Environment International 69 (2014) 90–99

Contents lists available at ScienceDirect

Environment International

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

Review

Evaluating the application of multipollutant exposure metrics in air pollution health studies☆

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ARTICLE INFO

Article history:
Received 20 December 2013
Accepted 30 March 2014
Available online xxxx

Keywords:
Multipollutant
Air pollution
Exposure
Health effects

ABSTRACT

Background: Health effects associated with air pollution are typically evaluated using a single pollutant approach, yet people are exposed to mixtures consisting of multiple pollutants that may have independent or combined effects on human health. Development of exposure metrics that represent the multipollutant environment is important to understand the impact of ambient air pollution on human health.
Objectives: We reviewed existing multipollutant exposure metrics to evaluate how they can be applied to understand associations between air pollution and health effects.
Methods: We conducted a literature search using both targeted search terms and a relational search in Web of Science and PubMed in April and December 2013. We focused on exposure metrics that are constructed from ambient pollutant concentrations and can be broadly applied to evaluate air pollution health effects.
Results: Multipollutant exposure metrics were identified in 57 eligible studies. Metrics reviewed can be categorized into broad pollutant grouping paradigms based on: 1) source emissions and atmospheric processes or 2) common health outcomes.
Discussion: When comparing metrics, it is apparent that no universal exposure metric exists; each type of metric addresses different research questions and provides unique information on human health effects. Key limitations of these metrics include the balance between complexity and simplicity as well as the lack of an existing "gold standard" for multipollutant health effects and exposure.
Conclusions: Future work on characterizing multipollutant exposure error and joint effects will inform development of improved multipollutant metrics to advance air pollution health effects research and human health risk assessment.

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http://dx.doi.org/10.1016/j.envint.2014.03.030

1. Introduction

Studies examining health effects associated with air pollution traditionally consider responses to individual pollutants, such as ozone (O_3), fine particulate matter ($PM_{2.5}$), and nitrogen dioxide (NO_2). Results of these single pollutant studies form the basis for air quality standards in the United States intended to protect public health with an adequate margin of safety under the Clean Air Act (U.S. Code, 1970). In reality, people are exposed to a combination of pollutants simultaneously, and there is uncertainty whether these pollutants act independently or in combination (in an additive, synergistic, antagonistic, or interactive manner) to affect human health. These combined effects of pollutant mixtures are likely not accounted for in traditional single pollutant health studies. Therefore, the scientific community has urged the extension of the current single pollutant risk assessment and risk management approach to account for multiple pollutants (Dominici et al., 2010; Hidy and Pennell, 2010; Johns et al., 2012; Mauderly et al., 2010; National Research Council, 2004).

Different approaches have been used to characterize independent and multipollutant exposures in epidemiologic analyses. In the past, epidemiologic studies have used co-pollutant models (e.g., including two pollutants as independent variables) to estimate health effects of single pollutants while adjusting for the concentration of additional pollutants (e.g., Tolbert et al., 2007). More recent studies, however, have developed and applied different types of multipollutant metrics (i.e., combining multiple pollutants into one variable) to represent exposure to various pollutant mixtures related to source emissions and/or specific classes of toxic pollutants. These metrics not only have the potential for providing a robust representation of multipollutant mixtures, they also reduce variable dimensions in an epidemiologic analysis that in turn can decrease effect estimate uncertainty that stems from the use of highly correlated, single pollutant exposure variables. While the development of multipollutant exposure metrics is possible, representing the multipollutant environment has been difficult considering that various pollutants are measured with different averaging times, units of measurement, and uncertainties. Furthermore, limited analysis exists on determining whether or not these advanced, multipollutant metrics capture the complex temporal or spatial patterns of personal or community-based exposure.

As multipollutant science continues to progress, it is important to identify metrics that are currently available and reveal research gaps. This article reviews existing approaches for estimating health effects of multipollutant exposure. Strengths and limitations for each approach are discussed, with attention to which approaches may be appropriate for specific aspects of multipollutant air quality health effects assessment.

2. Methodology

2.1. Study criteria

In this study, we identified and characterized different multipollutant exposure metrics used to study air pollution health effects in epidemiology and toxicology studies. We also reviewed other air quality tools, such as air quality indexes, which have utilized multipollutant approaches that can be used to inform future development of exposure metrics for use in health studies. We focused on studies that met the following criteria:

1) Focused on the development or application of a metric used to represent exposure to ambient air pollution
2) Included a metric that is constructed from ambient pollutant concentrations
3) Presented original data (i.e., excludes review articles)
4) Introduced a metric that has the potential for broad-scale application

Based on these criteria, we excluded studies that used multipollutant tools for characterizing air quality without considering an exposure or health effect aspect, and thus did not include source apportionment studies without a health or exposure component. Studies that focused on indoor or occupational air quality were excluded. We also excluded studies that used an individual pollutant as a larger indicator of a multipollutant mixture; examples include $PM_{2.5}$ as a multipollutant indicator for particle components or O_3 as a representative photochemical oxidant. Metrics that were constructed without using ambient air pollution concentrations were excluded; examples include GIS-based metrics such as location-specific annual average daily traffic counts (AADT) used to represent exposure to traffic pollution. Last, we only reviewed metrics that showed the potential for application to health studies in diverse contexts, rather than metrics developed for a specific location or situation.

2.2. Systematic review process

A comprehensive, systematic literature search following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) paradigm (Moher et al., 2009) was used to identify eligible studies/metrics to review. The PRISMA approach is a multi-stage screening process aimed at improving the transparency of reporting in scientific reviews. Fig. 1 displays the step-by-step systematic review approach used for assessing the eligibility of exposure metric studies. The first step of our systematic review involved an initial broad literature search within Web of Science and PubMed databases in April 2013 followed by an updated search in December 2013. The following search strings were used in 1) Web of Science (WOS) and 2) PubMed to identify studies relevant to multipollutant exposure and health effects.

1) Web of Science search string: (((TS = “multipollut*” OR TS = “multi-pollut*” OR TS = “apportion*”) AND (TS = “air” OR TS = “ambient”) AND TS = “health”) OR (TS = “air quality index” OR TS = “air pollution index”)) = 829 references.
2) PubMed search string: (((multipollut* OR multi-pollut* OR apportion*) AND (air OR ambient) AND health) OR (“air quality index” OR “air pollution index”)) = 390 references.

A total of 1219 studies were identified in the broad literature search. Overlapping studies identified in both WOS and PubMed literature searches were de-duplicated by removing one record from the original 1219 articles. An initial screening process was conducted on each article to select studies that met the review criteria (previously listed) based on article title and abstract. Following the initial screen, the remaining 108 articles were subjected to a full text screen to eliminate any irrelevant articles. Fourteen additional articles were identified independently outside of the search (e.g., either cited within a considered article or identified in presentations) and were included in the review. Based on our broad literature search and additional independent efforts to identify articles, a total of 53 studies were deemed eligible to review.

A relational search was also conducted to identify potentially relevant articles not found by the broad literature search. In the relational search, a computer algorithm retrieved all articles in WOS that cited any of the 53 eligible studies (either identified independently or in the broad literature search). These articles were ranked by how many of the 53 studies they cited, on the assumption that articles citing several studies were more likely to be relevant than articles citing only one study of the initial 53. References frequently citing the 53 eligible articles were subjected to initial and full text screens, similar to the approach used in the broad literature search. The algorithm was only applied to WOS, since PubMed does not provide the citation data needed for the algorithm. Three additional studies met the criteria using this search approach. Additionally, one study was identified during the peer-review process, resulting in a total of 57 articles reviewed in this paper. Additional information on “considered” and “cited” articles in this review can be found on the Health & Environmental Research