

# Urban greenness and mortality in Canada's largest cities: a national cohort study

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## Summary

**Background** Findings from published studies suggest that exposure to and interactions with green spaces are associated with improved psychological wellbeing and have cognitive, physiological, and social benefits, but few studies have examined their potential effect on the risk of mortality. We therefore undertook a national study in Canada to examine associations between urban greenness and cause-specific mortality.

**Methods** We used data from a large cohort study (the 2001 Canadian Census Health and Environment Cohort [2001 CanCHEC]), which consisted of approximately 1.3 million adult (aged  $\geq 19$  years), non-immigrant, urban Canadians in 30 cities who responded to the mandatory 2001 Statistics Canada long-form census. The cohort has been linked by Statistics Canada to the Canadian mortality database and to annual income tax filings through 2011. We measured greenness with images from the moderate-resolution imaging spectroradiometer from NASA's Aqua satellite. We assigned estimates of exposure to greenness derived from remotely sensed Normalized Difference Vegetation Index (NDVI) within both 250 m and 500 m of participants' residences for each year during 11 years of follow-up (between 2001 and 2011). We used Cox proportional hazards models to estimate associations between residential greenness (as a continuous variable) and mortality. We estimated hazard ratios (HRs) and corresponding 95% CIs per IQR (0.15) increase in NDVI adjusted for personal (eg, education and income) and contextual covariates, including exposures to fine particulate matter, ozone, and nitrogen dioxide. We also considered effect modification by selected personal covariates (age, sex, household income adequacy quintiles, highest level of education, and marital status).

**Findings** Our cohort consisted of approximately 1 265 000 individuals at baseline who contributed 11 523 770 person-years. We showed significant decreased risks of mortality in the range of 8–12% from all causes of death examined with increased greenness around participants' residence. In the fully adjusted analyses, the risk was significantly decreased for all causes of death (non-accidental HR 0.915, 95% CI 0.905–0.924; cardiovascular plus diabetes 0.911, 0.895–0.928; cardiovascular 0.911, 0.894–0.928; ischaemic heart disease 0.904, 0.882–0.927; cerebrovascular 0.942, 0.902–0.983; and respiratory 0.899, 0.869–0.930). Greenness associations were more protective among men than women (HR 0.880, 95% CI 0.868–0.893 vs 0.955, 0.941–0.969), and among individuals with higher incomes (highest quintile 0.812, 0.791–0.834 vs lowest quintile 0.991, 0.972–1.011) and more education (degree or more 0.816, 0.791–0.842 vs did not complete high school 0.964, 0.950–0.978).

**Interpretation** Increased amounts of residential greenness were associated with reduced risks of dying from several common causes of death among urban Canadians. We identified evidence of inequalities, both in terms of exposures to greenness and mortality risks, by personal socioeconomic status among individuals living in generally similar environments, and with reasonably similar access to health care and other social services. The findings support the development of policies related to creating greener and healthier cities.

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## Introduction

Globally, more than half of the world's population lives in cities, and in developed countries, this figure exceeds 75%.<sup>1</sup> In Canada, two-thirds of the population currently live in census metropolitan areas (that have populations greater than 100 000 individuals).<sup>2</sup> With more people moving to cities every year, there is interest in understanding how urban settings and aspects of the built-up environment affects health outcomes. Residents in large cities might be exposed regularly to environmental stresses, including

traffic congestion, heat island effects, poor air quality, and noise pollution, which might have adverse effects on their health. Natural environments, including green spaces, are recognised as features of the built-up environment with potential to mitigate some of these adverse effects by acting as visual amenities or as places that offer opportunities for social or physical activities.<sup>3</sup> Green spaces and indices describing the presence of green vegetation have been associated with reduced negative perception of noise,<sup>4</sup> urban heat,<sup>5</sup> concentrations of air

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### Research in context

#### Evidence before this study

We searched the PubMed database for epidemiological studies of associations between mortality and exposure to natural environments, defined as “nature”, “parks”, “greenness”, “Normalized Difference Vegetation Index”, “NDVI”, “green space”, “greenspace”, and “presence of green vegetation”. We included peer-reviewed studies published up to May 1, 2017, regardless of location of study or language of publication. We also perused the bibliographies of relevant articles and of published reviews. Although several published studies had examined associations between natural environments and other outcomes, we identified only 12 articles that looked at associations with mortality. Most of these studies were ecological or cross-sectional in design; about half were done in Europe and about half in North America. Only two studies were national in scope, one of which was cross-sectional, and one of which had a small sample size and only included women. Despite the shortage of evidence, findings generally suggested that living in areas with higher amounts of green spaces was associated with reduced mortality, with the strongest association for deaths from cardiovascular disease. Findings from a review concluded that cohort studies that accounted better for socioeconomic status, among other issues, were needed to provide stronger evidence on this topic.

#### Added value of this study

We showed significant protective effects for several common causes of mortality associated with living in greener areas of cities. We also showed increasingly protective effects associated

with each increment of higher income and higher levels of education. The key strengths of our research compared with previous studies included the study design (a nationally representative prospective cohort study), the large sample size (nearly 1.3 million participants), and that we reported results for effect modification by several indicators of socioeconomic status. We also had the advantage of controlling our survival models for many personal and contextual covariates, including exposures to ambient fine particulate matter, ozone, and nitrogen dioxide.

#### Implications of all the available evidence

Within Canada and globally, more people are moving to cities and urban areas every year. There is great interest in understanding how urban settings and aspects of a built-up environment can change health outcomes. Residents in cities might be exposed regularly to environmental stresses such as traffic congestion, heat island effects, poor air quality, and noise pollution, with adverse results on their health; natural environments have been identified as having the potential to mitigate some of these adverse effects. Our findings suggest that increasing the amount of green vegetation in urban areas might have important benefits in reducing mortality. Given the potential benefits to health as reported here, findings from this study should be of interest to city planners, urban designers, landscape architects, and policy makers seeking evidence to support the development of policies related to creating greener and healthier cities.

pollution,<sup>6</sup> and psychological stress.<sup>7</sup> Overall, findings from reviews<sup>3,8</sup> have identified that interactions with natural spaces are associated with both physiological and psychological benefits to health.

Few studies, however, have examined the link between natural green spaces and mortality. Most of these have relied on cross-sectional or ecological study designs, and have produced inconsistent findings.<sup>9</sup> Despite limitations and differences in design among the previous studies, findings from a systematic review concluded that there is moderate to strong evidence for an association between green spaces and both all-cause and cardiovascular mortality.<sup>10</sup> For example, James and colleagues<sup>11</sup> reported lower mortality rates for non-accidental deaths among people living in areas with the highest quintile of green vegetation around their home compared with those in the lowest quintile, in a cohort of around 100 000 American women. A Canadian cohort study of approximately 575 000 adults in urban Ontario also showed significant reductions in cause-specific mortality associated with increased greenness around participants' residences.<sup>12</sup> However, no nationally representative cohort studies have been done in Canada or elsewhere examining the association between greenness and mortality. We therefore sought to examine the benefit of living in

greener areas on the health of urban Canadians in a large, national cohort study (the 2001 Canadian Census Health and Environment Cohort [2001 CanCHEC]). We looked at whether residential greenness was associated with reduced risk of dying from cause-specific mortality among urban, non-immigrant adults, while controlling for a wide range of individual and contextual covariates, and exposures to ambient fine particulate matter (PM<sub>2.5</sub>), nitrogen dioxide, and ozone. Additionally, we investigated whether associations between greenness and risk of mortality varied by selected personal characteristics.

## Methods

### Study cohort

2001 CanCHEC has been described in detail previously.<sup>13</sup> Briefly, it is a nationally representative sample of approximately 1.3 million individuals in 30 cities. The cohort consists of respondents to the mandatory 2001 Statistics Canada long-form census, and is linked by Statistics Canada to the Canadian mortality database and to annual income tax filings through 2011.<sup>13</sup> Individuals were eligible for the cohort if they were aged at least 19 years, were usual residents of Canada on the census day; were not long-term residents of an institution, and had filed a tax return during the follow-up period. The

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