorities.[8,33-35] Similarly, a European review on promoting environmental justice through urban greenspace access indicated that walkable and accessible green infrastructure was frequently clustered in wealthy neighbourhoods.[10]

The observed inequalities in greenness values are attributable to many historical, sociocultural, economic and demographic factors. While an examination of the underlying causes of these inequalities was beyond the scope of the current study, the role of housing availability, historical settlement patterns and housing policies, as well as the distribution and maintenance of rental housing stock, merit further study, particularly in Canada, where such studies are lacking. A study in Fredericton, Halifax and Winnipeg found that different populations, namely older people and women, rate the importance of urban forests more highly, and this may influence their housing choices.[36]

The finding that people of Filipino ancestry had the least exposure to residential greenness may be explained, in part, by high concentrations of this population in large cities (namely Toronto, Vancouver, Montréal and Winnipeg) and more recent waves of immigration than for many other groups, beginning in the 1960s,[37] with larger waves in the 1990s and 2000s.[38] In Montréal and Winnipeg, Filipino immigrants have tended to cluster in specific neighbourhoods that are frequently characterized by low-rise apartments and less greenspace.[38] An analysis of settlement patterns in Toronto found that Filipino immigrants favoured affordable rental housing and mixed-used neighbourhoods, selecting areas with accessible public transit or workplace proximity,[38] all of which may correspond to lower residential greenness. However, when examined at the individual city level (Table 2), people of Filipino ancestry did not have markedly lower greenness than some of the other groups designated as visible minorities considered in this study.

Limitations

This study has several limitations, mainly associated with the use of the NDVI to approximate greenness and the cross-sectional nature of the study. This study did not assess the quality or accessibility of greenspace, only the average NDVI within a buffer around the home. No distinction was made between greenness resulting from publicly accessible parks and greenness from private, inaccessible spaces, such as golf courses or agricultural land. However, limiting the study area to suburban or core areas of the city likely removed most areas that

would have included agricultural lands. Maintenance of greenspace is known to vary across income and demographic gradients in cities,[10] and examining the overall quantity of greenness may overestimate any real health benefits from greenspace. For example, in Baltimore and Los Angeles, overall park acreage was greater in predominantly Black or Latino neighbourhoods, but these parks had lower levels of maintenance and fewer sports facilities, and the acreage was overall less accessible to the population.[39,40] Similarly, a study in Montréal showed that overall availability of park spaces did not differ by neighbourhood socioeconomic status, but the parks in higher-income neighbourhoods had more recreational amenities and were better maintained.[41] Alternative greenness measures used in smaller-scale studies include tree density[7] and proportion of city blocks, streets or residential yards covered by trees and shrubs,[22,31] although these measures are not yet available nationally.

Greenness measures alone may not represent a benefit, as greenness may sometimes indicate areas of foreclosure or abandonment,[17] as well as reflect poor maintenance of nuisance trees, as was the case in Baltimore along property lines.[40] Other possible detrimental attributes of greater greenness may be higher pollen counts, possible pest habitats,[10] and real or perceived crime and insecurity in forested areas.[11] Future development of geographic datasets for these purposes, such as maps of accessible parks and recreational areas, as well as park quality indexes, may assist researchers in further exploring inequalities in access to these neighbourhood benefits.

Some spatial error is inherent in assigning geographic coordinates based on postal codes. Point estimates of residential location from the PCCF+ program are estimated as having a median spatial error of 160 m for ordinary urban households and 110 m for large urban apartment buildings,[25] which are the most typical postal code types within this study. However, error of this magnitude is unlikely to affect NDVI estimates, as these were calculated as a mean within a larger-sized buffer, representing values across the neighbourhood. Furthermore, only a single spatial scale (500 m) was included in this study, although it is possible that other elements of greenspace, such as park access or acreage of green areas, may be better captured at a different scale.[40] However, previous research on the health effects of greenness found similar effects using different-sized buffers (i.e., 250 m, 500 m and 1 km buffers).[14]

Changes in exposure to greenness over time may be an interesting avenue for future study, as historical greenness and census data could be used to provide a snapshot of how inequalities have evolved over time.[17] Studying changes over time in exposure to greenness could highlight another issue: the urban greenspace paradox.[42,43] This paradox is that the action of greening a neighbourhood may lead to unintended consequences, where property values may increase, leading to gentrification and driving out groups that were meant to benefit from the original greening efforts. As a result, efforts to improve greenness equity must be conducted in a manner that ensures that other neighbourhood characteristics are preserved.

Conclusion

In Canadian urban areas, residential greenness (the NDVI) was unequally distributed across socioeconomic and population groups. Greenness estimates were lower around the residences of people with lower income; recent immigrants; tenants; and most members of groups designated as visible minorities, particularly respondents identifying as Filipino. By contrast, residential greenness was greater for non-immigrant White populations and those with higher income. These findings may be of particular interest to urban planners or those who are involved in reforestation efforts within cities. Given the increasing body of literature relating residential greenness to health outcomes,[1-5,9,14] differential patterns of household greenness in Canada may represent an indirect mechanism by which health inequities are further perpetuated.

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