Environment and Climate Change Canada / Environnement et Changement climatique Canada

AIR HEALTH TRENDS

CANADIAN ENVIRONMENTAL SUSTAINABILITY INDICATORS

Canada

Suggested citation for this document: Environment and Climate Change Canada (2022) Canadian Environmental Sustainability Indicators: Air Health Trends. Consulted on *Month day, year*.
Available at: www.canada.ca/en/environment-climate-change/services/environmental-indicators/air-health-trends.html.

Cat. No.: En4-144/85-2022E-PDF
ISBN: 978-0-660-46730-6
Project code: EC22011

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CANADIAN ENVIRONMENTAL SUSTAINABILITY INDICATORS
AIR HEALTH TRENDS

December 2022

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Air health trends

Canadians are regularly exposed to air pollution from the burning of fuels for electricity, transportation, and industry. This can affect Canadians' health and lead to work absences, hospital visits and even death. The Air health trends indicators track the risk to Canadians of death or hospitalization from short-term exposures[1] to 2 major air pollutants: ground-level ozone (O_3) and fine particulate matter ($PM_{2.5}$).[2] They estimate the likely risk of death or hospitalization that can be attributed to exposure to concentrations of the pollutants in the air, and present the change in that risk over time.

National air health trends

This section presents national indicators on the risk of deaths and hospitalizations that can be attributed to short-term exposures to O_3 and $PM_{2.5}$. The indicators show the difference in the attributable risks, expressed as percentage of deaths or hospitalizations, over 7-year periods from a reference period (first 7-year period). In order to determine trends, 7-year periods were used. The years presented for each health outcome and air pollutant vary depending on the data availability.

For the risk of deaths attributed to:

- O_3, data are presented for the years 1990 to 2015
- $PM_{2.5}$, data are presented for the years 2001 to 2015

For the risk of hospitalizations attributed to:

- O_3, data are presented for the years 1996 to 2018
- $PM_{2.5}$, data are presented for the years 2001 to 2018

Risk of deaths due to short-term exposure to ground-level ozone and fine particulate matter

Key results

Although substantial efforts have been made to improve air quality in Canada over the last few decades, outdoor air pollution continues to be an important public health issue.

The risk of deaths in Canada, excluding those as a result of injury,[3] from short-term exposures to O_3 and $PM_{2.5}$:

- show a decreasing trend for O_3 between the first 7-year reference period (1990 to 1996) and the most recent 7-year period (2009 to 2015)
- show a decreasing trend for $PM_{2.5}$ between the reference period (2001 to 2007) and the most recent 7 years (2009 to 2015)

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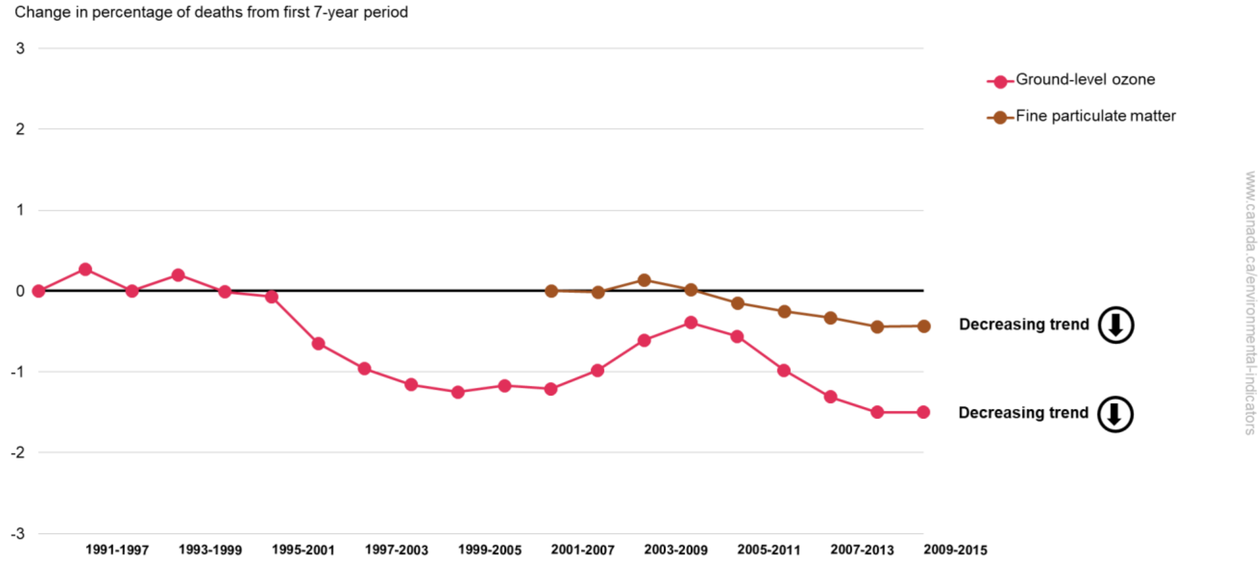
[1] The indicators relate daily deaths and hospitalizations to the air pollution concentrations on the same day only; they do not include the health impacts of long-term exposures to the air pollutants. For more information, please consult the Methods section.

[2] The Air health trends indicators are different from the Air Quality Health Index (AQHI). The indicators are national annual indicators, while the AQHI is location-specific and updated many times a day. For more information on the AQHI, visit the Environment and Climate Change Canada Air Quality Health Index website.

[3] The indicators only include deaths that can be attributed to disease and exclude deaths from injuries as a result of accidents.

Figure 1. Change in percentage of deaths attributable to short-term exposure to ground-level ozone (1990 to 2015) and fine particulate matter (2001 to 2015), Canada



Data for Figure 1

Note: The indicator reports estimates of the percentage of deaths attributable to short-term exposure to O_3 and $PM_{2.5}$ over 7-year periods and shows differences in the estimates relative to the respective reference period (first 7-year period). In order to determine trends, 7-year periods were used to avoid abnormally high or low estimates due to data availability. An up arrow means an increasing trend; a down arrow means a decreasing trend; an "X" means no trend. For more information, please consult the Methods section.
Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division.

Over the past 26 years, the risk of deaths due to short-term exposure to O_3 shows a decreasing trend over the reporting period. Exposures to outdoor O_3 were linked to 2.7% of the deaths during the reference period (1990 to 1996) and reduced to 1.2% during the most recent years (2009 to 2015), resulting in a difference of 1.5% which corresponds to a reduced effect on deaths. Similarly, the Air quality indicators show a slight decrease in the peak annual O_3 levels while no trend is observed in average annual O_3 from 2005 to 2019.

Similar to O_3, during the past 15 years, the risk of deaths due to short-term $PM_{2.5}$ exposure shows a decreasing trend over the reporting period. Exposures to outdoor $PM_{2.5}$ were linked to 0.8% of the deaths during the reference period (2001 to 2007) and reduced to 0.4% during the most recent years (2009 to 2015), resulting in a difference of 0.4% which corresponds to a reduced effect on deaths. This is in line with the Air quality indicators which show declines in annual $PM_{2.5}$ at both peak and average levels from 2005 to 2019.

Deaths from all causes except injuries are the result of a variety of risk factors. Aside from pollution exposure, other risk factors include age, sex, race, obesity, smoking history, education, marital status, diet, medicine usage, alcohol consumption, occupational exposures, and pre-existing health conditions. The indicator estimates deaths related solely to the risk from short-term exposure to air pollution.

Risk of hospitalizations due to short-term exposure to ground-level ozone and fine particulate matter

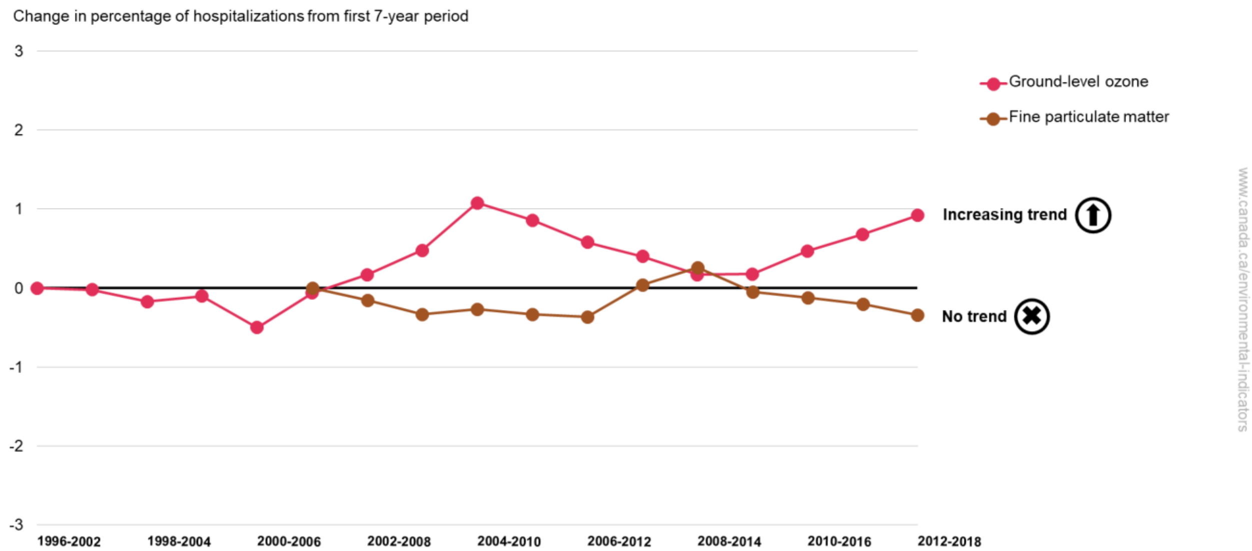
Key results

In addition to deaths, hospitalizations are another important public health impact attributable to daily exposures to outdoor air pollution. In Canada, the risk of hospitalizations, excluding those as a result of injury, from short-term exposures to O_3 and $PM_{2.5}$:

- show an increasing trend for O_3 between the first 7-year reference period (1996 to 2002) and the most recent 7-year period (2012 to 2018)

- show no trend for $PM_{2.5}$ between the reference period (2001 to 2007) and the most recent 7 years (2012 to 2018)

Figure 2. Change in percentage of hospitalizations attributable to short-term exposure to ground-level ozone (1996 to 2018) and fine particulate matter (2001 to 2018), Canada



Data for Figure 2

Note: The indicator reports estimates of the percentage of hospitalizations attributable to short-term exposure to O_3 and $PM_{2.5}$ over 7-year periods and shows differences in the estimates relative to the respective reference period (first 7-year period). In order to determine trends, 7-year periods were used to avoid abnormally high or low estimates due to data availability. An up arrow means an increasing trend; a down arrow means a decreasing trend; an "X" means no trend. For more information, please consult the Methods section.
Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division.

Over the past 23 years, the risk of hospitalizations due to short-term exposure to O_3 shows an increasing trend over the reporting period. Exposures to outdoor O_3 were linked to 0.2% of the hospitalizations during the reference period (1996 to 2002) and increased to 1.1% during the most recent years (2012 to 2018), resulting in a difference of 0.9% which corresponds to an increased effect on hospitalizations. This is opposite to the downward trend observed in the percentage of deaths attributable to O_3 exposure.

Unlike O_3, during the past 18 years, the risk of hospitalizations due to short-term exposure to $PM_{2.5}$ shows no trend over the reporting period. Exposures to outdoor $PM_{2.5}$ were linked to 0.4% of the hospitalizations during the reference period (2001 to 2007) and reduced to 0.1% during the most recent years (2012 to 2018), but resulted in no trend overall which corresponds to no change in effect on hospitalizations. The reason for the difference in trends between O_3 and $PM_{2.5}$ may be related to differences in the toxic effects of the pollutants once they enter the body.

Like deaths, hospitalizations from all causes except injuries are the result of a variety of risk factors. Aside from air pollution exposure, other risk factors include age, sex, race, obesity, smoking history, education, marital status, diet, medicine usage, alcohol consumption, occupational exposures, genetics and pre-existing health conditions. The indicator estimates hospitalizations related solely to the risk from short-term exposure to air pollution.

Regional air health trends

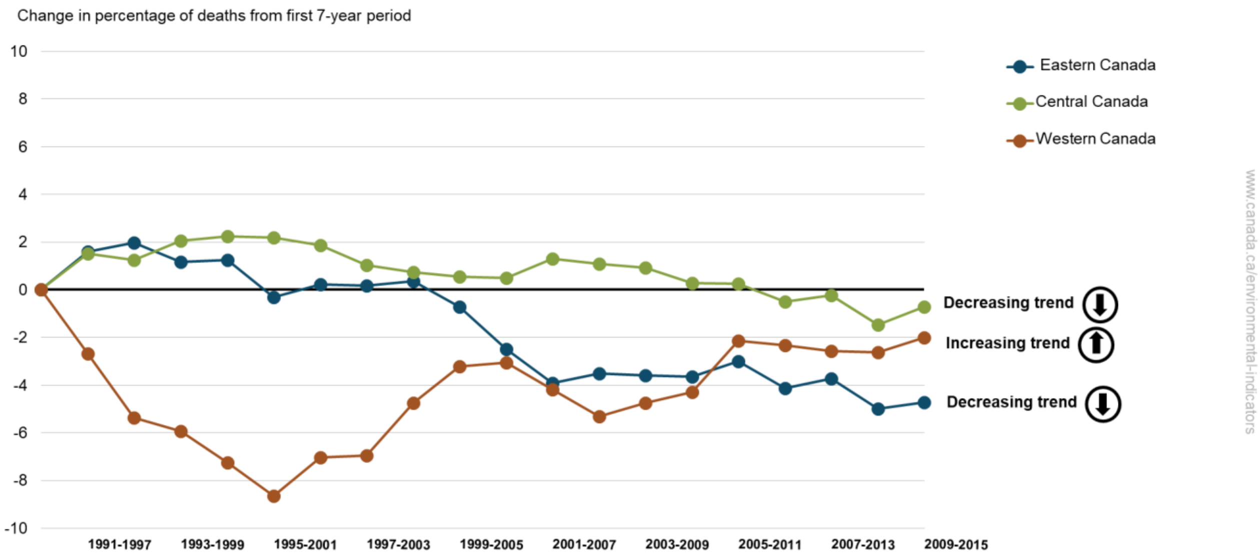
The regional indicators provide a view of the public health impacts attributable to short-term exposures to O_3 and $PM_{2.5}$ in 3 regions in Canada: Eastern Canada[4] (Newfoundland and Labrador, Nova Scotia, New Brunswick, and Quebec), Central Canada (Ontario), and Western Canada (Manitoba, Saskatchewan, Alberta, and British Columbia). The indicators show the difference in attributable risks, expressed as percentage of deaths or hospitalizations, over 7-year periods from a reference period (first 7-year period).

Risk of deaths due to short-term exposure to ground-level ozone and fine particulate matter

Key results

- The risk of deaths attributable to O_3 exposure shows different trends between the reference period (1990 to 1996) and most recent 7-year period (2009 to 2015) for the 3 regions:
  - Western Canada displays an upward trend
  - Central Canada and Eastern Canada demonstrate downward trends
- The risk of deaths attributable to $PM_{2.5}$ exposure shows an increasing trend in Eastern Canada between the reference period (2001 to 2007) and the most recent years (2009 to 2015). However, no trends were observed for Central Canada or Western Canada

Figure 3. Change in percentage of deaths attributable to short-term exposure to ground-level ozone by region, Canada, 1990 to 2015

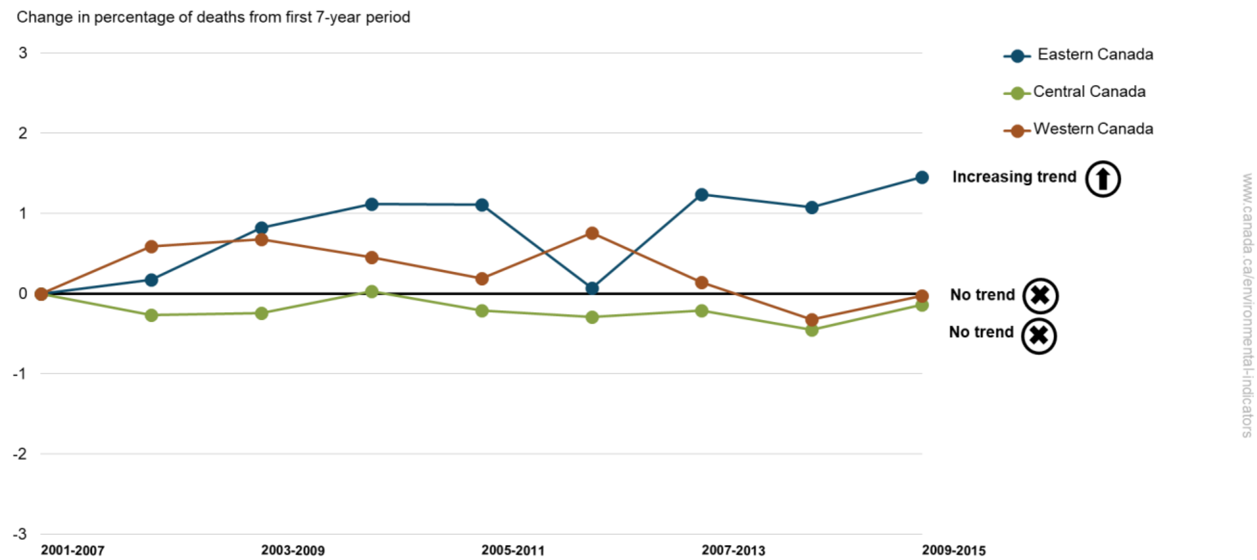


Data for Figure 3

Note: The indicator reports estimates of the percentage of deaths attributable to short-term exposure to O_3 over 7-year periods and shows differences in the estimates relative to the respective reference period (first 7-year period). A total of 84 communities were analyzed for the regional indicator for O_3, covering 78% of the Canadian population. The Eastern Canada (Newfoundland and Labrador, Nova Scotia, New Brunswick, and Quebec) region is composed of 32 communities (covering 18% of the Canadian population); Central Canada (Ontario) has 31 communities (covering 35% of the Canadian population); and Western Canada (Manitoba, Saskatchewan, Alberta, and British Columbia) has 21 communities (covering 25% of the Canadian population). In order to determine trends, 7-year periods were used to avoid abnormally high or low estimates due to data availability. An up arrow means an increasing trend; a down arrow means a decreasing trend; an "X" means no trend. For more information, please consult the Methods section.
Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division.

[4] The province of Prince Edward Island was not included in the indicators because no city in the province was included during the reporting period. For more information, please consult the Methods section.

Figure 4. Change in percentage of deaths attributable to short-term exposure to fine particulate matter by region, Canada, 2001 to 2015



Data for Figure 4

Note: The indicator reports estimates of the percentage of deaths attributable to short-term exposure to $PM_{2.5}$ over 7-year periods and shows differences in the estimates relative to the respective reference period (first 7-year period). A total of 89 communities were analyzed for the regional indicator for $PM_{2.5}$, covering 79% of the Canadian population. The Eastern Canada (Newfoundland and Labrador, Nova Scotia, New Brunswick, and Quebec) region is composed of 29 communities (covering 18% of the Canadian population); Central Canada (Ontario) has 30 communities (covering 35% of the Canadian population); and Western Canada (Manitoba, Saskatchewan, Alberta, and British Columbia) has 30 communities (covering 27% of the Canadian population). In order to determine trends, 7-year periods were used to avoid abnormally high or low estimates due to data availability. An up arrow means an increasing trend; a down arrow means a decreasing trend; an "X" means no trend. For more information, please consult the Methods section.
Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division.

The regional indicators show some disparities among the 3 regions of the country, which are more apparent for O_3 than $PM_{2.5}$. In particular, regional differences in the risk of deaths attributable to O_3 were visible in the 1990s but have been reduced over time. For example, for O_3, a visible drop in risk in Western Canada is observed which appears to be related to a few earlier years (1992, 1997, 1999 and 2001) of relatively low annual risk of deaths (not shown in the indicator). The 7-year rolling average periods in the indicator that include these years result in reduced risks of death. Once these years are no longer included in the 7-year rolling average, there is a gradual upward trend in risk in Western Canada.

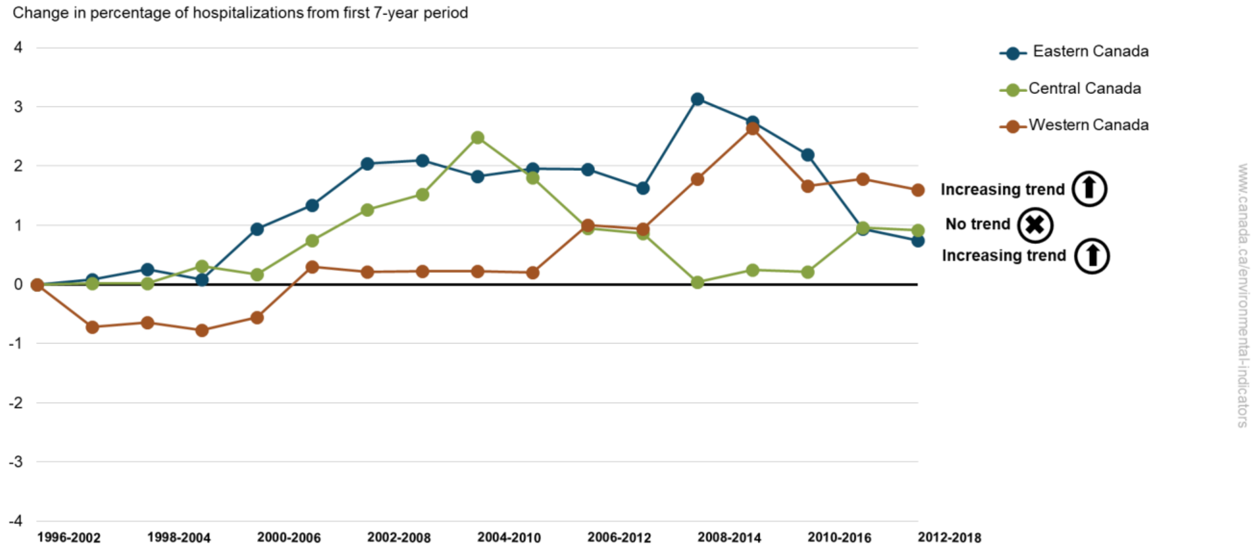
While all 3 regions show upward or downward trends in the risk of deaths attributable to O_3, Eastern Canada is the only region that displays an upward trend in deaths attributable to $PM_{2.5}$ over the 15 years (2001 to 2015) with a difference of 1.4% in percentage of deaths, corresponding to an increased effect on deaths compared to the first 7-year reference period. Overall, Central Canada showed the least changes in percentage of deaths during the reporting periods for both O_3 and $PM_{2.5}$.

Risk of hospitalizations due to short-term exposure to ground-level ozone and fine particulate matter

Key results

- Between the reference period (1996 to 2002) and the most recent 7-year period (2012 and 2018), the risk of hospitalizations attributable to O_3 show:
    - upward trends for Eastern and Western Canada
    - no trend for Central Canada
- The risk of hospitalizations attributable to $PM_{2.5}$ show no trend for all 3 regions between the reference period (2001 to 2007) and the most recent years (2012 and 2018)

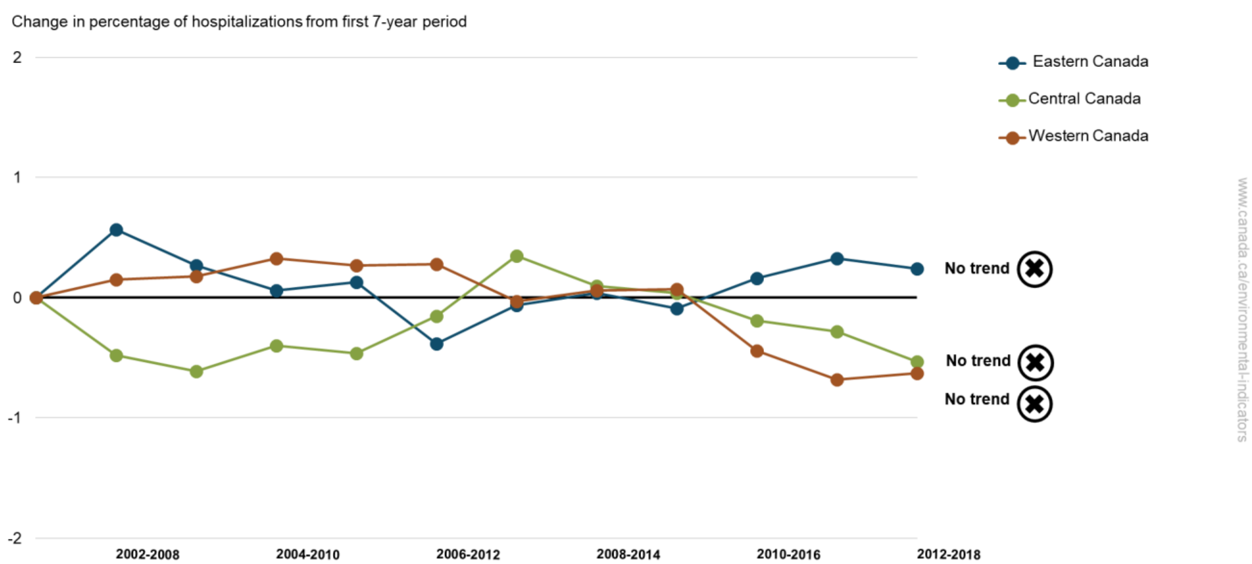
Figure 5. Change in percentage of hospitalizations attributable to short-term exposure to ground-level ozone by region, Canada, 1996 to 2018



Data for Figure 5

Note: The indicator reports estimates of the percentage of hospitalizations attributable to short-term exposure to O_3 over 7-year periods and shows differences in the estimates relative to the respective reference period (first 7-year period). A total of 84 communities were analyzed for the regional indicator for O_3, covering 78% of the Canadian population. The Eastern Canada (Newfoundland and Labrador, Nova Scotia, New Brunswick, and Quebec) region is composed of 32 communities (covering 18% of the Canadian population); Central Canada (Ontario) has 31 communities (covering 35% of the Canadian population); and Western Canada (Manitoba, Saskatchewan, Alberta, and British Columbia) has 21 communities (covering 25% of the Canadian population). In order to determine trends, 7-year periods were used to avoid abnormally high or low estimates due to data availability. An up arrow means an increasing trend; a down arrow means a decreasing trend; an "X" means no trend. For more information, please consult the Methods section.
Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division.

Figure 6. Change in percentage of hospitalizations attributable to short-term exposure to fine particulate matter by region, Canada, 2001 to 2018



Data for Figure 6

Note: The indicator reports estimates of the percentage of hospitalizations attributable to short-term exposure to $PM_{2.5}$ over 7-year periods and shows differences in the estimates relative to the respective reference period (first 7-year period). A total of 89 communities were analyzed for the regional indicator for $PM_{2.5}$, covering 79% of the Canadian population. The Eastern Canada (Newfoundland and Labrador, Nova Scotia, New Brunswick, and Quebec) region is composed of 29 communities (covering 18% of the Canadian population); Central Canada (Ontario) has 30 communities (covering 35% of the Canadian population); and Western Canada (Manitoba, Saskatchewan, Alberta, and British Columbia) has 30 communities (covering 27% of the Canadian population). In order to determine trends, 7-year periods were used to avoid abnormally high or low estimates due to data availability. An up arrow means an increasing trend; a down arrow means a decreasing trend; an "X" means no trend. For more information, please consult the Methods section.
Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division.

The regional indicators show some disparities among the 3 regions of the country, but not for $PM_{2.5}$. Both Eastern and Western Canada show upward trends in the percentage of hospitalizations attributable to O_3 with a difference of 0.7% in Eastern Canada and 1.6% in Western Canada, corresponding to an increased effect on hospitalizations compared to the most recent 7-year period (2012 to 2018).

Air health trends by age and sex

The indicators provide a view of the public health impacts (risks of deaths and hospitalizations) attributable to short-term exposures to O_3 and $PM_{2.5}$ by age and sex. Sex refers to a set of biological attributes of humans such as physical features, hormones and anatomy usually categorized as female and male, which affects physiological functions. Three (3) groups of people are assessed by the indicators:

- Seniors (aged 66 years and older)
- Females (aged 1 year and older)
- Males (aged 1 year and older)

The indicators show the difference in attributable risks, expressed as percentage of deaths or hospitalizations, over 7-year periods from a reference period (first 7-year period).

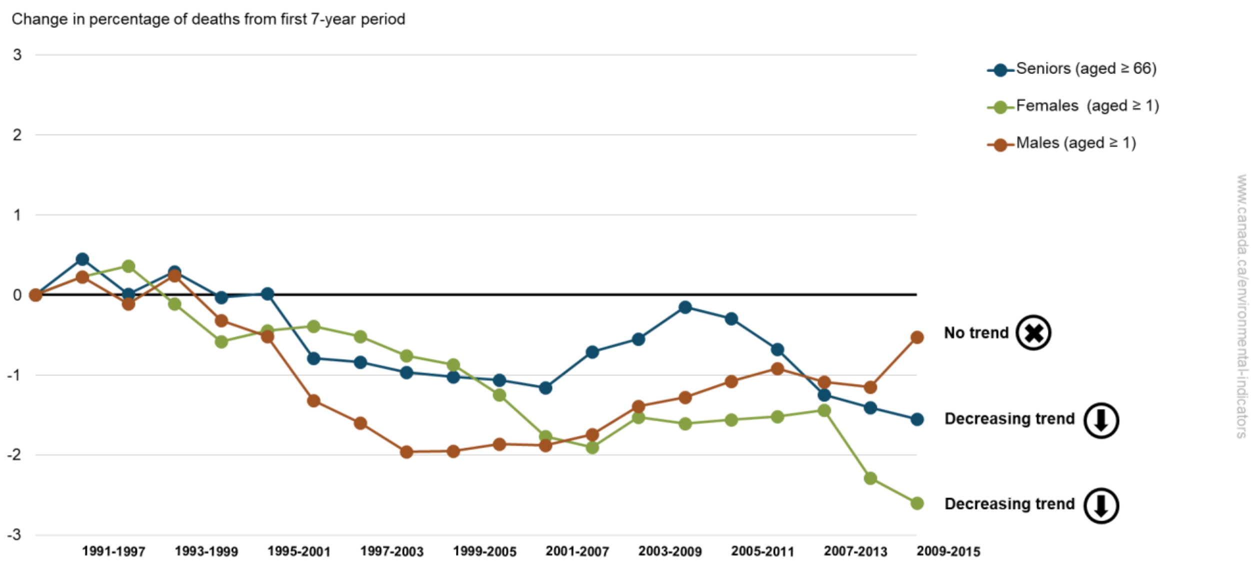
Risk of deaths due to short-term exposure to ground-level ozone and fine particulate matter

Key results

Nationally, the risk of deaths attributable to exposure to O_3 and $PM_{2.5}$ by age and sex shows that between the reference period (1990 to 1996 for O_3 and 2001 to 2007 for $PM_{2.5}$) and the most recent 7-year period (2009 to 2015):

- there are downward trends for seniors for O_3 and $PM_{2.5}$
- there is a downward trend for females for both O_3 and $PM_{2.5}$
- for males, there is no trend for O_3 and a downward trend for $PM_{2.5}$

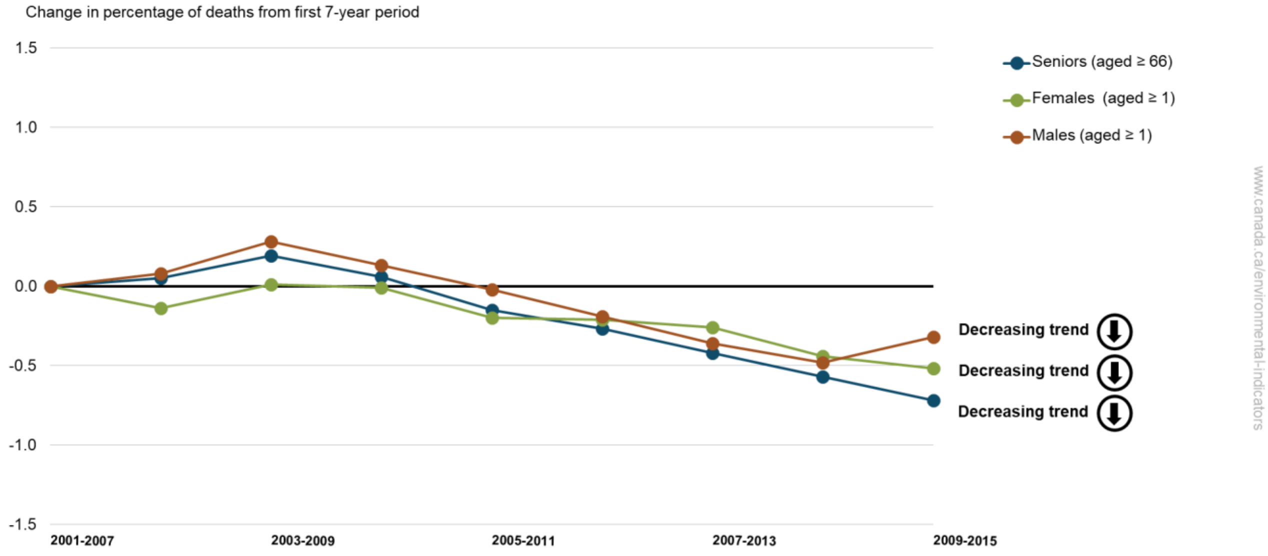
Figure 7. Change in percentage of deaths attributable to short-term exposure to ground-level ozone by age and sex, Canada, 1990 to 2015



Data for Figure 7

Note: The indicator reports estimates of the percentage of deaths attributable to short-term exposure to O_3 over 7-year periods and shows differences in the estimates relative to the respective reference period (first 7-year period). In order to determine trends, 7-year periods were used to avoid abnormally high or low estimates due to data availability. An up arrow means an increasing trend; a down arrow means a decreasing trend; an "X" means no trend. For more information, please consult the Methods section.
Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division.

Figure 8. Change in percentage of deaths attributable to short-term exposure to fine particulate matter by age and sex, Canada, 2001 to 2015



Data for Figure 8

Note: The indicator reports estimates of the percentage of deaths attributable to short-term exposure to $PM_{2.5}$ over 7-year periods and shows differences in the estimates relative to the respective reference period (first 7-year period). In order to determine trends, 7-year periods were used to avoid abnormally high or low estimates due to data availability. An up arrow means an increasing trend; a down arrow means a decreasing trend; an "X" means no trend. For more information, please consult the Methods section.
Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division.

For seniors, there are downward trends for both pollutants over the reporting periods with the trend for O_3 being more visible in recent years. For the last 7 years (2009 to 2015), approximately 1.2% and 0.3% of seniors' deaths can be attributed to O_3 and $PM_{2.5}$, respectively. When compared with the general population (females and males), there are no substantial differences in the trend of risk of deaths attributable to O_3 and $PM_{2.5}$ exposure for seniors over the reporting periods.

There are, however, some different trends between females and males. While females show downward trends for both O_3 and $PM_{2.5}$ between 2001 to 2015, males show no trend for O_3 and a downward trend for $PM_{2.5}$. For females, estimates of risk of deaths decreased for O_3 from 2.9% for the reference period (1990 to 1996) to 0.3% for the last 7 years (2009 to 2015), and for $PM_{2.5}$ from 1.1% for the reference period (2001 to 2007) to 0.6% for the last 7 years (2009 to 2015). Explanations for sex-differences in deaths due to air pollution have been inconsistent in previous studies.[5]

Risk of hospitalizations due to short-term exposure to ground-level ozone and fine particulate matter

Key results

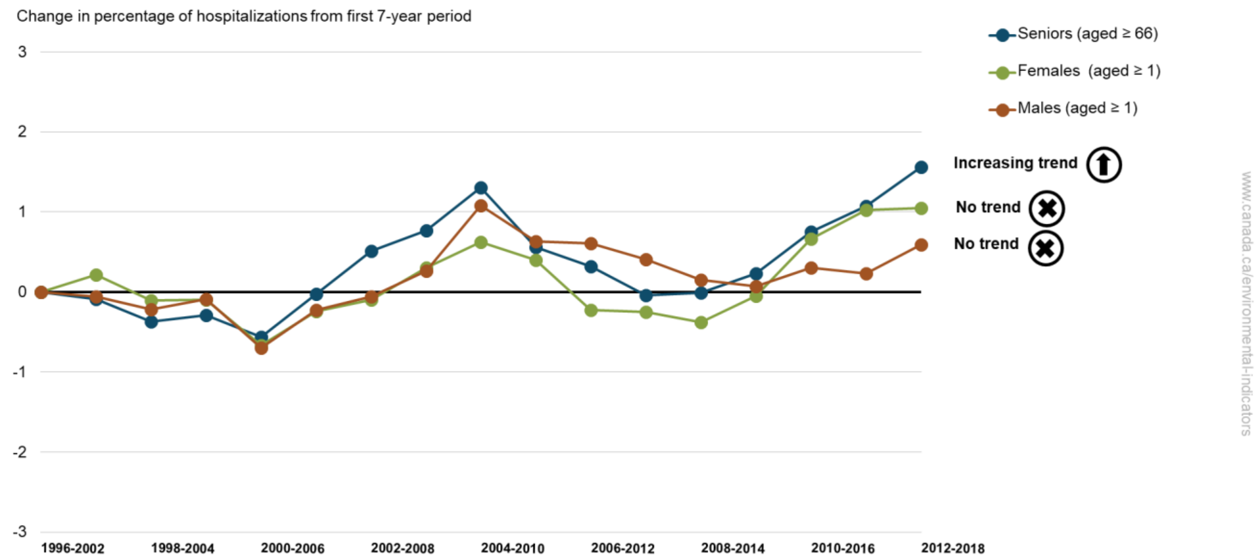
Nationally, the risk of hospitalizations attributable to short-term exposure to O_3 and $PM_{2.5}$ by age and sex shows that between the reference period (1996 to 2002 for O_3 and 2001 to 2007 for $PM_{2.5}$) and most recent 7-year period (2012 to 2018):

- there are different trends for O_3 and $PM_{2.5}$ for seniors (aged 66 years and older): an upward trend in the risk of hospitalizations attributable to O_3 and a downward trend for $PM_{2.5}$

[5] Shin HH et al. (2021) Sex-difference in air pollution-related acute circulatory and respiratory mortality and hospitalization. Sci Total Environ. 1;806(3):150515. doi: 10.1016/j. Retrieved on July 24, 2022.

- there are no trends in the risk of hospitalizations for females (aged 1 year and older) and males (aged 1 year and older) attributable to the pollutants

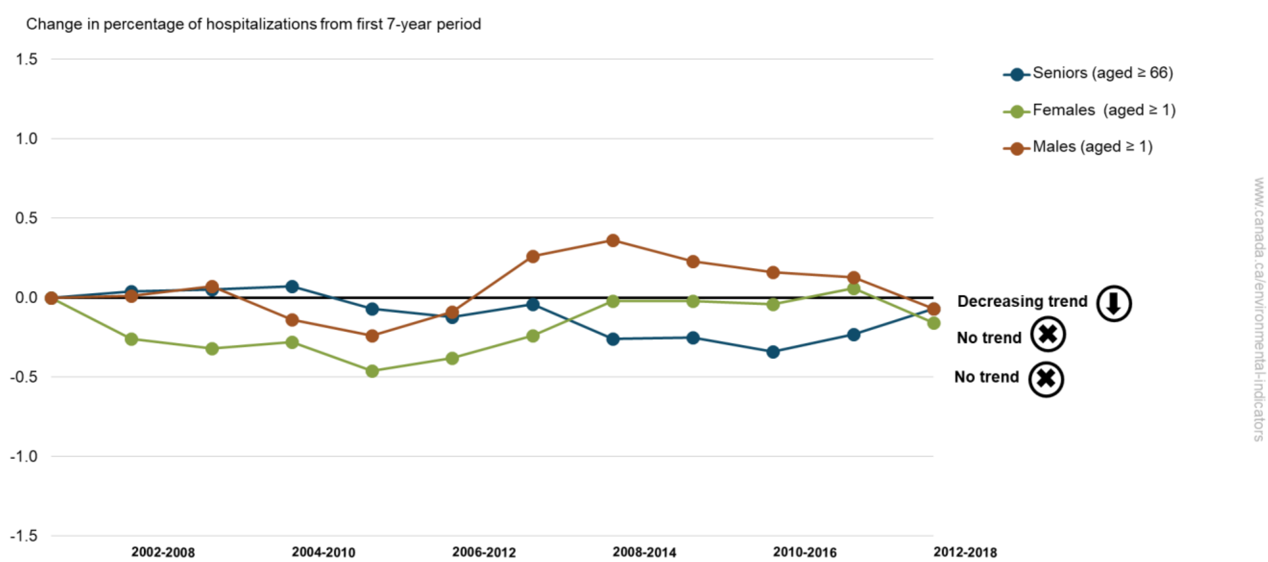
Figure 9. Change in percentage of hospitalizations attributable to short-term exposure to ground-level ozone by age and sex, Canada, 1996 to 2018



Data for Figure 9

Note: The indicator reports estimates of the percentage of hospitalizations attributable to short-term exposure to O_3 over 7-year periods and shows differences in the estimates relative to the respective reference period (first 7-year period). In order to determine trends, 7-year periods were used to avoid abnormally high or low estimates due to data availability. An up arrow means an increasing trend; a down arrow means a decreasing trend; an "X" means no trend. For more information, please consult the Methods section.
Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division.

Figure 10. Change in percentage of hospitalizations attributable to short-term exposure to fine particulate matter by age and sex, Canada, 2001 to 2018



Data for Figure 10

Note: The indicator reports estimates of the percentage of hospitalizations attributable to short-term exposure to $PM_{2.5}$ over 7-year periods and shows differences in the estimates relative to the respective reference period (first 7-year period). In order to determine trends, 7-year periods were used to avoid abnormally high or low estimates due to data availability. An up arrow means an increasing trend; a down arrow means a decreasing trend; an "X" means no trend. For more information, please consult the Methods section.
Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division.

For seniors' exposure to O_3, over the last 23 years, the percentage of hospitalizations due to short-term exposure shows an upward trend. Exposures to O_3 were linked to 0.3% of the hospitalizations during the reference period (1996 to 2002) and increased to 1.8% during the most recent period (2012 to 2018), resulting in a difference of 1.6% which corresponds to an increased effect on hospitalizations. This implies that there have been fewer deaths but more hospitalizations attributable to outdoor O_3 exposures. Over the reporting periods, there are no substantial differences in the trend of hospitalizations attributable to either O_3 and $PM_{2.5}$, between seniors and the general population.

For females and males, there are no statistically significant trends in the risk of hospitalizations attributable to both O_3 and $PM_{2.5}$ over the reporting periods. However, males overall appear to be at higher risk of hospitalization for $PM_{2.5}$ than females. Little is known of how sex-differences in physiological functions might affect hospitalizations due to outdoor air pollution.

About the indicators

What the indicators measure

The Air health trends indicators were developed as a tool to monitor trends in public health impacts in Canada attributable to short-term exposure to 2 major outdoor air pollutants: ground-level ozone (O_3) and fine particulate matter ($PM_{2.5}$). Specifically, the indicators estimate over time the change in the percentage of all deaths, excluding those from injuries, and hospitalizations that can be attributed to exposure to O_3 and $PM_{2.5}$.

Why these indicators are important

Ground-level ozone (O_3) and $PM_{2.5}$ are key components of smog and 2 of the most widespread air pollutants. Exposure to these air pollutants can lead to chronic lung disease, heart attacks, strokes, and mortality. These adverse health effects contribute to economic costs through lost productivity, additional visits to doctors' offices and hospitals, and burden on the health care system. They also influence overall well-being when individuals and families must deal with illness and death.

Consult the Air pollution: drivers and impacts web page for more information on the impacts of air pollution on human health, the economy, and the environment.

Related initiatives

These indicators contribute to the Sustainable Development Goals of the 2030 Agenda for Sustainable Development. They are linked to the 2030 Agenda's Goal 3: Good Health and Well-being and Target 3.9: "By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination" and Goal 11: Sustainable Cities and Communities and Target 11.6: "By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management."

Related indicators

The Air quality indicators track ambient concentrations of $PM_{2.5}$, O_3, sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and volatile organic compounds (VOCs) at the national and regional levels and at local monitoring stations.

The Air pollutant emissions indicators track emissions from human-related sources of 6 key air pollutants: sulphur oxides (SO_X), nitrogen oxides (NO_X), VOCs, ammonia (NH_3), carbon monoxide (CO), and $PM_{2.5}$. Black carbon, which is a component of $PM_{2.5}$, is also reported. For each air pollutant, data are provided at the national, provincial/territorial, and facility level, and by major source.

The Population exposure to outdoor air pollutants indicator tracks the proportion of the population living in areas where outdoor concentrations of air pollutants are less than or equal to the 2020 Canadian Air Ambient Quality Standards.

The International comparison of urban air quality indicators present and compare the air quality in selected Canadian urban areas with a population greater than 1 million to the air quality in selected international urban areas having comparable data.

Data sources and methods

Data sources

The number of health outcomes, deaths (or mortality), and hospitalizations, excluding injury-related health outcomes, was based on daily non-accidental health outcome data obtained from 4 sources. For all provinces except Quebec, the daily mortality counts come from the national Vital Statistics - Death Database (CVSD) maintained by Statistics Canada and the daily hospitalization counts come from the Discharge Abstract Database (DAD) maintained by the Canadian Institute for Health Information. For the province of Quebec, the daily mortality counts come from the Death database of the Quebec Ministry of Health and Social Services and the daily hospitalization counts come from the Quebec MED-ECHO hospital discharge database (in French only) of the Quebec Ministry of Health and Social Services.

The daily ground-level ozone (O_3) and fine particulate matter ($PM_{2.5}$) concentration data were obtained from the National Air Pollution Surveillance Program operated by Environment and Climate Change Canada.

Daily mean temperature data were obtained from the National Climate Data and Information Archive of Environment and Climate Change Canada.

More information

To estimate the risk of health outcomes (deaths and hospitalizations) attributable to air pollution, 3 main datasets were used: daily mortality, hospitalization, and air pollution concentrations. Additional data were also used to adjust the estimates to account for confounding factors that could influence the relationship between air pollution exposure and the health outcomes:

- calendar time, to account for seasonal and long-term variations in daily counts of health outcomes and air pollution concentrations
- daily temperature, to take into consideration the short-term effect of weather on daily counts of health outcomes and air pollution concentrations
- days of the week, to account for variability of counts of health outcomes and air pollution concentrations according to weekday activity patterns

Selection of study periods

Data are from different periods depending on their availability.

Death (mortality) data covered:

- a 26-year period (1990 to 2015) for O_3
- a 15-year period (2001 to 2015) for $PM_{2.5}$

Hospitalization data covered:

- a 23-year period (1996 to 2018) for O_3
- a 18-year period (2001 to 2018) for $PM_{2.5}$

Selection of communities

For reporting the indicators, communities are defined as Statistics Canada census divisions. Communities (or census divisions) were selected based on data availability and completeness. To be included in the indicators, the community required mortality, hospitalization, weather, and air pollution concentrations data, provided by the National Air Pollution Surveillance (NAPS) program, available for at least 50% of the days (more than 182 days) in each year.

Population coverage

The indicators were based on 94 communities, covering about 80% of the Canadian population: 79 communities were included for both O_3 and $PM_{2.5}$, 5 additional communities for O_3, and 10 additional communities for $PM_{2.5}$. Three (3) regions were determined based on geographical locations and population sizes. Eastern Canada includes 33 communities, Central Canada includes 31 communities, and Western Canada includes 30 communities, covering 18%, 35%, and 27%, respectively, of the

Canadian population. Depending on data availiability, not all 94 communities were included for each pollutant (see Table 1 and Table 2).

Health data

Daily mortality and hospitalization data were extracted for the specified communities. Data were included only when the community of residence was the same as the community of mortality or hospitalization occurrence, and when the mortality and hospitalization were from internal causes (that is, excluding external causes such as injuries).[6]

Air pollution concentrations

The air pollutants of interest are O_3 and $PM_{2.5}$, which are strongly linked to adverse health effects in Canada, including mortality and hospitalization.[7] The same metrics as those used by the Canadian Council of Ministers of the Environment were applied to ozone (daily 8-hour maximum) and $PM_{2.5}$ (daily 24-hour average) on an annual basis. For each monitoring station, the daily average concentration was calculated only if at least 18 out of 24 hourly concentrations (75%) for that day were available. Otherwise, it was recorded as missing. For each community, daily average concentrations were averaged over monitoring stations if there were 2 or more stations located in that community. Imputations based on spectral analysis in time series were done for hourly data and then daily data.

Methods

Results are expressed as the percentage of health outcomes (mortality and hospitalizations) attributable to exposure to short-term exposure to the air pollutants. This is estimated by multiplying the annual air pollutant concentrations by the factor "annual health risk" multiplied by 100. The annual health risk for a given year is derived from the time series of 7 years, including that year of interest as well as the 6 years prior. In order to identify changes in annual health risks, greater weight is assigned to more recent years by applying the tri-cubed function to generate appropriate weights. The tri-cubed function is a popular weight function used for locally-weighted smoothers.[8] For example, for a 7-year period of 2001 to 2007, data for year 2001 will be assigned the smallest weight of 0.01, while that for year 2007 will get the largest weight of 0.22.[9]

The reported results (differences in percentage) are a difference relative to the reference period (the first 7-years of the reporting period). For example, if the percentage of deaths attributable to O_3 decreased from 2.7% (reference period) to 1.2% (most recent 7-year period), the change is reported as a 1.5% difference between the two periods. This change can be interpreted as follows: short-term exposure to O_3 contributed to 2.7% of the deaths for the reference period and to 1.2% of the deaths for the most recent period, and thus there was a decline in attributable risks over the reporting period.

The annual mortality (or hospitalization) risk factor is a rate giving the likely increase in daily mortality (or hospitalizations) associated with a unit increase in that air pollutant concentration for a given year. For each year, the annual mortality and hospitalization risks of O_3 and the annual mortality and hospitalization risks of $PM_{2.5}$ were calculated for each community and adjusted for seasonal variation, weather, and day of the week. National annual health risks (mortality and hospitalizations) were then calculated by combining the annual health risks from all the communities.

More information

The annual mortality and hospitalization risks at national and regional levels are estimated using statistical models. Change over time can be detected by the differences in those annual mortality and hospitalization risks. It is assumed for each year that there is a single distribution of true risks for all

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[6] Based on the 10th revision of the International Classification of Diseases ICD-10 codes < 800 and ICD-10 codes A00-R99.

[7] Health Canada (2022) Outdoor air pollution and health. Retrieved on July 24, 2022.

[8] Hastie TJ and Tibshirani RJ (1990) Generalized Additive Models. Chapman and Hall, New York.

[9] Shin HH et al. (2008) A Temporal, Multi-City Model to Estimate the Effects of Short-Term Exposure to Ambient Air Pollution on Health. Environmental Health Perspectives 116(9):1147-1153.

communities across Canada and that this distribution can be characterized by a single risk model with national mean and variance among communities.

Statistical modelling for community-specific risk

The annual mortality and hospitalization risks from O_3 and $PM_{2.5}$ exposure for each community were estimated using overdispersed generalized Poisson models. Daily counts of mortality and hospitalization were assumed to depend on:

- air pollution and the day of the week in a linear manner
- temperature and calendar time in a non-linear manner

For community-specific risk estimates, $\hat{\beta}_{ij}$ with community location *i* and calendar year *j*, a generalized additive over-dispersed Poisson regression model was applied to the daily mortality (or hospitalization) counts, Y_{ij}. For this model we assumed that:

Equation 1.

$$\log(E[Y_i(t)]) = \beta_0 + \sum_{i=1}^{3} \beta_{1ij}(t) * x_{ij}(t) + dow_i(t) + f_i(t) + g_i\big(temp(t)\big)$$

Where:

t is the calendar time indicating day 1, 2,…, T

$Y_i(t)$ denotes, on the day *t*, the daily mortality (or hospitalization) counts

dow(t) denotes, on the day *t*, the day of the week

$x_{ij}(t)$ represents the concentrations of O_3 or $PM_{2.5}$ on the day *t* for community *i* and year *j*

$f_i(t)$ and $g_i\big(temp(t)\big)$ are non-linear smoothing functions for calendar time (accounting for long-term exposure association) and temperature, respectively

β_{ij} is the parameter of interest to be estimated indicating the adverse health effect of O_3 or $PM_{2.5}$ on mortality (or hospitalization)

Aggregating to a national model

For each year *j*, the national annual mortality (or hospitalization) risk is estimated by pooling the annual mortality (or hospitalization) risks by community in Equation 1. A random effects model was applied using a Bayesian approach. To enable tracking of not only spatial variations but also temporal variations, a 2-stage Bayesian hierarchical approach was adopted to model national risks as shown in equation 2.

The estimated risks in Equation 1 were modelled as follows:

Equation 2.

$$\hat{\beta}_{ij} \mid \beta_{ij} \sim N(\beta_{ij}, \hat{v}_{ij})$$

Where:

$\hat{\beta}_{ij}$ is the estimated community-specific risk obtained by Equation 1

$\hat{v}_{ij}$ is the estimated conditional sampling variance, var $(\hat{\beta}_{ij} \mid \beta_{ij})$

The unknown true risks for community (β_{ij}) were modelled as a normal distribution, with the mean as the annual pooled national risk (μ_j) and variance (σ_j^2) indicating the variation among the communities as summarized in equation 3.

Equation 3.

$$\beta_{ij} \mid \mu_j, \sigma_j^{\,2} \sim N(\mu_j, \sigma_j^{\,2})$$

Both the national annual mortality (or hospitalization) risk and variance among communities vary over time. The sampling uncertainty in the estimated annual mortality (or hospitalization) risk depends on the sample size of mortality (or hospitalization) risks by community, but the variance of the unknown true annual mortality (or hospitalization) risks is independent of this sample size.

For the prior distribution[10] for the true mean annual mortality (or hospitalization) risk *(μ_j)*, a normal distribution N(0, 10000) with large variance was chosen for the purpose of objectivity, meaning not favouring one value over another. Also, the normal distribution is conjugated and so offers some computational advantages over other potential prior distributions.

Trends

To help detect a trend, the indicators are based on a dynamic model (rather than a static model), which shows more annual variations. A static model returns just one risk estimate for all years combined, and thus no trend can be detected. A dynamic model, on the other hand, uses multi-year data (7-year moving periods are used for the indicators) for annual risk estimates and thus can detect annual changes or trends. For example, during 26 years (1990 to 2015) for O_3, there are 20 annual mortality risks calculated for each 7-year moving period instead of 26 annual mortality risks calculated for each year.

To detect trends in the annual mortality (or hospitalization) risk estimates, a Sen's linear trend test and a Mann-Kendall test were applied. Following the tests for trends, the estimated mortality (or hospitalization) attributable to air pollution was calculated as follows:

Equation 4.

For small values of concentrations and annual risks:

$$AR_j = C_j \times \beta_j \times 100$$

Where:

AR = attributable risk

C_j = annual air pollutant concentration

β_j = annual risk of the air pollutant

j = year

For large values of concentrations and annual risks:

AR = 100(RR-1)/RR*

Where:

RR = exp(CxB)

Communities considered

The total population of the 94 communities covers about 80% of the total Canadian population in census year 2016.

Table 1. Canadian communities used for the Air health trends indicators

Province or territory	Ground-level ozone (number of communities)	Fine particulate matter (number of communities)	Communities (census division code)
Newfoundland and Labrador	2	2	1001, 1005
Prince Edward Island	0	0	n/a

[10] A prior distribution is a probability distribution representing uncertain quantity before some evidence is taken into account.

Province or territory	Ground-level ozone (number of communities)	Fine particulate matter (number of communities)	Communities (census division code)
Nova Scotia	4	4	1207, 1209, 1212, 1217
New Brunswick	5	4	1301, 1305[A], 1307, 1309[A], 1310, 1315[B]
Quebec	21	19	2422[A], 2423, 2429, 2434, 2437, 2439, 2443, 2445, 2454, 2456, 2458, 2459[A], 2460, 2465, 2466, 2478, 2481, 2482, 2486, 2489, 2494
Ontario	31	30	3501, 3506, 3510, 3515, 3518, 3519, 3520, 3521, 3523, 3524, 3525, 3526, 3528, 3529, 3530, 3534, 3536, 3537, 3538, 3539, 3540, 3541, 3543, 3544, 3547, 3548, 3549, 3553, 3557, 3558, 3560[A]
Manitoba	2	2	4607, 4611
Saskatchewan	2	3	4706, 4711, 4715[B]
Alberta	7	10	4801[B], 4802, 4806, 4808, 4810, 4811, 4812[B], 4813[B], 4816, 4819
British Columbia	10	15	5903[B], 5907[B], 5909, 5915, 5917, 5919[B], 5921, 5924[B], 5931, 5933, 5935, 5937, 5939[B], 5941, 5953
Total	84	89	n/a

Note: [A] Communities included in the O_3 indicators only. [B] Communities included in the $PM_{2.5}$ indicators only. n/a = not available/ applicable.

Table 2. Canadian census division codes and common names

Census division code	Census division name	Census division code	Census division name
1001	Division No. 1 (St. John’s)	3530	Waterloo
1005	Division No. 5 (Corner Brook)	3534	Elgin
1207	Kings (Nova Scotia)	3536	Chatham-Kent
1209	Halifax	3537	Essex
1212	Pictou	3538	Lambton
1217	Cape Breton	3539	Middlesex
1301	Saint John	3540	Huron
1305	Kings (New Brunswick)	3541	Bruce

Census division code	Census division name	Census division code	Census division name
1307	Westmorland	3543	Simcoe
1309	Northumberland	3544	Muskoka
1310	York	3547	Renfrew
1315	Gloucester	3548	Nipissing
2422	La-Jacques-Cartier	3549	Parry Sound
2423	Quebec	3553	Greater Sudbury
2429	Beauce-Sartigan	3557	Algoma
2434	Portneuf	3558	Thunder Bay
2437	Francheville	3560	Kenora
2439	Arthabaska	4607	Division No. 7 (Brandon)
2443	Sherbrooke	4611	Division No. 11 (Winnipeg)
2445	Memphremagog	4706	Division No. 6 (Regina)
2454	Les Maskoutains	4711	Division No. 11 (Saskatoon)
2456	Le Haut-Richelieu	4715	Division No. 15 (Prince Albert)
2458	Longueuil	4801	Division No. 1 (Medicine Hat)
2459	Marguerite-D’Youville	4802	Division No. 2 (Lethbridge)
2460	L’Assomption	4806	Division No. 6 (Calgary)
2465	Laval	4808	Division No. 8 (Red Deer)
2466	Montreal	4810	Division No. 10 (Lamont County)
2478	Les Laurentides	4811	Division No. 11 (Edmonton)
2481	Gatineau	4812	Division No. 12 (Cold Lake)
2482	Les Collines-de-l’Outaouais	4813	Division No. 13 (Lac Ste-Anne County)
2486	Rouyn-Noranda	4816	Division No. 16 (Fort McMurray)

Census division code	Census division name	Census division code	Census division name
2489	La Vallee-de-l'Or	4819	Division No. 19 (Grand Prairie)
2494	Le Saguenay-et-son-Fjord	5903	Central Kootenay
3501	Stormont, Dundas and Glengarry	5907	Okanagan-Similkameen
3506	Ottawa	5909	Fraser Valley
3510	Frontenac	5915	Greater Vancouver
3515	Peterborough	5917	Capital
3518	Durham	5919	Cowichan Valley
3519	York	5921	Namaimo
3520	Toronto	5924	Strathcona
3521	Peel	5931	Squamish-Lillooet
3523	Wellington	5933	Thompson-Nicola
3524	Halton	5935	Central Okanagan
3525	Hamilton	5937	North Okanagan
3526	Niagara	5939	Columbia-Shuswap
3528	Haldimand-Norfolk	5941	Cariboo
3529	Brant	5953	Fraser-Fort George

Source: Statistics Canada (2018) Standard Geographical Classification, National map - Census divisions.

Regional

The indicators' communities are classified into 3 regions based on geographical location and population. While Eastern and Western Canada regions each consist of multiple provinces, the Central Canada region covers a single province:

- Eastern Canada: 33 communities in 4 provinces (Newfoundland & Labrador, Nova Scotia, New Brunswick, and Quebec)
- Central Canada: 31 communities in Ontario
- Western Canada: 30 communities in 4 provinces (Manitoba, Saskatchewan, Alberta, and British Columbia)

Recent changes

There are 4 noticeable changes from previous reporting of the indicators:

- **Health outcome**: A new public health outcome (hospitalizations) has been analyzed in addition to mortality. The health outcome of interest is non-accidental causes, which includes the heart and lung causes. This broader health outcome (hospitalizations) provides for a more general impact of air pollutants on the human body (that is, not limited to deaths).

- **Spatial coverage**: The number of communities has changed from 24 to 84 for O_3 and from 22 to 89 for $PM_{2.5}$. This is to include more communities with National Air Pollution Surveillance Program stations, having moderate population size over 40 000 people. The population size is required to obtain community-specific risk estimates.
- **Temporal coverage**: For mortality, the study periods have changed from 1984 to 2012 to 1990 to 2015 for O_3 and from 2001 to 2010 to 2001 to 2012 for $PM_{2.5}$. For hospitalization, the study periods are 1996 to 2018 for O_3 and 2001 to 2018 for $PM_{2.5}$. This extended study period provides more statistical power for detection of trends in annual mortality (or hospitalization) risk.
- **Annual risk estimates**: The reported time period for the annual risk estimates has changed from 1-year periods to 7 years. This change is to avoid abnormally high or low risk estimates when small data samples are used.

Caveats and limitations

The Air health trends indicators are undergoing continued development. The indicators are assessed in communities for which the required data were available. The indicators do not include assessments of the potential reasons behind changes in mortality (or hospitalizations) attributable to air pollutant exposure.

More information

Short-term versus long-term exposure

The current indicators relate mortality (or hospitalization) to the air pollution concentrations on the same day of the health outcome occurrence only, and thus they do not reflect the total impact associated with these pollutants' concentrations over multiple days. While the indicators estimate acute risk from short-term exposure to air pollution, there is also risk from long-term exposure.

The Air health trends indicators model estimates adverse health effects of exposure on a single day. However, the adverse effect manifests over a period that differs from one member of the population to another, due to different health status and thus different timing of reaction to exposure. Some people become sick immediately, whereas it may take days or even weeks for other people to feel the effects.

Typical models assume that the time delay between exposure and health effect will not be longer than 2 to 3 months: this is too far removed for the exposure to have any reasonable connection to mortality (or hospitalization). For the model used here, it was established that even 2 to 3 months strains plausibility, therefore the time delay between exposure and health effect was isolated down to a 0-day-to-14-day period following exposure and eliminated the rest from consideration to focus on short-term exposure. A 2-week period prior to the health outcome was considered "short-term" exposure for the indicators.

Trends

A dynamic model based on 7-year data was employed for annual risk estimates, which assumed a constant risk for that 7-year period. Due to relatively small sample size for annual dynamic model, a multi-year moving time period was preferred to a 1-year period. Based on previous simulation studies, a 7-year moving time period was applied. Unless a trend in the annual mortality (or hospitalization) risk estimates is identified based on statistical test methods such as non-parametric Sen's test and Mann-Kendall test, those annual risks can be interpreted as having the same adverse health effects from outdoor air pollution over the whole time period. However, both Sen’s tests and Mann-Kendall tests are for linearly or monotonically increasing or decreasing trends, assuming the observations are not serially correlated over time. If no significant trend in the annual changes is found, then it suggests either the same risk over all years or a non-linear trend of mixed upward and downward changes.

Weather effects

To account for weather effects, it might have been useful to add information on relative humidity and dew point temperature to the mean temperature data. However, among the 94 communities, 11 had no appropriate relative humidity or dew point temperature data for more than 10 years within the study period. In addition, when tested, no significant effects of relative humidity and dew point temperature were evident using only those communities that had data available for both of these variables. Therefore, it was decided not to include relative humidity and dew point temperature as covariates in the model.

Resources

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Related information

Air pollution: drivers and impacts

Outdoor air pollution and health

Annex

Annex A. Data tables for the figures presented in this document

Table A.1. Data for Figure 1. Change in percentage of deaths attributable to short-term exposure to ground-level ozone (1990 to 2015) and fine particulate matter (2001 to 2015), Canada

Years (7-year periods)	Risk of deaths attributable to ground-level ozone (percentage)	Change in percentage of deaths attributable to ground-level ozone (change from first 7-year period)	Risk of deaths attributable to fine particulate matter (percentage)	Change in percentage of deaths attributable to fine particulate matter (change from first 7-year period)
1990 to 1996	2.67	0.00	n/a	n/a
1991 to 1997	2.94	0.27	n/a	n/a
1992 to 1998	2.67	0.00	n/a	n/a
1993 to 1999	2.87	0.20	n/a	n/a
1994 to 2000	2.66	-0.01	n/a	n/a
1995 to 2001	2.60	-0.07	n/a	n/a
1996 to 2002	2.02	-0.65	n/a	n/a
1997 to 2003	1.71	-0.96	n/a	n/a
1998 to 2004	1.51	-1.16	n/a	n/a
1999 to 2005	1.42	-1.25	n/a	n/a
2000 to 2006	1.50	-1.17	n/a	n/a
2001 to 2007	1.47	-1.21	0.81	0.00
2002 to 2008	1.69	-0.98	0.80	-0.01
2003 to 2009	2.06	-0.61	0.95	0.14
2004 to 2010	2.28	-0.39	0.83	0.02
2005 to 2011	2.11	-0.56	0.67	-0.15
2006 to 2012	1.69	-0.98	0.56	-0.25
2007 to 2013	1.36	-1.31	0.48	-0.33

2008 to 2014	1.17	-1.50	0.37	-0.44
2009 to 2015	1.17	-1.50	0.38	-0.43

Note: n/a = not available.
Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division.

Table A.2. Data for Figure 2. Change in percentage of hospitalizations attributable to short-term exposure to ground-level ozone (1996 to 2018) and fine particulate matter (2001 to 2018), Canada

Years (7-year periods)	Risk of hospitalizations attributable to ground-level ozone (percentage)	Change in percentage of hospitalizations attributable to ground-level ozone (change from first 7-year period)	Risk of hospitalizations attributable to fine particulate matter (percentage)	Change in percentage of hospitalizations attributable to fine particulate matter (change from first 7-year period)
1996 to 2002	0.19	0.00	n/a	n/a
1997 to 2003	0.17	-0.02	n/a	n/a
1998 to 2004	0.03	-0.17	n/a	n/a
1999 to 2005	0.09	-0.10	n/a	n/a
2000 to 2006	-0.31	-0.50	n/a	n/a
2001 to 2007	0.13	-0.06	0.42	0.00
2002 to 2008	0.37	0.17	0.27	-0.15
2003 to 2009	0.68	0.48	0.09	-0.33
2004 to 2010	1.27	1.08	0.15	-0.27
2005 to 2011	1.05	0.86	0.09	-0.33
2006 to 2012	0.78	0.58	0.06	-0.36
2007 to 2013	0.60	0.40	0.46	0.04
2008 to 2014	0.37	0.17	0.68	0.26
2009 to 2015	0.38	0.18	0.37	-0.05
2010 to 2016	0.66	0.47	0.30	-0.12
2011 to 2017	0.87	0.68	0.22	-0.20
2012 to 2018	1.11	0.92	0.08	-0.34

Note: n/a = not available.
Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division.

Table A.3. Data for Figure 3. Change in percentage of deaths attributable to short-term exposure to ground-level ozone by region, Canada, 1990 to 2015Figure 2. Change in percentage of hospitalizations attributable to short-term exposure to ground-level ozone (1996 to

	Eastern Canada		Central Canada		Western Canada	
Years (7-year periods)	**Risk of deaths attributable to ground-level ozone** (percentage)	**Change in percentage of deaths attributable to ground-level ozone** (change from first 7-year period)	**Risk of deaths attributable to ground-level ozone** (percentage)	**Change in percentage of deaths attributable to ground-level ozone** (change from first 7-year period)	**Risk of deaths attributable to ground-level ozone** (percentage)	**Change in percentage of deaths attributable to ground-level ozone** (change from first 7-year period)
1990 to 1996	3.86	0.00	1.31	0.00	4.32	0.00
1991 to 1997	5.45	1.60	2.81	1.51	1.65	-2.67
1992 to 1998	5.84	1.98	2.56	1.25	-1.04[A]	-5.36
1993 to 1999	5.04	1.18	3.37	2.06	-1.61[A]	-5.93
1994 to 2000	5.11	1.25	3.56	2.25	-2.94[A]	-7.26
1995 to 2001	3.54	-0.32	3.50	2.19	-4.33[A]	-8.65
1996 to 2002	4.08	0.23	3.17	1.86	-2.72[A]	-7.04
1997 to 2003	4.04	0.18	2.35	1.04	-2.63[A]	-6.95
1998 to 2004	4.21	0.36	2.05	0.74	-0.42[A]	-4.74
1999 to 2005	3.16	-0.70	1.85	0.54	1.11	-3.21
2000 to 2006	1.37	-2.49	1.81	0.50	1.28	-3.04
2001 to 2007	-0.07[A]	-3.92	2.60	1.29	0.14	-4.18
2002 to 2008	0.35	-3.51	2.40	1.10	-0.98[A]	-5.30

	Eastern Canada		Central Canada		Western Canada	
Years (7-year periods)	**Risk of deaths attributable to ground-level ozone** (percentage)	**Change in percentage of deaths attributable to ground-level ozone** (change from first 7-year period)	**Risk of deaths attributable to ground-level ozone** (percentage)	**Change in percentage of deaths attributable to ground-level ozone** (change from first 7-year period)	**Risk of deaths attributable to ground-level ozone** (percentage)	**Change in percentage of deaths attributable to ground-level ozone** (change from first 7-year period)
2003 to 2009	0.26	-3.59	2.25	0.94	-0.43[A]	-4.75
2004 to 2010	0.22	-3.64	1.58	0.27	0.03	-4.29
2005 to 2011	0.84	-3.01	1.56	0.26	2.17	-2.15
2006 to 2012	-0.27[A]	-4.13	0.82	-0.49	1.99	-2.33
2007 to 2013	0.13	-3.73	1.07	-0.24	1.75	-2.57
2008 to 2014	-1.13[A]	-4.99	-0.16[A]	-1.47	1.70	-2.62
2009 to 2015	-0.87[A]	-4.73	0.60	-0.71	2.33	-2.00

Note: [A] It is not uncommon and expected for epidemiologic studies on the impacts of air pollution on health to produce negative estimates for some periods either by chance or due to background change.[11]
Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division.

Table A.4. Data for Figure 4. Change in percentage of deaths attributable to short-term exposure to fine particulate matter by region, Canada, 2001 to 2015Figure 2. Change in percentage of hospitalizations attributable to short-term exposure to ground-level ozone (1996 to

	Eastern Canada		Central Canada		Western Canada	
Years (7-year periods)	**Risk of deaths attributable to fine particulate matter** (percentage)	**Change in percentage of deaths attributable to fine particulate matter** (change from first 7-year period)	**Risk of deaths attributable to fine particulate matter** (percentage)	**Change in percentage of deaths attributable to fine particulate matter** (change from first 7-year period)	**Risk of deaths attributable to fine particulate matter** (percentage)	**Change in percentage of deaths attributable to fine particulate matter** (change from first 7-year period)
2001 to 2007	-0.22[A]	0.00	0.78	0.00	-0.02[A]	0.00
2002 to 2008	-0.06[A]	0.17	0.51	-0.27	0.57	0.59
2003 to 2009	0.60	0.82	0.55	-0.24	0.66	0.68
2004 to 2010	0.90	1.12	0.81	0.03	0.43	0.45
2005 to 2011	0.89	1.11	0.58	-0.21	0.17	0.19
2006 to 2012	-0.15[A]	0.07	0.50	-0.29	0.74	0.76
2007 to 2013	1.02	1.24	0.58	-0.21	0.12	0.14
2008 to 2014	0.86	1.08	0.33	-0.45	-0.34[A]	-0.32
2009 to 2015	1.23	1.45	0.64	-0.14	-0.05[A]	-0.03

Note: [A] It is not uncommon and expected for epidemiologic studies on the impacts of air pollution on health to produce negative estimates for some periods either by chance or due to background change.[11]
Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division.

Table A.5. Data for Figure 5. Change in percentage of hospitalizations attributable to short-term exposure to ground-level ozone by region, Canada, 1996 to 2018

	Eastern Canada		Central Canada		Western Canada	
Years (7-year periods)	**Risk of hospitalizations attributable to ground-level ozone** (percentage)	**Change in percentage of hospitalizations attributable to ground-level ozone** (change from first 7-year period)	**Risk of hospitalizations attributable to ground-level ozone** (percentage)	**Change in percentage of hospitalizations attributable to ground-level ozone** (change from first 7-year period)	**Risk of hospitalizations attributable to ground-level ozone** (percentage)	**Change in percentage of hospitalizations attributable to ground-level ozone** (change from first 7-year period)
1996 to 2002	-0.32[A]	0.00	-0.39[A]	0.00	0.69	0.00
1997 to 2003	-0.24[A]	0.08	-0.37[A]	0.02	-0.03[A]	-0.72
1998 to 2004	-0.06[A]	0.26	-0.37[A]	0.02	0.05	-0.64
1999 to 2005	-0.25[A]	0.08	-0.08[A]	0.31	-0.07[A]	-0.77
2000 to 2006	0.62	0.94	-0.22[A]	0.17	0.13	-0.56
2001 to 2007	1.01	1.34	0.34	0.74	0.99	0.30
2002 to 2008	1.72	2.04	0.87	1.26	0.90	0.21
2003 to 2009	1.78	2.10	1.12	1.52	0.91	0.22
2004 to 2010	1.49	1.82	2.09	2.49	0.91	0.22
2005 to 2011	1.64	1.96	1.40	1.80	0.89	0.20
2006 to 2012	1.62	1.94	0.56	0.95	1.69	1.00
2007 to 2013	1.31	1.63	0.46	0.86	1.63	0.94
2008 to 2014	2.81	3.13	-0.36[A]	0.04	2.47	1.78
2009 to 2015	2.43	2.75	-0.14[A]	0.25	3.33	2.64

Years (7-year periods)	Eastern Canada: Risk of hospitalizations attributable to ground-level ozone (percentage)	Eastern Canada: Change in percentage of hospitalizations attributable to ground-level ozone (change from first 7-year period)	Central Canada: Risk of hospitalizations attributable to ground-level ozone (percentage)	Central Canada: Change in percentage of hospitalizations attributable to ground-level ozone (change from first 7-year period)	Western Canada: Risk of hospitalizations attributable to ground-level ozone (percentage)	Western Canada: Change in percentage of hospitalizations attributable to ground-level ozone (change from first 7-year period)
2010 to 2016	1.86	2.19	-0.19[A]	0.21	2.35	1.66
2011 to 2017	0.62	0.94	0.57	0.96	2.47	1.78
2012 to 2018	0.41	0.74	0.53	0.92	2.29	1.60

Note: [A] It is not uncommon and expected for epidemiologic studies on the impacts of air pollution on health to produce negative estimates for some periods either by chance or due to background change.[11]
Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division.

Table A.6. Data for Figure 6. Change in percentage of hospitalizations attributable to short-term exposure to fine particulate matter by region, Canada, 2001 to 2018

Years (7-year periods)	Eastern Canada: Risk of hospitalizations attributable to fine particulate matter (percentage)	Eastern Canada: Change in percentage of hospitalizations attributable to fine particulate matter (change from first 7-year period)	Central Canada: Risk of hospitalizations attributable to fine particulate matter (percentage)	Central Canada: Change in percentage of hospitalizations attributable to fine particulate matter (change from first 7-year period)	Western Canada: Risk of hospitalizations attributable to fine particulate matter (percentage)	Western Canada: Change in percentage of hospitalizations attributable to fine particulate matter (change from first 7-year period)
2001 to 2007	0.71	0.00	0.81	0.00	0.44	0.00
2002 to 2008	1.28	0.57	0.33	-0.48	0.58	0.15
2003 to 2009	0.98	0.27	0.20	-0.61	0.62	0.18

	Eastern Canada		Central Canada		Western Canada	
Years (7-year periods)	**Risk of hospitalizations attributable to fine particulate matter** (percentage)	**Change in percentage of hospitalizations attributable to fine particulate matter** (change from first 7-year period)	**Risk of hospitalizations attributable to fine particulate matter** (percentage)	**Change in percentage of hospitalizations attributable to fine particulate matter** (change from first 7-year period)	**Risk of hospitalizations attributable to fine particulate matter** (percentage)	**Change in percentage of hospitalizations attributable to fine particulate matter** (change from first 7-year period)
2004 to 2010	0.77	0.06	0.41	-0.40	0.77	0.33
2005 to 2011	0.84	0.13	0.35	-0.46	0.71	0.27
2006 to 2012	0.34	-0.38	0.66	-0.15	0.71	0.28
2007 to 2013	0.65	-0.06	1.16	0.35	0.41	-0.03
2008 to 2014	0.75	0.04	0.91	0.10	0.49	0.06
2009 to 2015	0.62	-0.09	0.85	0.04	0.50	0.07
2010 to 2016	0.88	0.16	0.62	-0.19	0.00	-0.44
2011 to 2017	1.04	0.33	0.53	-0.28	-0.25[A]	-0.68
2012 to 2018	0.96	0.24	0.28	-0.53	-0.19[A]	-0.63

Note: [A] It is not uncommon and expected for epidemiologic studies on the impacts of air pollution on health to produce negative estimates for some periods either by chance or due to background change.[11]

Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division.

Table A.7. Data for Figure 7. Change in percentage of deaths attributable to short-term exposure to ground-level ozone by age and sex, Canada, 1990 to 2015Figure 2. Change in percentage of hospitalizations attributable to short-term exposure to ground-level ozone (1996 to

	Seniors (aged ≥ 66)		Females (aged ≥ 1)		Males (aged ≥ 1)	
Years (7-year periods)	Risk of deaths attributable to ground-level ozone (percentage)	Change in percentage of deaths attributable to ground-level ozone (change from first 7-year period)	Risk of deaths attributable to ground-level ozone (percentage)	Change in percentage of deaths attributable to ground-level ozone (change from first 7-year period)	Risk of deaths attributable to ground-level ozone (percentage)	Change in percentage of deaths attributable to ground-level ozone (change from first 7-year period)
1990 to 1996	2.79	0.00	2.92	0.00	3.54	0.00
1991 to 1997	3.24	0.45	3.14	0.23	3.77	0.23
1992 to 1998	2.80	0.01	3.28	0.36	3.43	-0.11
1993 to 1999	3.08	0.29	2.81	-0.11	3.78	0.24
1994 to 2000	2.76	-0.03	2.34	-0.58	3.22	-0.32
1995 to 2001	2.82	0.02	2.47	-0.45	3.02	-0.52
1996 to 2002	2.01	-0.79	2.53	-0.39	2.22	-1.32
1997 to 2003	1.95	-0.84	2.40	-0.52	1.94	-1.60
1998 to 2004	1.82	-0.97	2.16	-0.76	1.58	-1.96
1999 to 2005	1.78	-1.02	2.05	-0.87	1.59	-1.95
2000 to 2006	1.73	-1.06	1.67	-1.25	1.68	-1.86
2001 to 2007	1.63	-1.16	1.15	-1.77	1.66	-1.88
2002 to 2008	2.08	-0.71	1.01	-1.90	1.80	-1.74

Years (7-year periods)	Seniors (aged ≥ 66) Risk of deaths attributable to ground-level ozone (percentage)	Seniors (aged ≥ 66) Change in percentage of deaths attributable to ground-level ozone (change from first 7-year period)	Females (aged ≥ 1) Risk of deaths attributable to ground-level ozone (percentage)	Females (aged ≥ 1) Change in percentage of deaths attributable to ground-level ozone (change from first 7-year period)	Males (aged ≥ 1) Risk of deaths attributable to ground-level ozone (percentage)	Males (aged ≥ 1) Change in percentage of deaths attributable to ground-level ozone (change from first 7-year period)
2003 to 2009	2.24	-0.55	1.39	-1.53	2.15	-1.39
2004 to 2010	2.64	-0.15	1.30	-1.61	2.26	-1.28
2005 to 2011	2.50	-0.29	1.36	-1.56	2.46	-1.08
2006 to 2012	2.11	-0.68	1.40	-1.52	2.62	-0.92
2007 to 2013	1.54	-1.25	1.48	-1.44	2.45	-1.09
2008 to 2014	1.38	-1.41	0.63	-2.29	2.39	-1.15
2009 to 2015	1.24	-1.55	0.32	-2.60	3.01	-0.53

Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division.

Table A.8. Data for Figure 8. Change in percentage of deaths attributable to short-term exposure to fine particulate matter by age and sex, Canada, 2001 to 2015Figure 2. Change in percentage of hospitalizations attributable to short-term exposure to ground-level ozone (1996 to

	Seniors (aged ≥ 66)		Females (aged ≥ 1)		Males (aged ≥ 1)	
Years (7-year periods)	Risk of deaths attributable to fine particulate matter (percentage)	Change in percentage of deaths attributable to fine particulate matter (change from first 7-year period)	Risk of deaths attributable to fine particulate matter (percentage)	Change in percentage of deaths attributable to fine particulate matter (change from first 7-year period)	Risk of deaths attributable to fine particulate matter (percentage)	Change in percentage of deaths attributable to fine particulate matter (change from first 7-year period)
2001 to 2007	1.00	0.00	1.08	0.00	0.55	0.00
2002 to 2008	1.05	0.05	0.94	-0.14	0.64	0.08
2003 to 2009	1.19	0.19	1.09	0.01	0.83	0.28
2004 to 2010	1.07	0.06	1.07	-0.01	0.68	0.13
2005 to 2011	0.85	-0.15	0.88	-0.20	0.53	-0.02
2006 to 2012	0.73	-0.27	0.87	-0.21	0.37	-0.19
2007 to 2013	0.58	-0.42	0.82	-0.26	0.19	-0.36
2008 to 2014	0.43	-0.57	0.64	-0.44	0.07	-0.48
2009 to 2015	0.28	-0.72	0.56	-0.52	0.23	-0.32

Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division.

Table A.9. Data for Figure 9. Change in percentage of hospitalizations attributable to short-term exposure to ground-level ozone by age and sex, Canada, 1996 to 2018Figure 2. Change in percentage of hospitalizations attributable to short-term exposure to ground-level ozone (1996 to

	Seniors (aged ≥ 66)		Females (aged ≥ 1)		Males (aged ≥ 1)	
Years (7-year periods)	**Risk of hospitalizations attributable to ground-level ozone** (percentage)	**Change in percentage of hospitalizations attributable to ground-level ozone** (change from first 7-year period)	**Risk of hospitalizations attributable to ground-level ozone** (percentage)	**Change in percentage of hospitalizations attributable to ground-level ozone** (change from first 7-year period)	**Risk of hospitalizations attributable to ground-level ozone** (percentage)	**Change in percentage of hospitalizations attributable to ground-level ozone** (change from first 7-year period)
1996 to 2002	0.25	0.00	0.34	0.00	0.73	0.00
1997 to 2003	0.16	-0.09	0.54	0.21	0.67	-0.06
1998 to 2004	-0.11[A]	-0.37	0.23	-0.11	0.51	-0.22
1999 to 2005	-0.04[A]	-0.29	0.24	-0.10	0.64	-0.09
2000 to 2006	-0.30[A]	-0.56	-0.33[A]	-0.67	0.03	-0.70
2001 to 2007	0.23	-0.03	0.10	-0.24	0.50	-0.23
2002 to 2008	0.77	0.51	0.24	-0.10	0.67	-0.06
2003 to 2009	1.02	0.77	0.63	0.30	0.99	0.26
2004 to 2010	1.55	1.30	0.96	0.62	1.81	1.08
2005 to 2011	0.82	0.56	0.74	0.40	1.36	0.63
2006 to 2012	0.58	0.32	0.11	-0.23	1.34	0.61
2007 to 2013	0.21	-0.04	0.08	-0.25	1.14	0.41
2008 to 2014	0.24	-0.01	-0.04[A]	-0.38	0.88	0.15

	Seniors (aged ≥ 66)		Females (aged ≥ 1)		Males (aged ≥ 1)	
Years (7-year periods)	**Risk of hospitalizations attributable to ground-level ozone** (percentage)	**Change in percentage of hospitalizations attributable to ground-level ozone** (change from first 7-year period)	**Risk of hospitalizations attributable to ground-level ozone** (percentage)	**Change in percentage of hospitalizations attributable to ground-level ozone** (change from first 7-year period)	**Risk of hospitalizations attributable to ground-level ozone** (percentage)	**Change in percentage of hospitalizations attributable to ground-level ozone** (change from first 7-year period)
2009 to 2015	0.48	0.23	0.29	-0.05	0.80	0.07
2010 to 2016	1.00	0.75	1.00	0.66	1.03	0.30
2011 to 2017	1.32	1.07	1.35	1.02	0.96	0.23
2012 to 2018	1.82	1.56	1.38	1.05	1.32	0.59

Note: [A] It is not uncommon and expected for epidemiologic studies on the impacts of air pollution on health to produce negative estimates for some periods either by chance or due to background change.[11]
Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division.

Table A.10. Data for Figure 10. Change in percentage of hospitalizations attributable to short-term exposure to fine particulate matter by age and sex, Canada, 2001 to 2018Figure 2. Change in percentage of hospitalizations attributable to short-term exposure to ground-level ozone (1996 to

	Seniors (aged ≥ 66)		Females (aged ≥ 1)		Males (aged ≥ 1)	
Years (7-year periods)	**Risk of hospitalizations attributable to fine particulate matter** (percentage)	**Change in percentage of hospitalizations attributable to fine particulate matter** (change from first 7-year period)	**Risk of hospitalizations attributable to fine particulate matter** (percentage)	**Change in percentage of hospitalizations attributable to fine particulate matter** (change from first 7-year period)	**Risk of hospitalizations attributable to fine particulate matter** (percentage)	**Change in percentage of hospitalizations attributable to fine particulate matter** (change from first 7-year period)
2001 to 2007	0.44	0.00	0.40	0.00	0.35	0.00
2002 to 2008	0.48	0.04	0.14	-0.26	0.36	0.01

Years (7-year periods)	Seniors (aged ≥ 66)		Females (aged ≥ 1)		Males (aged ≥ 1)	
	Risk of hospitalizations attributable to fine particulate matter (percentage)	Change in percentage of hospitalizations attributable to fine particulate matter (change from first 7-year period)	Risk of hospitalizations attributable to fine particulate matter (percentage)	Change in percentage of hospitalizations attributable to fine particulate matter (change from first 7-year period)	Risk of hospitalizations attributable to fine particulate matter (percentage)	Change in percentage of hospitalizations attributable to fine particulate matter (change from first 7-year period)
2003 to 2009	0.49	0.05	0.08	-0.32	0.41	0.07
2004 to 2010	0.51	0.07	0.12	-0.28	0.20	-0.14
2005 to 2011	0.37	-0.07	-0.06[A]	-0.46	0.11	-0.24
2006 to 2012	0.32	-0.12	0.02	-0.38	0.26	-0.09
2007 to 2013	0.41	-0.04	0.16	-0.24	0.60	0.26
2008 to 2014	0.18	-0.26	0.38	-0.02	0.70	0.36
2009 to 2015	0.19	-0.25	0.38	-0.02	0.58	0.23
2010 to 2016	0.10	-0.34	0.36	-0.04	0.51	0.16
2011 to 2017	0.21	-0.23	0.46	0.06	0.48	0.13
2012 to 2018	0.37	-0.07	0.24	-0.16	0.28	-0.07

Note: [A] It is not uncommon and expected for epidemiologic studies on the impacts of air pollution on health to produce negative estimates for some periods either by chance or due to background change.[11]
Source: Health Canada (2022) Environmental Health Science and Research Bureau, Population Studies Division

[11] Hernandez C et al. (2022) The impact of air pollution on COVID-19 incidence, severity, and mortality: A systematic review of studies in Europe and North America. Environ Research. 215(1):114155. 10.1016/j.envres.2022.114155 and Orellano P et al. (2020) Short-term exposure to particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), and ozone (O_3) and all-cause and cause-specific mortality: Systematic review and meta-analysis. Environ Int. 142:105876. doi: 10.1016/j.envint.2020.105876. Epub 2020 Jun 23. PMID: 32590284. Retrieved on November 9, 2022.

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