Science of the Total Environment 506–507 (2015) 409–421

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Health impact assessment of traffic-related air pollution at the urban project scale: Influence of variability and uncertainty

Chidsanuphong Chart-asa [a], Jacqueline MacDonald Gibson [b,*]

[a] Institute for the Study of Natural Resources and Environmental Management, Mae Fah Luang University, Chiang Rai, Thailand
[b] Department of Environmental Sciences and Engineering, Gillings School of Global Public Health, University of NC, Chapel Hill, USA

ARTICLE INFO

Article history:
Received 2 December 2013
Received in revised form 30 October 2014
Accepted 5 November 2014
Available online xxxx

Editor: Lidia Morawska

Keywords:
$PM_{2.5}$
Traffic
Health impact assessment
Variability
Uncertainty

ABSTRACT

This paper develops and then demonstrates a new approach for quantifying health impacts of traffic-related particulate matter air pollution at the urban project scale that includes variability and uncertainty in the analysis. We focus on primary particulate matter having a diameter less than 2.5 μm ($PM_{2.5}$). The new approach accounts for variability in vehicle emissions due to temperature, road grade, and traffic behavior variability; seasonal variability in concentration–response coefficients; demographic variability at a fine spatial scale; uncertainty in air quality model accuracy; and uncertainty in concentration–response coefficients. We demonstrate the approach for a case study roadway corridor with a population of 16,000, where a new extension of the University of North Carolina (UNC) at Chapel Hill campus is slated for construction. The results indicate that at this case study site, health impact estimates increased by factors of 4–9, depending on the health impact considered, compared to using a conventional health impact assessment approach that overlooks these variability and uncertainty sources. In addition, we demonstrate how the method can be used to assess health disparities. For example, in the case study corridor, our method demonstrates the existence of statistically significant racial disparities in exposure to traffic-related $PM_{2.5}$ under present-day traffic conditions: the correlation between percent black and annual attributable deaths in each census block is 0.37 ($t(114) = 4.2$, $p < 0.0001$). Overall, our results show that the proposed new campus will cause only a small incremental increase in health risks (annual risk 6×10^{-10}; lifetime risk 4×10^{-8}), compared to if the campus is not built. Nonetheless, the approach we illustrate could be useful for improving the quality of information to support decision-making for other urban development projects.

1. Introduction

In the United States, nonprofit organizations and public health practitioners increasingly advocate for formal health impact assessments (HIAs) to inform regional and local land-use and transportation planning decisions (Wernham, 2011; Bhatia and Corburn, 2011). Signaling the heightened interest in HIAs, the U.S. National Academy of Sciences in 2011 published a report, *Improving Health in the United States: The Role of Health Impact Assessment*, concluding that "HIA is a particularly promising approach for integrating health implications into decision-making" (National Research Council, 2011). The report offered the following formal definition of HIA:

> HIA is a systematic process that uses an array of data sources and analytic methods and considers input from stakeholders to determine the potential effects of a proposed policy, plan, program, or project on the health of a population and the distribution of those effects within the population. HIA provides recommendations on monitoring and managing those effects.

As the National Academies' report explains, the increasing demand for HIAs in the United States is driven by the growing recognition that reducing obesity and chronic disease rates will require substantial changes to decision-making processes in arenas outside the traditional healthcare sector. For example, decisions by transportation and municipal planning organizations can promote or limit opportunities for physical activity and can exacerbate or decrease exposure to ambient air pollution. While HIAs of local and regional decisions have been used in Europe, Australia, Canada, and Thailand for decades, the first U.S. HIA of a local project was completed in 1999 by the San Francisco Department of Public Health (Bhatia and Corburn, 2011; National Research Council, 2011). By the end of 2012, however, at least 115 HIAs of local or regional U.S. projects had been completed, and another 64 were under way (Singleton-Baldrey, 2012). Of the completed HIAs, 70 (more than 60%) focused on proposed local or regional changes to the built environment and/or transportation networks (Singleton-Baldrey, 2012; Dannenberg et al., 2008).

* Corresponding author at: Department of Environmental Sciences and Engineering, Gillings School of Global Public Health, University of North Carolina, Campus Box 7431, Chapel Hill, NC, 27599-7431, USA. Tel.: +1 919 966 7892.
E-mail addresses: chidsanuphong@gmail.com (C. Chart-asa), jackie.macdonald@unc.edu (J.M. Gibson).

http://dx.doi.org/10.1016/j.scitotenv.2014.11.020

To facilitate comparison of alternatives and guide decision-making, HIAs ideally would provide quantitative estimates of the health outcomes of the decision options under consideration. That is, they would estimate the number of deaths and illnesses prevented or caused by each alternative. This information could be used to quantify the health costs (positive or negative) of each alternative. Quantification can present health impacts more concisely (as numerical summaries) than lengthy qualitative discussions. In addition (rightly or wrongly), quantitative assessment can lend legitimacy to the analysis. Furthermore, some federal and state regulations require quantitative cost–benefit analyses (Federal Highway Administration, 2003). However, only 5 of the 70 U.S. HIAs focusing on local or regional transportation projects carried out prior to 2013 quantified the expected health impacts (Singleton-Baldrey, 2012; Bhatia and Seto, 2011). Table 1 summarizes these HIAs. The remaining HIAs expressed qualitative conclusions.

The *Aerotropolis Atlanta Brownfield Redevelopment HIA* (Ross et al., 2011) illustrates the qualitative approach used by most previous local and regional U.S. HIAs. This HIA evaluated a plan to convert a former Ford assembly plant near Atlanta, Georgia, to a new community called “Aerotropolis Atlanta.” The HIA's analysis of air quality impacts was based on a review of previous studies (not associated with this project) of traffic impacts on air quality and health. It concluded, “Aerotropolis may lead to a change in traffic volume around the site …, potentially impacting people who live, work, or visit within the air-shed of the affected streets.” The HIA recommended several mitigation measures, including congestion pricing, increased public transit, zoning of sensitive uses away from roadways, and vegetation buffers around roadways. However, the HIA did not quantify the air quality or health impacts of the proposed new development or these mitigation alternatives.

While the above-mentioned five previous quantitative HIAs estimate the magnitude of air quality and related health impacts, none considers the potential variability and uncertainty of the estimates. Rather, these HIAs each provide a single, deterministic prediction of health impacts for each decision option (see Table 1). In so doing, these HIAs not only convey a potentially misleading degree of certainty but also neglect to provide decision-makers with information about the plausible range of impacts. U.S. Environmental Protection Agency guidance documents indicate that health risk assessments of national and state policies should include sensitivity and uncertainty analyses (U.S. Environmental Protection Agency, 2001). Indeed, sensitivity and uncertainty analyses are cornerstones of health impact estimates the agency prepares to inform national policy decisions, such as changes to air pollution standards (US Environmental Protection Agency, 2010). Nonetheless, current U.S. local-level HIAs do not report variability and uncertainty in their health impact estimates.

The reliance of local HIA practitioners on deterministic estimates is a major limitation for several reasons. First, it fails to consider the full range of potential risks—that is, the potential for risks at the tails of the risk distribution. For example, vulnerable populations are often at the upper tails, not the centers, of the exposure and effect distributions (Fann et al., 2011). Second, risk estimates relying only on central tendencies of each input variable may differ from those considering the full distributions of each input variable. Except in special cases, the expected value of a function of random variables is not the same as the function applied to the expected values of each variable. Third, deterministic approaches ignore the potential dependencies among model input variables (for example, dependencies in meteorological characteristics used to estimate pollutant dispersion). Fourth, deterministic

Table 1
Previous quantitative transportation-related HIAs in the United States.

Title	Project scenario analyzed	Traffic-related air pollutants considered	Study area population	Estimated annual health impacts[a]
Pittsburg Railroad Avenue specific plan HIA (Human Impact Partners, 2008)	Construction of new Bay Area Rapid Transit (BART) station and mixed-use village in Pittsburg, CA, including 1600 housing units and 450,000 sq. ft. of retail, commercial, and public service spaces	$PM_{2.5}$	4770	• 6 deaths (age ≥ 30) from long-term exposures, $\beta = 0.0046$ (0.0034, 0.0058) • 5 hospital admissions for asthma (age < 65) from short-term exposures, $\beta = 0.0025$ (0.0015, 0.0036) • 12 lower respiratory symptom days (ages 7–14) from short-term exposures, $\beta = 0.0182$ (0.0124, 0.0241)
Evaluating the healthfulness of affordable housing opportunity sites along the San Pablo Avenue Corridor using HIA (Human Impact Partners, 2009)	Construction of affordable housing sites in El Cerrito and Richmond, CA	$PM_{2.5}$	1,000,000	• 33–41 deaths (all ages) from long-term exposures, $RR = 1.014$ (no report of 95% confidence interval)
Oak to Ninth Avenue HIA (UC Berkeley Health Impact Group, 2006)	Development of new waterfront community in Oakland, CA, including 3100 housing units and 200,000 sq. ft. of retail, commercial, and public service spaces	PM_{10}	10,000	• 0.8 deaths (age ≥ 30) from long-term exposures, $\beta = 0.0046$ (0.0034, 0.0058) • 0.4 chronic bronchitis cases (age ≥ 27) from long-term exposures, $\beta = 0.0132$ (0.0064, 0.0200) • 10.6 emergency room visits for asthma (age < 65) from short-term exposures, $\beta = 0.0037$ (0.0024, 0.0049)
MacArthur BART Transit Village HIA (UC Berkeley Health Impact Group, 2007)	Redevelopment of parking lot into a mixed-use village in Oakland, CA, including 625 housing units and 30,000 sq. ft. of retail, commercial, and public service spaces	$PM_{2.5}$	100,000	• 2.7 deaths (age ≥ 30) from long-term exposures, $\beta = 0.0046$ (0.0034, 0.0058) • 1.0 chronic bronchitis cases (age ≥ 27) from long-term exposures, $\beta = 0.0132$ (0.0064, 0.0200) • 34.2 acute bronchitis cases (ages 8-12) from short-term exposures, $\beta = 0.0272$ (0.0101, 0.0443) • 0.1 hospital admissions for asthma (age < 65) from short-term exposures, $\beta = 0.0025$ (0.0015, 0.0036) • 26.9 lower respiratory symptom days (ages 7–14) from short-term exposures, $\beta = 0.0182$ (0.0124, 0.0241)
Health impact assessment of the Port of Oakland (UC Berkeley Health Impact Group, 2010)	Ongoing growth of port operations in West Oakland, CA	$PM_{2.5}$	22,000	• 1.3 deaths (age ≥ 30) from long-term exposures, $\beta = 0.0046$ (0.0034, 0.0058)

[a] β = concentration–response coefficient used to estimate health impacts; RR = relative risk used to estimate health impacts.