BURDEN OF ILLNESS AS AN INDICATOR OF COMMUNITY AIR POLLUTION IMPACT, AND ITS SENSITIVITY TO STATISTICAL DESIGN.

L. David Pengelly[1], Monica Campbell[2], Monica Bienefeld[2] and Julie Sommerfreund[3].
Department of Medicine, McMaster University[1], 1200 Main Street West, Hamilton, Ontario L8N 3Z5; Toronto Public Health[2]; University of Toronto[3]. pengelly@mcmaster.ca

ABSTRACT

Burden of illness (BOI) estimates have been used increasingly as indicators of air quality impact by governments, by non-governmental agencies and community groups. A BOI study based on local air quality and health data, using risk coefficients from the epidemiological literature, is a cost-effective and reliable approach to air quality risk evaluation and risk communication for a community. In May 2000, we estimated that from 700 to 1300 premature deaths were associated with air pollution in Toronto, Ontario (approximately 2.5 million people), based on Toronto air quality and mortality information applied to risk coefficients obtained up to 2000. In mid-2002 it was reported that risk coefficients derived from generalized additive models (GAMs) using default convergence criteria and non-parametric smoothing techniques could be artificially biased to larger values, and narrower confidence intervals. In the past year, many epidemiological studies having used these techniques have been revised, in general reducing the risk coefficients associated with particulate pollution roughly by half. We undertook to revise our May 2000 estimate of BOI in light of the changes in scientific understanding in the intervening period. Our estimate in 2004 for premature mortality associated with acute exposure to air pollution in Toronto is 700, based on coefficients from a recently published multipollutant gas model and a particle risk coefficient derived from ten of the revised studies. If the risk associated with particles is estimated on the basis of chronic, rather than acute exposure, the estimate for premature mortality rises to 1700. (Supported by Toronto Public Health).

INTRODUCTION

In May 2000, Toronto Public Health released the report *Air Pollution Burden of Illness in Toronto* [1]. Using 1995 as its base year, the study estimated that exposure to five common air pollutants contributed to about 1,000 premature deaths and 5,500 hospitalizations each year in Toronto, a city of 2.4 million residents. The recent discovery of an error in the application of a computer program used by most international researchers in estimating the health impacts of air pollution raised some concern about the continued validity of these estimates. In the light of this, we have undertaken a new assessment of the magnitude of the health risk associated with common air pollutants in Toronto, based on more recent scientific literature regarding the health effects of pollutants, and utilizing current data regarding air pollution levels, mortality rates and hospitalizations for Toronto. This paper draws on information from the Technical Report and Summary of that assessment [2, 3].

In Canada, there has been growing use of burden of illness estimates as an indicator of air quality impact at all levels of government (federal, provincial and municipal), by non-governmental agencies and community groups. Its greatest application seems to be in the planning mode: to stimulate action; to address perceived errors; and to avoid harm from planned changes which will have environmental consequences. The population in general has noted that governments can be called into action much more by drawing attention to threats to community health than by focussing on adverse impacts on the natural environment. There is a danger, however that a community may call for a primary research "community health study" which, for the most part, is likely to be doomed to failure by virtue of its limited statistical power [4]. Thus to a properly educated and convinced community, the burden of illness study based on local air quality and health data, but using risk coefficients from the literature is a much more cost-effective and reliable approach to the problem of risk evaluation and risk communication.

METHODS

The fundamental assumption in BOI estimation is that air pollution is associated with adverse health effects in a similar way in all human populations. Recent epidemiological studies have confirmed this assumption by quantifying the adverse health effects associated with population exposure to air pollution in Europe, Asia, South and Central America, the United States and Canada. These studies in large populations have provided "risk coefficients" associating disease-specific health outcomes with individual air pollutants, both alone and in combination. Coefficients may then be used to estimate the air pollution burden of illness in a community, even if no explicit epidemiological studies have been previously conducted in that community. This can be done if air pollution levels have been measured in the community (or can be otherwise estimated), and if disease-specific overall burden of illness data (e.g., hospital admissions, mortality) are also available for that community. In simple terms:

$$H_p(\text{outcomes/yr}) = H_b \times F_p \qquad (1)$$

Where: H_p = estimated air-pollution related burden of illness

H_b = background rate of adverse health outcomes/year

F_p = fraction due to air pollution. ($F_p = \Delta H_p/\text{unit} \times P$) , where ΔH_p/unit is the "risk coefficient" per unit pollutant from the literature, and P is the effective annual pollutant concentration. Details of the method have been reported elsewhere [1].

As indicated above, three sets of information are required for BOI estimation in a given community: background outcome-specific yearly morbidity and mortality rates; continuously measured or otherwise estimated air quality, and appropriate pollutant and outcome-specific risk coefficients from the literature.

In Canada, as in other countries with universal health care systems we are fortunate in having access to high quality and up-to-date sets of administrative health outcome information. In urban areas we also have access to air pollution data of similar quality and timeliness. For risk coefficients, selection of those appropriate is crucial to the credibility of the final BOI estimates, and should be carried out systematically. First, the air pollutants and health outcomes of concern in a community should be identified in consultation with those who have an interest and information. Next, it should be determined if useful data for these outcomes and pollutants exists, or can be estimated with confidence. Then the literature should be consulted to determine if risk coefficients are available for these outcomes and pollutants in a form that can be used with the method, and an assessment of the quality of the coefficients and the studies in which they are found should be carried out. Finally, taking into account the limitations of the data and the coefficients, a summary form of the coefficient is developed from those available (weighted mean, upper and lower bound, etc.) and the calculation made of the estimate(s) of BOI. As indicated above, we carried out this process in 2000 for the City of Toronto, and with the passage of time it was thought necessary to update the estimate.

RESULTS OF UPDATE

After determining that the priorities for health outcomes and associated pollutants had not changed, and that more recent (1999, compared with 1995) data were available, we turned our attention to a re-examination of the literature to determine the most appropriate risk coefficients.

Literature Review

For the update to the APBIT May 2000 report, a review of epidemiological studies evaluating the associations between air pollution and health was conducted for the period January 2000 to September 2003. The review began with searches using the following databases: Biological Sciences, Environmental Pollution and Management, Epidemiology, Medline and Toxline; with keywords including: air pollution, health, time series, particulate matter and gaseous pollutants. In order to be selected the study had to include the pollutants and end points of interest in addition to being a time-series study. Twenty-eight articles were selected which met the criteria. An indication of the activity in the air pollution scientific community is demonstrated in Figure 1 below. Over the last 15 years the number of epidemiological time series studies has grown by ten times.

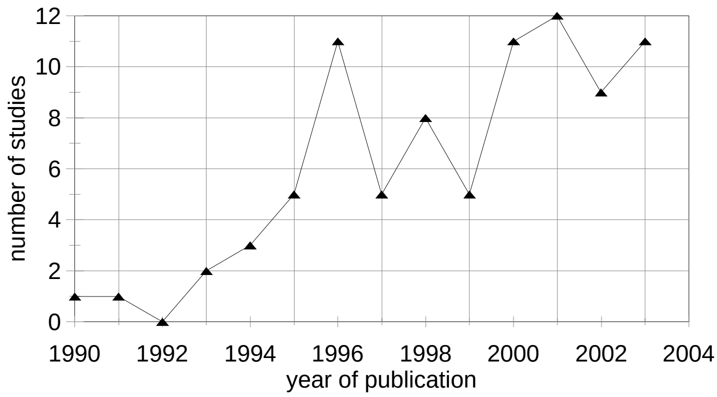

Figure 1. Air pollution / health time series studies by year

Particles

Since 1987, when the US EPA promulgated a 24-hr standard for fine particles, EPA has been mindful of the need to support and review scientific knowledge of the effects of fine particles on health, and as a result set a substantial research effort in motion, a major portion of which has been coordinated by the US-based Health Effects Institute. Thus in 1996 the Health Effects Institute funded two complementary studies, which together are referred to as the National Morbidity, Mortality, and Air Pollution Study (NMMAPS) [5,6]. In the summer of

2002, two groups of investigators independently reported to the Health Effects Institute that epidemiological time-series study designs employing statistical Generalized Additive Models (GAMs) using non-parametric smoothing methods could result in incorrect estimates of effects of air pollution on health [7,8]. These observations raised questions about the validity of risk coefficients based on GAMs methodology made up to that time. It was recognized that this could have a major impact on the NMMAPS study, as well as many other studies in the literature using the same methodology. The Health Effects Institute responded by initiating and funding a comprehensive re-analysis of the NMMAPS studies, as well as selected studies undertaken elsewhere in the world. The Health Effects Institute concluded, in part: “Common practice has come to use effect estimates from observational air pollution studies to estimate the impact of air pollution on a large population such as an entire country. If effect estimates from the NMMAPS 90 cities mortality study were applied, the revised impact would be approximately half of the estimated impact derived using the original effect estimates.”[9].

The impact of the GAMs problem is such that the only recent epidemiological data currently considered acceptable for the purposes of determining human health risk estimates associated with air pollution are either those which derive from the re-analysis reports, or those from studies which have explicitly avoided the GAMs problem.

From the literature review, we found that by far the greatest effort in the period 2000-2004 has been to examine the relationship between non-traumatic (NT) mortality and fine particles, measured in a number of different ways.

Gases

It should be noted that the focus of the NMMAPS studies and the subsequent re-analysis was the health effect of particulate air pollution, and as a result relatively little recent attention has been paid to studies directed explicitly to determine the role of gaseous pollutants. A few studies in the HEI re-analysis examined gases as co-pollutants of the relationships for particles, and some coefficients might be derived from them. In addition, a small number of studies in the last decade either did not use GAMs, or used them in a way that was relatively unaffected by the problems identified by Dominici *et al.*, and Ramsay *et al.* [7,8]. The most useful of these is a recent study by Burnett and co-workers who carried out a study of air pollution-related mortality in Canadian cities utilizing different statistical methods not subject to the GAMS problem [11]. Burnett provided us with a table supplemental to those in the publication, which shows coefficients for the relationship between NT mortality and the four gaseous pollutants in a statistical model including all four together. It is these coefficients we have used to determine the NT mortality associated with gaseous pollutants in Toronto.

Examination of the literature between 2000 and 2004 has yielded only a few studies of hospital admissions in the whole population, although there have been studies examining morbidity in children and seniors; in children, primarily studies of asthma, and in seniors, studies of obstructive lung disease and heart disease. Although useful, these have not allowed us to make direct comparisons with the APBIT 2000 study. As a result, 4 of the 8 coefficients we have used to estimate hospital admissions in the current study are from APBIT 2000.

In our previous report (APBIT 2000) we took note of the evidence in the literature that seemed to demonstrate a greater risk of premature mortality associated with chronic (long-term: of the order of years) exposure to particulate pollution in comparison to acute (short-term: a few days) exposure. The revised risk coefficients from the re-analysis of the two studies now have a very strong scientific basis [10]; and for this reason we have used the chronic, rather than the acute exposure coefficient to assess the level of NT mortality from fine particle exposure in Toronto. Table 1 summarizes the coefficients and their sources for the coefficients we have used for the current BOI estimation.

Pollutant	PM_{10}	$PM_{2.5}$	CO	NO_2	O_3	SO_2
unit	μg/m3	μg/m3	Ppm	ppb	ppb	ppb
NT mortality (acute exp)	0.060[a]			0.075[11]	0.085[11]	0.046[11]
NT mortality (chron. exp)		0.70[10]				
Resp. hosp admissions	0.17[1]		2.16[12]	0.38[12]	0.11[1]	0.28[1]
Card hosp admissions	0.063 [b]			0.39[1]		0.07[15]

Table 1. Per cent change in health outcome per unit change in pollutant (ΔH% / unit)

Note: (a) For $PM_{10,}$ (acute NT mortality) we took the mean of the lowest in the range for 10 of the studies re-analysed. (b) For cardiac hospital admissions we used the mean of the coefficients from [13] and [14]. For additional details see [2].

AIR POLLUTION-RELATED BURDEN OF ILLNESS

Using the methods described, with1999 health outcome and air quality data, we estimated that there were approximately 1700 premature deaths, and between 3000 and 6000 hospital admissions associated with the criteria pollutants O3, NO2, SO2, CO and $PM_{2.5}$ in Toronto.

Pollutant	$PM_{2.5}$	CO	NO_2	O_3	SO_2	Total
NT mortality	1236	20	249	219	30	1754
Respiratory admissions	597	272	1461	337	215	2882
Cardiac admissions	421		2857		104	3382

Table 2. Annual Pollutant-specific burden of illness for Toronto, 1999.

CONCLUSION

Burden of illness studies provide an important context for developing health-protective policies and programs. Given the magnitude of health risk associated with Toronto's air pollution, this study reinforces the importance of taking actions at all levels of government to ensure that the private and public sectors intensify air improvement initiatives. Given that the major sources of these pollutants are fossil fuel-based transportation and energy production, this study underscores the need to expand and sustain the public transit infrastructure and to stimulate the shift to cleaner sources of energy.

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