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Systematic Review of Environmental Burden of Disease in Canada

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Summary

- Few studies have estimated the environmental burden of disease (EBD) in Canada.
- Available data suggest that the total EBD for high-income, developed countries, like Canada, may range from as low as 1 – 5% to as high as 15 - 22%, depending on how EBD is calculated and defined.
- Potentially preventable illnesses and deaths resulting from exposure to environmental contaminants have been estimated to account for $3.6 to $9.1 billion in annual health care costs in Canada.
- Excluding lifestyle and occupational risk factors, the strongest evidence is for air pollution as a major contributor to EBD in Canada and elsewhere.
- To ensure the design of effective intervention strategies, future EBD studies in Canada should be conducted at provincial or local levels.

Introduction

The concept that the world's disease burden is attributable to a range of environmental, lifestyle, and occupational risk factors has been recognized for many years. In a landmark study by Doll and Peto,[1] the percentage of avoidable cancer deaths attributable to different risk factors, in the United States, was estimated; this represented one of the first attempts to quantify the relationship between risk factors and health outcomes. Similarly, the Global Burden of Disease (GBD) study was one of the first global efforts to evaluate premature mortality and disability from a large number of diseases and injuries due to a variety of population exposures.[2] Since then, a number of global, regional, and national burden of disease and EBD studies have been conducted.

The current recommended framework for EBD studies is based on a causal web structure that links environmental hazards and risk factors to disease burden.[3,4] Both exposure-based and outcome-based approaches are typically used to estimate EBD; the latter approach being used most often, due to data limitations regarding population exposure levels and unavailable quantitative dose-response relationships. The outcome-based approach involves compiling population-level health statistics data for different disease categories and determining the environmentally attributable fraction (EAF) or percentage of estimated disease burden due to environmental exposures.

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The current summary is based on a systematic review of EBD studies that have been conducted in Canada or are potentially relevant for the Canadian context (see full report for more details). This information is relevant for policy-makers and health practitioners who are responsible for allocating scarce resources and designing or implementing environmental health policies to directly address specific sources of disease; it can also be used as a teaching tool to better educate and inform the public about the relative importance of potential exposures and risks.

Global/Regional/National (Non-Canadian) EBD Studies

Available global/regional EBD studies suggest that the total EBD for high-income, developed countries may range from as low as 1 – 5% to as high as 15 – 22%, depending on how EBD is calculated and defined. The wide disparity in published EBD estimates is due primarily to the use of different methodological approaches, data sets, assumptions, and units of analysis, as well as the inclusion of different disease categories and environmental risk factors. Nearly all EBD studies also rely heavily on expert judgment to draw conclusions about disease burden and the EAF. The primary disease categories, identified or evaluated in EBD studies for developed countries, include acute and chronic respiratory diseases, cardiovascular disease, diarrhea, neurobehavioral disorders, cancer, and congenital afflictions (see Table 1). The primary environmental (non-lifestyle) risk factors, associated with these and other diseases in developed countries, include ambient air pollution, indoor smoke from solid fuels, poor water and sanitation, inorganic lead exposure, and occupational exposures (see Table 2).

In the United States, the study by Landrigan et al. (2002)[5] estimated the contribution of environmental pollutants to the burden of paediatric disease for four categories of illness. Best estimates of EAFs from this study were 100% for lead poisoning, 30% for asthma, 5% for cancer, and 10% for neurobehavioral disorders. These estimates have been used in other statewide assessments in the United States to quantify the disease burden and economic costs associated with major diseases and disabilities attributable to environmental contaminants. EAF estimates from this study are potentially relevant for evaluating the EBD among Canadian children because they are based on extensive reviews of the available exposure and epidemiological literature and focus on disease categories that are relevant for developed countries. However, as is the case for most EBD studies, EAF estimates are highly uncertain (particularly for cancer) and are largely dependent on expert judgment.

Several EBD studies, primarily focused on children, have also been conducted for various countries or regions in Europe. For example, Valent et al. (2004)[6] evaluated the burden of disease attributable to four environmental risk factors among children and adolescents in three subregions of Europe. Among children aged 0 – 4 years, it was estimated that 1.8 - 6.4% of deaths from all diseases were attributable to outdoor air pollution, 4.6% of deaths and 3.1% of disability-adjusted life years (DALYs) from acute lower-respiratory-tract infections were attributable to indoor air pollution, and 4.4% of DALYs from mild mental retardation were a result of lead exposure. In the age group 0 – 14 years, 5.3% of all deaths and 3.5% of DALYs from diarrhea were attributed to inadequate water and sanitation. Finally, in the age group 0 – 19 years, 22.6% of all deaths and 19% of all DALYs were attributed to injuries. Besides varying by age group, the burden of disease was found to vary significantly by sub-region.

In a separate study, Mathews and Parry (2005)[7] evaluated the burden of disease, attributed to environmental pollution, for a larger number of health outcomes among children in England and Wales. Estimated EAFs, some of which were based on prior studies, were 30% for asthma, 5% for cancer, 10% for neurobehavioral disorders, 3% for allergies, 20% for congenital abnormalities, 6% for respiratory disease, and 0.8% for cardiovascular disease.

It is noteworthy that there are several ongoing research studies in Europe related to the development of the next generation of EBD studies, including the Health and Environment Integrated Methodology and Toolbox for Scenario Assessment (HEIMTSA) and the Integrated Assessment of Health Risks of Environmental Stressors in Europe (INTARESE). In future, these research efforts should provide relevant data with respect to the relationship between environmental exposures and population health outcomes in Europe; may also provide a useful framework for other national or local level EBD studies.

Canadian EBD Studies

In Canada, EBD estimates are only available from a few sources and no Canada-specific EAFs have been derived. The World Health Organization (WHO) has estimated that approximately 13% of all preventable diseases in Canada are related to environmental causes, including secondary environmental tobacco smoke, occupational exposures and stress, and selected lifestyle factors. According to WHO (2009),[8] the disease categories that contribute most to the total burden of disease in Canada are neuropsychiatric disorders, cardiovascular diseases, lung and other cancers, other unintentional injuries, asthma, and musculoskeletal diseases. Two environmental risk factors - outdoor air pollution (mean urban PM_{10}) and water, sanitation and hygiene (diarrhea only) – are estimated to account for approximately 7% of the total reported preventable deaths and 4% of the total reported preventable DALYs/1000 capita each year in Canada (contribution from other risk factors is not provided). The WHO country-wide profile is useful for understanding the EBD in Canada from a high-level perspective, but the contribution of individual (or joint) risk factors to specific disease outcomes is not specified, making it difficult to design or evaluate effective intervention strategies in Canada.

Using the WHO estimates and other published data to quantify the EBD in Canada, Boyd and Genuis (2008)[9] assumed preliminary EAFs ranging from 10 – 30% for chronic obstructive pulmonary disease, 26 – 53% for asthma, 7.5 – 15% for cardiovascular disease, 5 - 15% for cancer, and 2 – 10% for congenital afflictions (see Table 3). Based on these estimates and Canada-specific health statistics data, environmental exposures in Canada were predicted to account for $3.6 to $9.1 billion in annual health care costs due to potentially preventable illnesses and deaths. Estimates from this study provide a general indication or approximation of risk and are likely to be the most relevant for Canada at this time, given the reliance on up-to-date country statistics and an initial attempt to evaluate the relevance of existing EAF estimates. However, the results of this study are largely driven by the EAFs from WHO, which are based primarily on expert judgment and consider a broad range of environmental risk factors. Additionally, no details are presented with respect to which specific risk factors (or set of factors) contribute most to each of the four disease categories and it is unclear whether (or to what extent) these EAFs are applicable to Canada. Without more detailed or country-specific information, it is not possible to determine what types of public health intervention strategies will be most effective at different geographic scales.

Two more focused (unpublished) studies in Canada have estimated mortality and morbidity effects associated with air pollution in different regions. For example, the estimated annual excess deaths within eight census divisions of Canada, associated with short-term and long-term air pollution exposures, was 1,800 and 4,200, respectively, for the period 1998 – 2000.[10] In another study, approximately 5,800 annual deaths, 16,000 total hospital admissions, 60,000 emergency room visits, and 29 million minor illnesses were associated with smog and air pollution exposures in Ontario in 2005.[11] Although not published in the peer-reviewed literature and much more narrow in scope, these studies provide good examples of how to link a specific environmental risk factor to specific health outcomes, using more relevant population exposure and dose-response data. Additional studies in Canada have assessed certain aspects of an EBD evaluation, such as establishing a concentration- or dose-response relationship for a specific environmental risk factor (e.g., air pollution), or qualitatively assessing the link between environmental exposures and a specific health endpoint (e.g., cancer). These studies do not represent an actual or complete EBD assessment *per se*, but they provide useful support data that can be used in more quantitative EBD evaluations.

Potentially, the most significant effort currently underway with respect to estimating the EBD in Canada is the Population Health Impact (PHI) of Disease in Canada program, sponsored by the Public Health Agency of Canada.[12] Using a single comparable indicator, this program is intended to provide summary measures of population health that combine the impact of both death and reduced functioning and will assess the impact of approximately 200 diseases, injuries, and risk factors. The PHI builds on the WHO burden of disease studies by: adapting the methods to address diseases and injuries most relevant to Canadians, applying them to Canadian data, and measuring them within a Canadian societal context. Although still in its infancy (preliminary results are available for cancer and diabetes), the outcome of the PHI project will provide policy-makers with a useful set of integrative tools to evaluate the EBD in Canada, within a larger burden of disease context.

Evidence Gaps

The available literature suggests that significant health gains could be achieved by reducing or eliminating selected environmental exposures in Canada. However, it is often difficult to apply these findings to the design of effective public health intervention strategies. In particular, strategies aimed at reducing EBD are likely to be most effective at the local or provincial level (rather than the global or national level) and such efforts require a better understanding of environmental exposures and subsequent health-related outcomes at these geographic scales.

Additional research and effort is needed in several areas to help fill key data gaps and to ensure the design of effective intervention strategies aimed at reducing the EBD in Canada. Some of the more important data gaps related to EBD assessments include:

- Lack of well-defined or relevant environmental risk factors and disease categories;
- Inadequate data on population-level exposures for different risk factors, subpopulations, and geographical scales;
- Limited data on causation, relative risks, and dose-response relationship for many risk factors and disease outcomes;
- Lack of longitudinal studies and environmental surveillance programs;
- Limited attempts to address the full range of uncertainty in EBD and EAF estimates;
- Extensive use of expert judgment;
- Need for improved and innovative methodologies that address complex issues (e.g., multiple or early life-stage exposures, gene-environment interactions).

Conclusions and Recommendations

Excluding lifestyle and occupational risk factors, the strongest evidence based on the available data for Canada and other developed countries relates to mortality and morbidity effects (e.g., respiratory disease, asthma) attributed to air pollution (e.g., particulate matter). Specifically, ambient air monitoring data are available for many countries or regions and the concentration-response relationship for particulate exposures and adverse health effects has been quantified in a number of epidemiology studies, including many conducted in Canada. The consistent finding, among virtually all EBD studies showing air pollution as a major environmental risk factor, suggests that public health interventions aimed at reducing air pollution exposures is likely to have a notable impact on reducing the EBD in Canada. However, it is important to recognize that although the evidence, with respect to air pollution and illness, represents a situation where good methods have been employed and reasonable estimates have been made of the health impact, this does not mean that air pollution is the most important factor contributing to environmental health impacts; there are many regional differences with respect to air quality in Canada. The health impact of many other environmental factors is simply not known at this time and could be greater or less than indoor and outdoor air pollution; these require further study.

The following set of recommendations are intended to improve the current level of knowledge with respect to the EBD in Canada and to assist policy-makers and health practitioners in Canada in their efforts to design and prioritize among effective public health intervention strategies in the short and longer-term:

- Make choices about which environmental risk factors and disease outcomes to target, based on national, regional, or local EBD estimates in Canada (not global estimates);
- Develop a consistent framework for Canada-specific EBD that relies on the same types of data and information sources and adequately characterizes the uncertainty in EBD estimates;
- Conduct more research to fill key data gaps to ensure the design of the most optimal intervention strategies;
- Make addressing air pollution a top priority for current health intervention strategies in Canada, until additional data are collected on other risk factors;
- Develop an explicit strategy for evaluating and prioritizing other environmental risk factors and disease outcomes in Canada, for which less supporting data are available.

In summary, the most effective EBD estimates for informing public health policy in Canada will require synthesizing and integrating methods and data across disciplines. Ultimately, in order for EBD studies to become more useful for prioritizing across risks and designing effective intervention strategies, they need to link multiple risk factors to multiple health outcomes in an integrated, dynamic framework that reflects site-specific population exposures as they relate to site-specific population-level health outcomes. Recent and ongoing efforts in Canada, such as the PHI project, appear to be promising venues to provide useful data on the relationship between environmental exposures and health outcomes in different regions of Canada.

Table 1. *Estimates of EBD by disease category potentially relevant to Canada based on global/regional/national studies*

Disease Outcome	EAF (%)	Geographic Region	Source
Acute respiratory infections / Asthma	5 – 15% 26 – 53% 10 – 35%	High-income OECD region Global (includes occupational) United States (children)	Melse and de Hollander 2001[13] Prüss-Üstün and Corvalán 2006, 2007[14,15] Landrigan et al., 2002[5]
Neurobehavioral disorders	10 – 16% 5 – 20%	Global (includes occupational) United States (children)	Prüss-Üstün and Corvalán 2006, 2007[14,15] Landrigan et al., 2002[5]
Cardiovascular diseases / Ischaemic heart disease	5 – 15% 7 – 13%	High-income OECD region Global (includes occupational)	Melse and de Hollander 2001[13] Prüss-Üstün and Corvalán 2006, 2007[14,15]
COPD / Chronic respiratory disease	5 – 15% 19 – 35% (males) 6 – 12% (females)	High-income OECD region Developed countries (includes occupational)	Melse and de Hollander 2001[13] Prüss-Üstün and Corvalán 2006, 2007[14,15]
Cancer	1 – 5% 6 – 55% (lung) 10 – 34% (other) 2 – 10%	High-income OECD region Developed countries (includes occupational) United States (children)	Melse and de Hollander 2001[13] Prüss-Üstün and Corvalán 2006, 2007[14,15] Landrigan et al., 2002[5]
Diarrhea	80 – 90%	High-income OECD region	Melse and de Hollander 2001[13]
Lead poisoning	100%	United States (children)	Landrigan et al., 2002[5]
Perinatal conditions	1 – 5% 2 – 10%	High-income OECD region Developed countries (includes occupational)	Melse and de Hollander 2001[13] Prüss-Üstün and Corvalán 2006, 2007[14,15]
Congenital anomalies	0 – 1% 2 – 10%	High-income OECD region Global (includes occupational)	Melse and de Hollander 2001[13] Prüss-Üstün and Corvalán 2006, 2007[14,15]
Total	1.4 – 4.3% 3 – 4% 15 – 22%	High-income OECD region Americas region Americas region (includes occupational)	Melse and de Hollander 2001[13] Ezzati et al., 2002[16] Prüss-Üstün and Corvalán 2006, 2007[14,15]

Table 2. *Estimates of EBD by risk factor potentially relevant to Canada based on global/regional/national studies*

Risk Factor	Deaths (%)	DALYS (%)	Geographic Region	Source
Water, sanitation, hygiene	0.9% 5.3% (0 – 14 years)	1.5% 3.5% (0 – 14 years)	Americas region Europe (3 subregions)	Ezzati et al., 2002[16] Valent et al., 2004[6]
Urban outdoor air pollution	1.1% 1.0% (cancer) 1.8 – 6.4% (0 – 4 years)	0.3%	Americas region High-income countries Europe (3 subregions)	Ezzati et al., 2002[16] Danaei et al., 2005[17] Valent et al., 2004[6]
Indoor smoke from solid fuels or indoor air pollution	0.4% 4.6% (0 – 4 years)	0.5 3.1% (0 – 4 years)	Americas region Europe (3 subregions)	Ezzati et al., 2002[16] Valent et al., 2004[6]
Lead	0.5%	1.4 4.4% (0 – 4 years)	Americas region Europe (3 subregions)	Ezzati et al., 2002[16] Valent et al., 2004[6]
Global climate change	0.0%	0.1%	Americas region	Ezzati et al., 2002[16]

Table 3. *Estimates of EBD by disease category in Canada (source: Boyd and Genius 2008)*

Disease Outcome	EAF Used to Calculate EBD	EBD (number attributable to environment)		
		Deaths	Hospitalizations	Days in Hospital
Respiratory disease COPD Asthma	10 – 30% (WHO) 26 – 53% (WHO)	977 – 2,932 75 – 153	25,646 – 76,938 8,060 – 16,430	170,611 – 511,832 28,448 – 57,989
Cardiovascular disease	7.5 – 15% (WHO, OECD)	5,456 – 10,911	33,541 – 67,083	291,419 – 582,838
Cancer	5 – 15% (professional judgment)	3,416 – 10,248	10,775 – 32,324	103,948 – 311,845
Congenital affliction	2 – 10% (WHO)	72 – 360	312 – 1,558	1,982 – 9,910
Totals	NA	9,996 – 24,604	78,334 – 194,333	596,409 – 1,474,414

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