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Exposure to fine particulate matter air pollution in Canada

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Abstract

Background: Exposure to ambient fine particulate matter ($PM_{2.5}$) has been associated with a greater risk of non-accidental, cardiovascular and respiratory mortality in Canada. Research based on Canadian cohorts suggests that exposure to $PM_{2.5}$ varies by demographic and socioeconomic characteristics. Studies of NO_2, another pollutant, indicate that persons of lower socioeconomic status and some visible minority groups have greater exposure in urban centres.

Data and methods: National residential $PM_{2.5}$ was estimated from a ~1 km^2 spatial layer for respondents to the 2006 Census long-form questionnaire. Weighted $PM_{2.5}$ estimates from personal-level estimates were determined for white, Aboriginal, visible minority and immigrant populations, as well as for socioeconomic groups (household income, educational attainment) and stratified by urban core, urban fringe and rural residence. Descriptive statistics were provided for selected comparisons.

Results: In Canada, $PM_{2.5}$ exposure was 1.61 $\mu g/m^3$ higher for visible minority (versus white) populations, and 1.55 $\mu g/m^3$ higher for immigrants (versus non-immigrants). When the relatively high percentages of these groups in large cities were taken into account, exposure differences in urban cores were much smaller. Exposure among urban immigrants did not decrease substantially with time since immigration (< 0.5 $\mu g/m^3$ between any two years). In urban cores, residents of low-income households had marginally higher exposure (0.56 $\mu g/m^3$) than did people who were not in low-income households.

Interpretation: Differences between specific population groups in exposure to $PM_{2.5}$ are due, at least in part, to higher percentages of these groups living in urban cores where air pollution levels are elevated.

Keywords: Environmental exposure, environmental monitoring, immigrants, rural health, socioeconomic factors, urban health, visible minority

Fine particulate matter ($PM_{2.5}$) is one of the primary components of air pollution. It refers to a mixture of particles less than 2.5 microns in diameter, including aerosols, smoke and dust. According to the Global Burden of Disease Study, $PM_{2.5}$ air pollution is responsible for an estimated 2.9 million deaths worldwide each year[1] and is associated with increased risk of non-accidental, circulatory and respiratory disease mortality.[2] In a study using the 1991 Canadian Census Health and Environment Cohort (CanCHEC),[3] this association was observed in Canada, a country where the level of ambient air pollution is relatively low. A subsequent study using the Canadian Community Health Survey (CCHS) and mortality cohort adjusted for behavioural covariates (for example, smoking) found an excess mortality risk at a lower concentration threshold.[4] The CCHS analysis used a fine-scale (1 km^2) national model of $PM_{2.5}$, which provided more accurate exposure estimates than did previous models.

An important part of understanding the health effects of air pollution is describing how exposure differs across demographic and socioeconomic groups. In Canada, land use regression models developed for nitrogen dioxide (NO_2) in urban centres allow researchers to assess within-city differences in exposure.[5-8] In large cities, NO_2 exposure tends to be greater among lower socioeconomic status populations, although the groups affected are city-specific.[9-12] A national study in the United States reported greater NO_2 exposure among non-white and low-income populations, particularly in urban centres.[13] The dataset used in the CCHS study[4] offers an opportunity to examine national patterns in $PM_{2.5}$ exposure in Canada.

Specific groups such as recent immigrants, who tend to be healthier overall, may have greater exposure to $PM_{2.5}$ (for instance, a disproportionate share may live in large cities). This creates challenges in estimating concentration-response associations for the entire Canadian population. Identifying groups with more or less exposure at a national level and the geographic regions where differences exist (urban versus rural) are useful in estimating health effects and associations between exposure and response. The present study (modelled methodologically on the U.S. NO_2 study)[13] describes residential exposure to ambient $PM_{2.5}$ by visible minority, immigrant and socioeconomic status in Canada, while stratifying the analysis across the urban-rural divide.

Data and methods

Characteristics of the Canadian population were derived from the 2006 Census long-form questionnaire, which was administered to a 20% sample of the population (except in some remote areas and Indian reserves where 100% were sampled).[14] The 2006 Census had a net undercoverage rate of 2.67%.[15] Institutional respondents were excluded from this study because they did not provide information on the characteristics of interest. Results from the long-form questionnaire were weighted to reflect

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the demographic and socioeconomic make-up of the entire population.[15]

The variables considered in the study were: age; Aboriginal, visible minority and immigration status; years since immigration; household income; low-income status; labour force status (age 25 or older); and education (age 25 or older). Visible minorities are persons, other than Aboriginal people, who are non-Caucasian in race or non-white in colour.[14] Low-income status was derived from the low-income cut-offs (LICO), which are based on after-tax household income, household size and area of residence. LICO identifies people spending 20% more of their income on food, shelter and clothing than does the average household

Table 1
Percentage distribution and mean residential fine particulate matter ($PM_{2.5}$) exposure, by urban/rural residence and selected characteristics, household population, Canada, 2006

	Population distribution (%)					$PM_{2.5}$ exposure (µg/m³)							
						Total		Urban core		Urban fringe		Rural	
Characteristic		Total	Urban core	Urban fringe	Rural	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Total	100.0	100.0	70.0	10.1	19.8	7.05	5.57	8.03	4.90	5.62	4.24	4.32	2.77
Age group													
Younger than 5	5.4	100.0	70.3	10.6	19.1	6.94	5.41	7.86	4.99	5.55	4.10	4.29	2.53
5 to 17	16.7	100.0	67.7	10.7	21.6	6.86	5.44	7.87	4.94	5.59	4.17	4.30	2.63
18 to 39	29.1	100.0	74.3	9.3	16.4	7.23	5.52	8.06	4.92	5.62	4.21	4.33	2.72
40 to 65	36.7	100.0	68.1	10.0	21.9	6.97	5.60	8.01	4.88	5.63	4.26	4.33	2.85
Older than 65	12.1	100.0	68.9	11.4	19.6	7.17	5.73	8.25	4.82	5.64	4.39	4.31	2.97
Visible minority or Aboriginal status													
White	80.1	100.0	65.9	11.7	22.4	6.84	5.68	7.89	5.05	5.65	4.30	4.37	3.01
Aboriginal	3.6	100.0	44.9	11.8	43.4	5.29	3.60	7.00	4.74	4.71	3.13	3.67	1.47
Visible minority	16.3	100.0	96.0	2.1	1.9	8.45	4.33	8.58	4.10	5.93	3.99	4.77	3.18
South Asian	4.1	100.0	96.8	1.6	1.6	8.36	4.30	8.46	4.14	5.86	3.78	5.02	3.07
Chinese	3.9	100.0	97.0	1.6	1.3	8.38	3.94	8.48	3.75	5.73	3.77	4.66	2.86
Black	2.5	100.0	94.9	2.3	2.7	8.71	4.54	8.89	4.18	6.10	4.31	4.65	3.44
Filipino	1.3	100.0	96.4	2.1	1.5	8.25	4.38	8.37	4.17	5.61	3.54	4.35	3.15
Latin American	1.0	100.0	94.4	2.8	2.8	8.78	4.46	8.95	4.19	6.48	4.50	5.21	2.98
Arab	0.9	100.0	96.3	1.9	1.8	8.73	4.37	8.87	4.05	5.38	3.66	4.61	3.39
Other Asian	2.0	100.0	94.7	3.0	2.2	8.31	4.54	8.47	4.30	6.04	3.89	4.69	3.05
Multiple visible minority	0.4	100.0	95.2	2.6	2.2	8.32	4.47	8.46	4.24	5.99	3.95	4.63	2.58
Other visible minority	0.2	100.0	95.1	2.3	2.6	8.68	4.52	8.83	4.22	6.43	4.14	4.94	4.33
Immigration status													
Not immigrant	79.3	100.0	64.9	11.8	23.3	6.73	5.52	7.81	5.02	5.58	4.23	4.29	2.73
Immigrant	20.7	100.0	89.8	3.9	6.3	8.28	4.82	8.63	4.26	6.07	4.23	4.73	3.29
Education (older than 25)													
Less than secondary graduation	16.7	100.0	61.1	12.1	26.8	6.78	5.70	8.17	4.90	5.50	4.28	4.20	2.64
Secondary graduation	16.1	100.0	69.4	10.6	19.9	7.08	5.64	8.06	4.92	5.73	4.34	4.38	2.97
Non-university diploma or certificate	21.8	100.0	69.3	10.6	20.1	6.98	5.58	7.93	4.94	5.64	4.27	4.39	2.93
University degree	14.0	100.0	82.6	6.3	11.0	7.59	5.37	8.17	4.77	5.66	4.07	4.39	2.89
Labour force status (older than 25)													
Employed	43.6	100.0	70.7	9.7	19.6	7.06	5.57	7.99	4.90	5.65	4.21	4.37	2.89
Unemployed	22.5	100.0	69.1	10.9	20.0	7.13	5.69	8.19	4.85	5.61	4.36	4.28	2.80
Not in labour force	2.5	100.0	67.4	9.4	23.2	7.02	5.79	8.30	4.86	5.34	4.27	3.99	2.36
Household income ($)													
Less than 30,000	17.7	100.0	69.6	9.9	20.4	7.21	5.67	8.37	4.79	5.51	4.35	4.11	2.36
30,000 to 50,000	18.6	100.0	67.4	10.2	22.4	7.05	5.73	8.21	4.89	5.59	4.32	4.23	2.66
50,000 to 90,000	31.7	100.0	68.1	10.7	21.1	6.94	5.60	7.96	4.95	5.62	4.25	4.34	2.85
More than 90,000	32.0	100.0	73.7	9.7	16.6	7.06	5.36	7.82	4.87	5.69	4.10	4.51	3.04
Low-income status†													
Low income	11.2	100.0	84.7	6.3	9.1	7.94	5.43	8.52	4.57	5.59	4.52	4.21	2.89
Not low income	87.0	100.0	69.1	10.7	20.2	6.98	5.68	7.96	4.96	5.64	4.31	4.37	3.06
Visible minority and low income†													
White - low income	7.1	100.0	78.3	8.7	13.0	7.59	5.76	8.37	3.85	5.61	4.56	4.28	2.96
White - not low income	73.0	100.0	65.0	12.0	23.1	6.78	5.71	7.84	5.09	5.65	4.32	4.38	3.08
Visible minority - low income	3.5	100.0	98.3	1.0	0.7	8.86	3.92	8.92	3.78	6.02	4.27	4.66	3.63
Visible minority - not low income	12.7	100.0	95.5	2.3	2.1	8.34	4.42	8.48	4.18	5.93	4.05	4.71	3.21

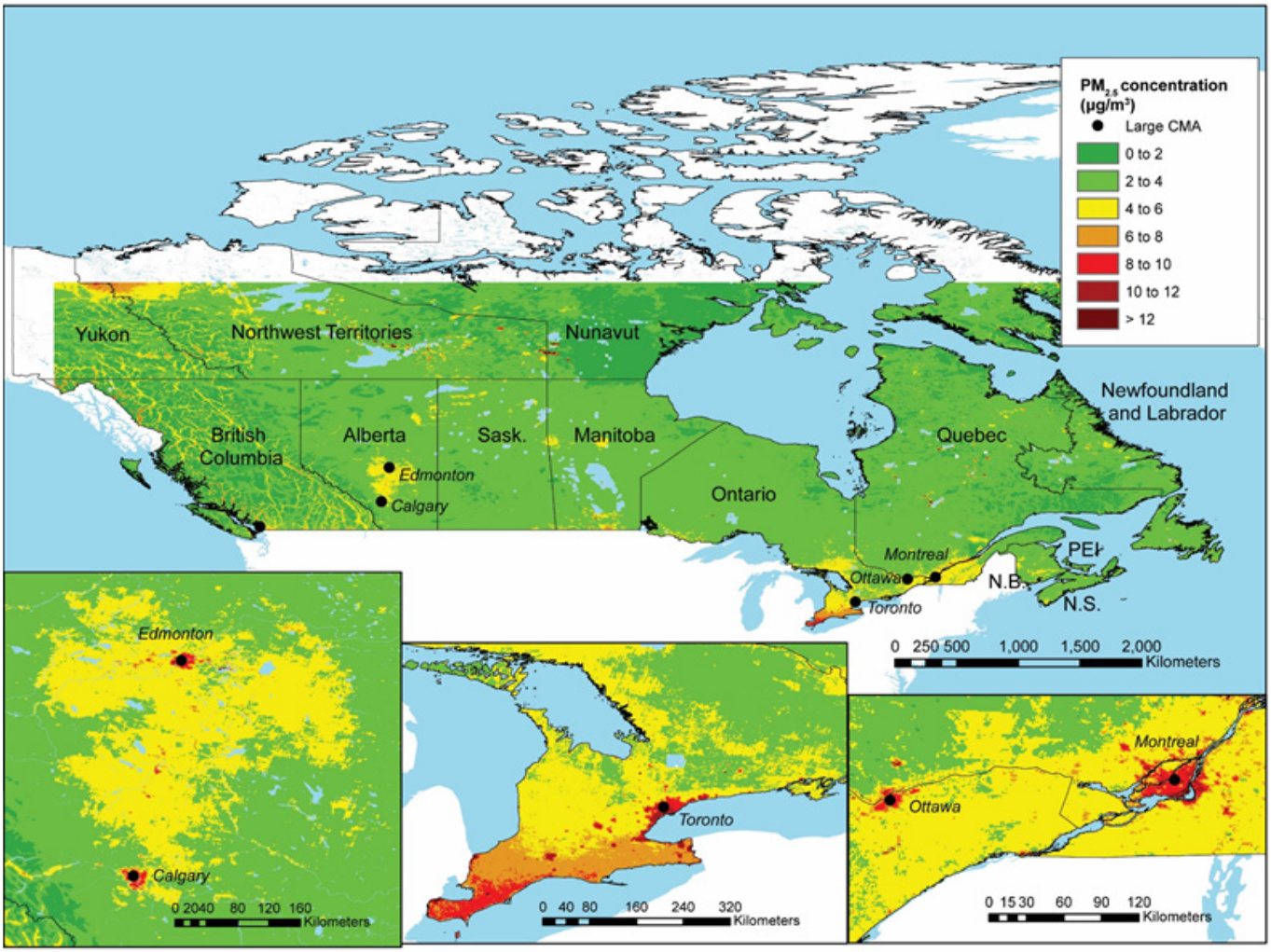
† after-tax household income below low-income income cut-off (LICO)
S.D. = standard deviation
Sources: 2006 Census of Canada; van Donkelaar A, Martin RV, Spurr RJD, et al. High-resolution satellite-derived $PM_{2.5}$ from optical estimation and geographically weighted regression over North America. *Environmental Science and Technology* 2015; 49(17): 10482-91.

in their region.[14] The geography variables were urban core/urban fringe/rural area and Census Metropolitan Area (CMA)/Census Agglomeration (CA). The urban core is the urban area within a CMA or CA with a population of at least 50,000 (CMA) or 10,000 (CA). Urban fringe refers to the urban areas within a CMA/CA that are not contiguous with the main core. Rural is all other regions with a population density less than 400 persons per km.[2,14]

The place of residence of non-institutional census respondents was mapped in a Geographic Information Systems (ArcGIS v. 10; ESRI) using the postal code reported on the census and Statistics Canada's Postal Code Conversion File plus (PCCF+, v6B). The PCCF+ uses a population-weighted random allocation algorithm to provide a geographical representative point for postal codes.[16] Census respondents were spatially linked in GIS to gridded estimates of $PM_{2.5}$ at 1 km^2 resolution from a published $PM_{2.5}$ dataset for 2006. The dataset was derived from column aerosol optical depth retrievals from the Moderate Resolution Imaging Spectroradiometer (MODIS) and related to near-surface $PM_{2.5}$ using information from the GEOS-Chem chemical transport model.[17] Geographically weighted regression (incorporating the gridded estimates, land use data and ground monitoring data) was applied to produce a surface layer of yearly average $PM_{2.5}$ at an approximately 1 km^2 resolution.[17] Outlier $PM_{2.5}$ estimates (values > 20 $\mu g/m^3$; fewer than 1% of respondents) were excluded from the analysis, because they are likely due to data quality issues associated with satellite retrievals.

Estimates of mean (± standard deviation) $PM_{2.5}$ exposure were derived for selected characteristics. Means were calculated for the total population and for urban core, urban fringe and rural popu-

Map 1
Modelled fine particulate matter ($PM_{2.5}$) air pollution estimates, Canada, 2006



Source: van Donkelaar A, Martin RV, Spurr RJD, et al. High-resolution satellite-derived $PM_{2.5}$ from optical estimation and geographically weighted regression over North America. *Environmental Science and Technology* 2015; 49(17): 10482-91.

lations. Graphs were used to examine changes in mean exposure by age over income, by community size, and for immigrants by years since immigration.

To compare differences in $PM_{2.5}$ exposure among selected groups, Student's t-test was used for significance testing. Because of the very large sample (and therefore, highly significant results), Cohen's *d* effect size was used to interpret the magnitude of differences between groups.[18,19] Cohen's *d* is independent of sample size; $d = 1$ signifies that group means differ by one standard deviation. Cohen's approximate definitions of effect size are: small ($d = 0.2$), medium ($d = 0.5$) and large ($d = 0.8$).[18,19] To determine if differences in $PM_{2.5}$ exposure exist in urban centres, a standard measure of inequality (difference in exposure between high-income whites (HIW) and low-income non-whites (LIN))[13] was calculated for all CMAs. A sensitivity analysis examined the urban population by residence in the Toronto CMA versus other urban cores.

Results

Geographic variations

Estimates of $PM_{2.5}$ exposure were assigned to 6,306,700 non-institutional respondents to the 2006 Census. National mean (standard deviation) exposure was 7.05 (5.57) μg/m³, with a range of < 0.1 to 19.1 μg/m³.

The urban core estimate was 8.03 (4.90) μg/m³. Mean urban fringe and rural estimates were, respectively, 5.62 (4.24) and 4.32 (2.77) μg/m³—2.41 and 3.71 μg/m³ lower than the urban core ($p < 0.001$ for both; urban fringe: $d = 0.53$ and rural: $d = 0.93$) (Table 1). $PM_{2.5}$ exposure estimates were very high in parts of southern Ontario (particularly around Toronto and Windsor) and in major cities (Map 1).

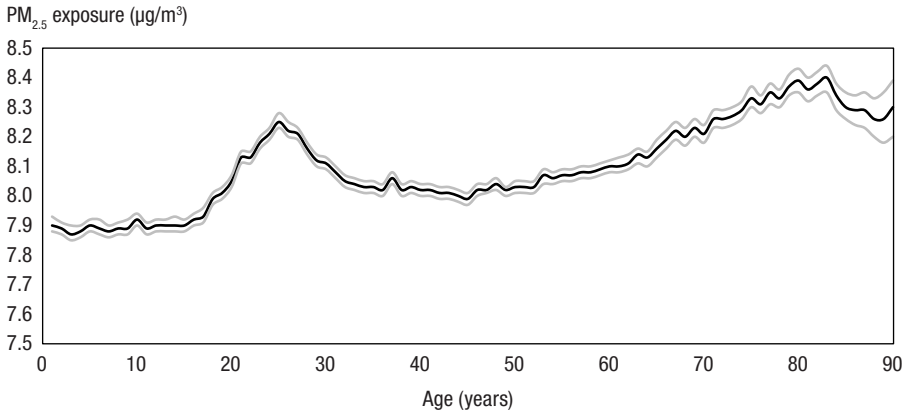
Age

Unlike geographic variations, differences in $PM_{2.5}$ exposure among demographic and socioeconomic groups were small. No obvious associations were apparent by age, except in urban cores where people aged 66 or older had slightly greater exposure than did other age groups ($p < 0.001$; $d = 0.05$). To examine this in more detail, mean (± 95% CI) $PM_{2.5}$ exposure at each year of age was determined for urban respondents (Figure 1). Exposure was lowest during childhood, peaked at age 25 (8.25 μg/m³), declined throughout adulthood, and peaked again at age 80 (8.39 μg/m³). The difference in exposure between any two years of age was < 0.50 μg/m³.

Visible minorities and immigrants

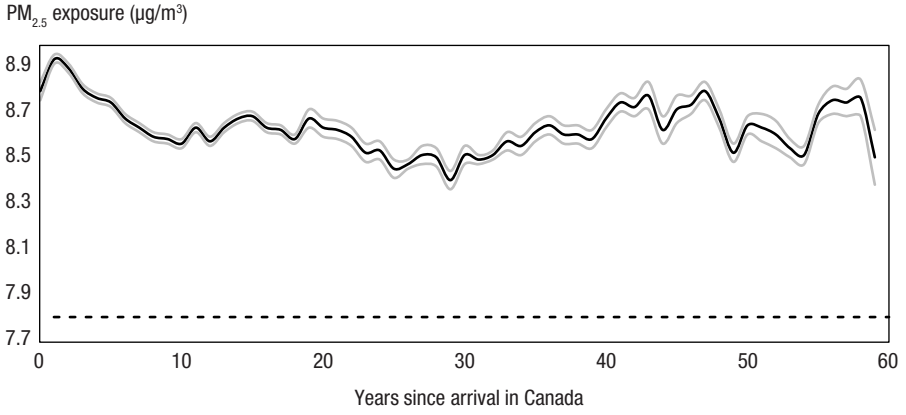
Nationally, exposure of visible minorities to $PM_{2.5}$ was 1.61 μg/m³ higher than that of the white population ($p < 0.001$; $d = 0.32$) (Table 1). However, almost all (96%) the visible minority population lived in urban cores, compared with 66% of the white population. When only urban cores were considered, the difference was reduced to 0.69 μg/m³ ($p < 0.001$; $d = 0.15$). The highest exposures in urban

Figure 1
Mean residential fine particulate matter ($PM_{2.5}$) exposure with 95% confidence interval, by age, urban core household population aged 0 to 90, Canada, 2006



Sources: 2006 Census of Canada; van Donkelaar A, Martin RV, Spurr RJD, et al. High-resolution satellite-derived $PM_{2.5}$ from optical estimation and geographically weighted regression over North America. *Environmental Science and Technology* 2015; 49(17): 10482-91.

Figure 2
Mean residential fine particulate matter ($PM_{2.5}$) exposure with 95% confidence interval, by immigrant status and years since arrival, urban core household population, Canada, 2006



Note: Dashed line is mean residential exposure among non-immigrants in urban cores.
Sources: 2006 Census of Canada; van Donkelaar A, Martin RV, Spurr RJD, et al. High-resolution satellite-derived $PM_{2.5}$ from optical estimation and geographically weighted regression over North America. *Environmental Science and Technology* 2015; 49(17): 10482-91.

cores were among Latin American (8.95 μg/m³), Black (8.89 μg/m³) and Arab (8.87 μg/m³) residents.

$PM_{2.5}$ exposure among Aboriginal people was 1.55 μg/m³ lower than that for white persons ($p < 0.001$; $d = 0.33$).

Immigrants' $PM_{2.5}$ exposure was 1.55 μg/m³ greater than that of non-immigrants ($p < 0.001$; $d = 0.30$) (Table 1). As was the case for visible minorities, a much larger percentage of immigrants (90%) than non-immigrants (65%) lived in urban cores. Among urban core residents, the difference between immigrants and non-immigrants was 0.82 μg/m³ ($p < 0.001$; $d = 0.18$) (Table 1). Urban core immigrants' $PM_{2.5}$ exposure peaked 1 year after they arrived in Canada (8.94 μg/m³) and remained high (8.41 to 8.80 μg/m³), never approaching the mean for the non-immigrant urban core population (7.81 μg/m³) (Figure 2).

Household income

No strong associations emerged between household income and $PM_{2.5}$ exposure overall. However, in urban cores, exposure was greater (0.56 μg/m³; $p < 0.001$; $d = 0.11$) for people in lower- versus higher-income households; in rural areas, their exposure was less (0.16 μg/m³ ; $p < 0.001$; $d = 0.05$) (Table 1). Exposure differed very little by labour force status or education.

Nationally, visible minority individuals in low-income households had the highest $PM_{2.5}$ exposure: 8.86 μg/m³, which was 2.08 μg/m³ greater than that of white people who did not live in low-income households ($p < 0.001$; $d = 0.42$) (Table 1).

$PM_{2.5}$ exposure of visible minority and white populations with similar household incomes was compared (Figure 3). Exposure did not differ greatly in urban fringe and rural areas, but in urban cores, at all household income levels, members of visible minorities had consistently higher exposure than did white individuals.

Census Metropolitan Areas

The difference in $PM_{2.5}$ exposure between low-income visible minorities and high-income white people was calculated for each CMA. In five CMAs, greater exposure of low-income visible minorities was observed, but in the vast majority of CMAs, exposure was greater among high-income white people (Table 2).

Mean Toronto urban core $PM_{2.5}$ exposure (9.33 μg/m³) surpassed the mean for urban cores outside Toronto (7.68 μg/m³) (Table 3). Among urban core residents, 43% who were members of visible minorities lived in Toronto, compared with 15% of those who were white. Similarly, 40% of urban core immigrants lived in Toronto versus 14% of urban core non-immigrants.

To disentangle the effect of Toronto, $PM_{2.5}$ exposure for residents of Toronto's urban core was compared with that of residents of other urban cores combined. In Toronto, exposure was generally similar between white and visible minority populations and immigrants and non-immigrants. However, the difference in $PM_{2.5}$ exposure between lower- and higher-income residents was greater in Toronto than in other urban cores.

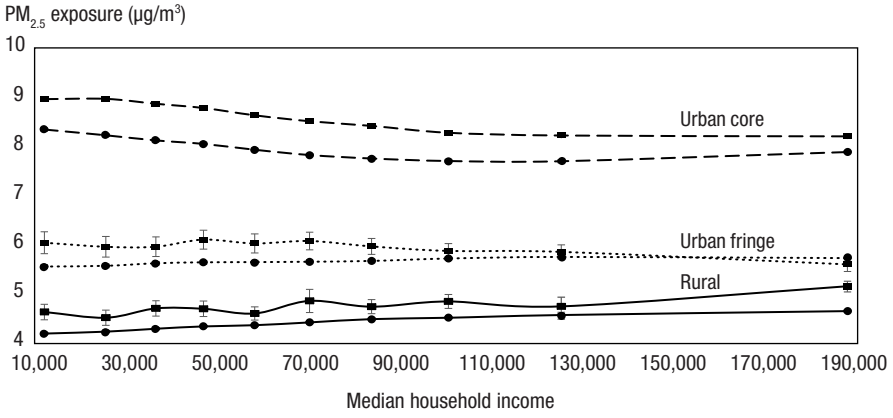
Discussion

The national mean estimate of $PM_{2.5}$ exposure in 2006—7.05 μg/m³—was somewhat below the estimate for the 2001-to-2006 period (8.7 μg/m³), which was based on an earlier $PM_{2.5}$ model.[3]

In the present study, $PM_{2.5}$ exposure was 1.61 μg/m³ higher for visible minorities than for the white population, and 1.51 μg/m³ higher for immigrants than for non-immigrants. This disparity appears to be due, at least in part, to the relatively large percentages of visible minorities and immigrants living in urban cores. Immigrants' exposure did not decline with years in Canada.

Associations between household income and exposure depended on location—in urban cores, $PM_{2.5}$ was weakly positively associated with decreasing income. When visible minority status was also considered, exposure among low-income visible minority populations was 2.08 μg/m³ greater than among high-income white people. However, at

Figure 3
Mean residential fine particulate matter ($PM_{2.5}$) exposure, by visible minority status, urban/rural residence and household income, household population, Canada, 2006



I = 95% confidence interval
▪ = visible minority
● = white

Note: Dashed line is mean residential exposure among non-immigrants in urban cores.
Sources: 2006 Census of Canada; van Donkelaar A, Martin RV, Spurr RJD, et al. High-resolution satellite-derived $PM_{2.5}$ from optical estimation and geographically weighted regression over North America. *Environmental Science and Technology* 2015; 49(17): 10482-91.

the CMA level, exposure among low-income visible minorities was higher than among high-income white people in only a handful of cities.

A unique strength of this study is the largest population dataset in Canada (census long-form questionnaire). Respondents were point-matched to their location of residence and geocoded using postal code to a very fine-scale spatial model for $PM_{2.5}$ (~1 km^2). Population characteristics and $PM_{2.5}$ estimates were derived for the same year (2006), and therefore, provide a relatively accurate cross-sectional match between the two datasets.

The findings highlight differences between the United States and Canada in patterns of exposure to air pollution. In the United States, although Clark et al. examined NO_2 rather than $PM_{2.5}$, they also reported greater exposure among visible minority (versus white) and lower-income groups.[13] As well, they observed a weakly positive association between household income and air pollution in rural areas, and a negative association in urban areas. However, in the United States at the regional, state, county and urban area levels, the difference in NO_2 exposure between low-income non-white and high-income white people was usually positive and often relatively high.[13] By contrast, in the present study, differences between these groups were rare at the city level; differences at the national level appear to be largely due to concentration of visible minorities in urban centres with high levels of $PM_{2.5}$.

Earlier studies of air pollution exposure using aggregate data and spatial regression techniques have been conducted for specific Canadian cities. Low income was associated with NO_2 exposure in Toronto, Vancouver and Montreal, although other social and material deprivation indicators were also significant.[9-11] For example, greater NO_2 exposure was observed in Montreal neighbourhoods with higher percentages of unemployed adults and persons living alone.[9] Not all these variables were considered in the present study of $PM_{2.5}$ exposure, although associations with education and labour force status were not apparent at the national level. However, the geographic distributions of $PM_{2.5}$ and NO_2 are not the same, so it may not be appropriate to expect associations between socioeconomic characteristics and exposure to be the same. An analysis of national patterns in NO_2 exposure would be useful to bridge the results of this study with previous Canadian work on NO_2 and allow a comparison with patterns in the United States. It is possible that considering NO_2 rather than $PM_{2.5}$ at the CMA level would reveal exposure patterns similar to those in the United States.[13]

Small changes in $PM_{2.5}$ concentrations can have substantial population health impacts. Pinault et al.[4] documented an association between non-accidental, circulatory and respiratory mortality and $PM_{2.5}$ in a Canadian cohort adjusted for socioeconomic, ecological and behavioural covariates with a relatively low exposure distribution (mean = 6.3 $\mu g/m^3$).

Table 2
Mean residential fine particulate matter ($PM_{2.5}$) exposure, by low-income status, visible minority status and Census Metropolitan Area (CMA), household CMA population, Canada, 2006

	$PM_{2.5}$ ($\mu g/m^3$)						
	Total		Low-income non-white (LIN)		High-income white (HIW)		Difference
Census Metropolitan Area	Mean	S.D.	Mean	S.D.	Mean	S.D.	(LIN - HIW)
St. John's	4.49	3.06	5.04	3.07	4.61	3.02	0.43
Vancouver	7.37	3.14	7.77	2.84	7.34	3.03	0.43
Kingston	6.33	4.40	6.93	3.60	6.71	4.58	0.23
St. Catharines-Niagara	10.40	4.75	10.85	4.57	10.65	4.65	0.20
Montreal	8.94	7.93	9.22	7.79	9.20	8.78	0.02
Kelowna	6.63	4.43	6.81	3.81	6.84	4.66	-0.03
Victoria	6.92	3.32	7.13	2.96	7.15	3.21	-0.03
Moncton	4.76	2.43	4.89	2.35	4.97	2.61	-0.08
Thunder Bay	5.67	2.74	5.74	2.57	5.92	2.49	-0.18
Greater Sudbury	6.24	3.91	6.43	4.22	6.62	4.08	-0.18
Halifax	4.74	2.90	4.65	2.67	4.89	2.85	-0.24
Winnipeg	5.90	2.47	5.83	2.09	6.10	2.28	-0.27
Québec	8.17	4.90	8.35	4.70	8.68	5.12	-0.33
Saguenay	6.07	3.50	5.96[E]	3.18	6.29	3.55	-0.33[E]
London	9.43	4.05	9.55	3.76	9.89	3.67	-0.34
Ottawa-Gatineau	6.84	4.18	6.82	3.86	7.18	4.22	-0.36
Saint John	5.07	2.77	4.87	2.78	5.26	2.92	-0.39
Saskatoon	4.74	5.23	4.64	3.81	5.06	5.57	-0.42
Peterborough	6.00	4.41	6.07	3.90	6.51	4.58	-0.43
Regina	4.63	2.73	4.48	2.62	4.98	2.59	-0.50
Abbotsford-Mission	7.07	3.43	6.99	2.99	7.54	3.52	-0.55
Brantford	8.70	4.05	8.59	3.73	9.15	3.97	-0.56
Windsor	10.39	4.44	10.33	4.03	10.89	4.46	-0.56
Edmonton	7.45	4.04	7.33	3.71	7.89	3.84	-0.56
Toronto	9.08	4.20	8.84	4.03	9.41	4.16	-0.58
Calgary	7.35	3.91	7.20	3.95	7.80	3.34	-0.60
Sherbrooke	7.07	3.30	6.78	2.86	7.39	3.23	-0.61
Hamilton	9.33	4.32	9.20	4.29	9.86	3.90	-0.66
Guelph	7.29	4.07	7.14	3.83	7.83	3.89	-0.68
Barrie	5.47	3.68	5.01	3.26	5.72	3.82	-0.72
Oshawa	8.57	4.32	8.29	4.30	9.01	3.95	-0.72
Kitchener-Cambridge-Waterloo	8.38	3.91	7.91	4.02	8.87	3.56	-0.95
Trois-Rivières	7.09	4.88	6.31[E]	3.29	7.48	5.37	-1.17[E]

[E] use with caution
S.D. = standard deviation
Sources: 2006 Census of Canada; van Donkelaar A, Martin RV, Spurr RJD, et al. High-resolution satellite-derived $PM_{2.5}$ from optical estimation and geographically weighted regression over North America. *Environmental Science and Technology* 2015; 49(17): 10482-91.

Concentration-response curves (and survival model relationships) from studies of the overall population may not be applicable to specific subpopulations. Differences in exposure are an important component in the framework of "triple jeopardy," whereby people experiencing greater deprivation may have disproportionate air pollution-related health effects owing to a combination of: 1) lower socioeconomic status (and associated stress); 2) greater exposure to air pollution; and 3) effect modification of the health effects air pollution due to lower socioeconomic status, and possibly, greater stress.[9,20,21] It would be useful to examine concentration-response associations among groups identified in this study as having greater $PM_{2.5}$ exposure to determine if they do, indeed, have a stronger response. In one study, a stronger concentration-response association was observed among Canadians in the lowest income quintile,[22] which suggests that effect modification may occur among other groups.

Limitations

The approach to estimating $PM_{2.5}$ exposure in this analysis has several limitations. The PCCF+ program is accurate to within a block face (a few households) in most urban areas, but less so in rural areas.[16] To some degree, this inaccuracy might be mitigated because $PM_{2.5}$ is more uniformly low in rural regions than in urban centres. Additional research is needed to determine the extent of exposure misclassification in rural regions when using the PCCF+ program.

The use of residential point estimates for air pollution[3,4,22] yields only a rough estimate of true exposure. Exposure occurs outside the home—for example, while commuting and in the workplace. Inclusion of workplace exposures might improve estimates. Owing to data limitations, this study was also unable to account for occupational or behavioural differences that would increase exposure.

The study depended on $PM_{2.5}$ estimates from a LUR model. While the model was validated using ground-based measurements, the model itself likely contributes to exposure misclassification, compared with direct measures.

Table 3
Percentage distribution and mean residential fine particulate matter ($PM_{2.5}$) exposure, by Toronto/not Toronto residence and selected characteristics, urban core household population, 2006

	Urban core population distribution (%)				$PM_{2.5}$ exposure (µg/m³)					
					Total		Toronto		Not Toronto	
Characteristic	Total	Total	Toronto	Not Toronto	Mean	S.D.	Mean	S.D.	Mean	S.D.
Total	100.0	100.0	21.0	79.0	8.03	4.90	9.33	3.56	7.68	4.91
Visible minority or Aboriginal status										
White	75.3	100.0	14.9	85.1	7.89	5.05	9.43	3.55	7.63	5.03
Aboriginal	2.3	100.0	4.2	95.8	7.00	4.74	9.59	3.43	6.89	4.63
Visible minority	22.4	100.0	43.3	56.7	8.58	4.10	9.21	3.55	8.09	4.16
South Asian	5.6	100.0	54.4	45.6	8.46	4.14	8.95	3.87	7.87	4.05
Chinese	5.4	100.0	40.4	59.6	8.48	3.75	9.26	3.06	7.95	3.69
Black	3.4	100.0	45.6	54.4	8.89	4.18	9.36	3.56	8.49	4.44
Filipino	1.8	100.0	41.8	58.2	8.37	4.17	9.32	3.36	7.68	4.00
Latin American	1.3	100.0	33.1	66.9	8.95	4.19	9.69	3.24	8.59	4.36
Arab	1.2	100.0	20.1	79.9	8.87	4.05	9.29	3.57	8.77	4.13
Other Asian	2.7	100.0	36.5	63.5	8.47	4.30	9.41	3.40	7.92	4.28
Multiple visible minority	0.6	100.0	45.4	54.6	8.46	4.24	9.13	3.66	7.91	4.27
Other visible minority	0.3	100.0	66.3	33.7	8.83	4.22	9.17	3.81	8.18	4.57
Immigration status										
Not immigrant	73.5	100.0	14.3	85.7	7.81	5.02	9.30	3.69	7.56	5.00
Immigrant	26.5	100.0	39.5	60.5	8.63	4.26	9.36	3.41	8.15	4.41
Household income ($)										
Less than 30,000	17.6	100.0	18.4	81.6	8.37	4.79	9.74	2.77	8.06	4.87
30,000 to 50,000	17.9	100.0	18.5	81.5	8.21	4.89	9.55	3.15	7.90	4.94
50,000 to 90,000	30.9	100.0	19.5	80.5	7.96	4.95	9.29	3.62	7.63	4.94
More than 90,000	33.7	100.0	25.0	75.0	7.82	4.87	9.11	3.82	7.38	4.79
Low-income status†										
Low income	13.5	100.0	23.6	76.4	8.52	4.57	9.64	3.00	8.17	4.68
Not low income	85.8	100.0	20.7	79.3	7.96	4.96	9.27	3.65	7.61	4.96

S.D. = standard deviation
† after-tax household income below low-income income cut-off (LICO)
Sources: 2006 Census of Canada; van Donkelaar A, Martin RV, Spurr RJD, et al. High-resolution satellite-derived $PM_{2.5}$ from optical estimation and geographically weighted regression over North America. *Environmental Science and Technology* 2015; 49(17): 10482-91.

What is already known on this subject?

- Studies of individual Canadian cities and a national American study find greater exposure to nitrogen dioxide (NO_2) among some visible minority populations and people of lower socioeconomic status.
- Another pollutant, fine particulate matter ($PM_{2.5}$), is associated with an elevated risk of mortality, but population-level differences in exposure are relatively unknown.

What does this study add?

- $PM_{2.5}$ exposure was 1.61 µg/m³ higher for members of visible minorities than for white people and 1.55 µg/m³ higher for immigrants than for non-immigrants; these differences were less pronounced in urban cores, where a large percentage of visible minorities and immigrants reside.
- Nationally, substantial differences in $PM_{2.5}$ exposure by socioeconomic status were not observed, but in urban cores, residents of low-income households had marginally higher exposure than did people who did not live in low-income households.
- Toronto has a large influence on disparities, because it has a very high level of $PM_{2.5}$ (9.08 µg/m³), and is home to 42% of visible minorities and 36% of immigrants.

Conclusion

In 2006, the national mean $PM_{2.5}$ exposure was 7.05 μg/m^3. The mean estimate for the urban core was 8.03 μg/m^3, compared with 5.62 μg/m^3 for the urban fringe and 4.32 μg/m^3 for rural areas. Exposure estimates were very high in parts of southern Ontario (particularly around Toronto and Windsor) and in major cities. $PM_{2.5}$ exposure was higher for visible minority (versus white) populations and for immigrants (versus non-immigrants). These exposure differences were smaller when residential location (for example, urban core) was considered. Exposure among urban immigrants did not decrease substantially with time since immigration. In urban cores, residents of low-income households had marginally higher exposure than did people who were not in low-income households.

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