ARTICLE IN PRESS

Environmental Research xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Environmental Research

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

Review article

Assessing the recent estimates of the global burden of disease for ambient air pollution: Methodological changes and implications for low- and middle-income countries

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ARTICLE INFO

Keywords:
Air pollution
Health impacts
Fine particles
PM2.5
Global Burden of Disease
Mortality

ABSTRACT

The Global Burden of Disease (GBD) is a comparative assessment of the health impact of the major and well-established risk factors, including ambient air pollution (AAP) assessed by concentrations of PM2.5 (particles less than 2.5 µm) and ozone. Over the last two decades, major improvements have emerged for two important inputs in the methodology for estimating the impacts of PM2.5: the assessment of global exposure to PM2.5 and the development of integrated exposure risk models (IERs) that relate the entire range of global exposures of PM2.5 to cause-specific mortality. As a result, the estimated annual mortality attributed to AAP increased from less than 1 million in 2000 to roughly 3 million for GBD in years 2010 and 2013, to 4.2 million for GBD 2015. However, the magnitude of the recent change and uncertainty regarding its rationale have resulted, in some cases, in skepticism and reduced confidence in the overall estimates. To understand the underlying reasons for the change in mortality, we examined the estimates for the years 2013 and 2015 to determine the quantitative implications of alternative model input assumptions. We calculated that the year 2013 estimates increased by 8% after applying the updated exposure data used in GBD 2015, and increased by 23% with the application of the updated IERs from GBD 2015. The application of both upgraded methodologies together increased the GBD 2013 estimates by 35%, or about one million deaths. We also quantified the impact of the changes in demographics and the assumed threshold level. Since the global estimates of air pollution-related deaths will continue to change over time, a clear documentation of the modifications in the methodology and their impacts is necessary. In addition, there is need for additional monitoring and epidemiological studies to reduce uncertainties in the estimates for low- and medium-income countries, which contribute to about one-half of the mortality.

1. Introduction

Efforts to quantify the worldwide burden of disease began in the early 1990s, when the World Bank commissioned the original Global Burden of Disease (GBD) study resulting in the World Development Report in 1993 (World Bank, 1993). The first comprehensive evaluations of ambient air pollution (AAP) was initiated by the World Health Organization (WHO) and World Bank for the year 2000 (Cohen et al., 2004) and then for the year 2004 (WHO, 2009). Funded by the Bill & Melinda Gates Foundation in 2010, the scope of GBD was updated and included 291 diseases and injuries, 67 risk factors including AAP in 21 regions around the world. Ultimately, the Institute for Health Metric

Abbreviations: AAP, Ambient air pollution;; AOD, Aerosol optical depth; COPD, Chronic obstructive pulmonary disease; CRF, Concentration-response function; CTM, Chemical Transport Model; GBD, Global Burden of Disease; IER, Integrated Exposure Risk; IHD, Ischemic heart disease; IHME, Institute for Health Metrics and Evaluation; LMIC, Low- and Middle-Income Countries; LRI, Lower respiratory infections; PM2.5, Particles less than 2.5 µm; PM10, Particles less than 10 µm; RMSE, Root mean square error; WB, World Bank; WHO, World Health Organization

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https://doi.org/10.1016/j.envres.2018.03.001
Received 22 December 2017; Received in revised form 21 February 2018; Accepted 2 March 2018
0013-9351/

Please cite this article as: Ostro, B., Environmental Research (2018), https://doi.org/10.1016/j.envres.2018.03.001

and Evaluation (IHME), housed at the University of Washington, became the main provider for a comprehensive set of GBD estimates which were provided for the years 2010, 2013, 2015, with technical support from WHO (Shaddick et al., 2017). AAP estimates were provided for mortality, years of life lost, years lived with disability, and disability-adjusted life years by country, age, and sex.

Over the last two decades, the GBD methodology for exposure assessment to AAP has made significant improvements and has become a useful instrument for health impact assessment. Exposure assessment, with some collaboration with WHO and other international agencies, is now based on several sources including ground-level monitors, chemical transport models, and remote sensing from multiple satellites, with each possessing unique advantages for certain types of terrain, altitude and geophysical characteristics (Brauer et al., 2012; Shaddick, 2017). In addition, the models that relate ambient concentrations to subsequent health risks have been updated integrating novel evidence provided by cohort studies of air pollution and smoking using advanced statistical techniques (Burnett et al., 2014).

Unfortunately, as the initially reported burden estimates significantly changed over a short period of time (from around 3 million global deaths per year in 2010 and 2013 to 4.2 million in 2015, a 40% increase), the confidence in these estimates may be impacted. This may lead to differing assessments of the information by international institutions, national governments and environmental policy makers. The issue is likely to particularly significant for low- and middle-income countries where there is less expertise and resources available to provide their own country assessment estimates. Thus, it is important to describe and analyze the methodological changes in the GBD assessment, document its inputs more transparently, and shed light on why the estimates have changed and what are the implications.

The review produced in this paper focused on PM2.5 since it dominates the overall mortality estimates and has been used most often to approximate the overall impact of air pollution. The scientific basis supporting the link between PM2.5 and adverse health outcomes is substantial. Dozens of studies of short-term exposure to PM2.5 and mortality have been published and include evidence from five continents. Several studies of long-term exposure form the basis for the concentration-response functions in GBD and the PM2.5 effect is the best documented and well supported by toxicological and human clinical studies. In addition, there is an extensive network of PM2.5 monitors around the world that can be used for calibration of global exposure models, although there are many low- and middle-income countries (LMIC) that have limited or no monitoring networks. All these factors set PM2.5 apart from all other air pollutants.

In Section 2, we briefly review the GBD model assumptions from 2010 to 2015 indicating how they have changed over time along with the resultant mortality estimates. In Section 3, we provide a quantitative analysis of the impacts that changes in the model inputs have had on the country-specific and global estimates. This is followed by summary (Section 4), conclusions (Section 5) and recommendations (Section 6) for future GBD studies.

2. Inputs and enhancements of GBD for 2010, 2013 and 2015

2.1. Inputs

There are five major inputs for the quantification process and different assumptions about them can generate significant differences in the outcome: 1) air pollution levels, 2) counterfactual selection; 3) population exposure; 4) death rates and 5) concentration-response function (CRF). Many of these components have changed with each successive GBD estimates of air pollution effects. They include the following:

1. An assessment of the annual concentration levels of an index pollutant, traditionally PM2.5, based on either ground-level monitors, remote sensing satellites, land use regression models, chemical transport models or some combination of the above. From the concentration levels population-weighted exposures are estimated (see input 3).
2. An alternative or minimum concentration of PM2.5, called a counterfactual, which could be either a background level, a target level such as a WHO guideline, a theoretical threshold or an assumed no-effects level.
3. A determination of the size of the population group being exposed to the given concentration is essential to estimate population-weighted exposure. For GBD, age-specific, population-weighted exposures are generated for every country.
4. The occurrence of the health effect being estimated such as the underlying cause-specific mortality rate in terms of annual deaths per 100,000 population, for example.
5. The concentration-response functions (CRFs) from the epidemiological literature that quantitatively relate ambient levels of PM2.5 to the risk of the health effect. For GBD, Integrated Exposure Response functions (IERs, see below) estimated for five disease categories (ischemic heart diseases, stroke, Chronic Obstructive Pulmonary Disease (COPD), lung cancer and acute respiratory infections), quantitatively relate population-weighed exposure to PM2.5 to the risk of the health effect.

2.2. GBD Enhancements and Limitations

There have been two major enhancements to the GBD estimates of 2010, 2013, 2015 and later compared to earlier estimates. First, the more recent estimates are based on exposures generated from models integrating multiple sources including remote sensing from satellites, chemical transport models (CTM) and ground-level monitors (Brauer et al., 2012; van Donkelaar et al., 2016; Shaddick et al., 2017). This is a significant improvement over earlier studies, such as for example the estimates of PM10 (particles less than 10 µm) for GBD 2000 (Pandey et al., 2000). However, each of these inputs used to estimate PM2.5 has some limitations.

For example, satellite observations are very limited during periods of significant cloudiness, such as during wintertime and at nighttime (van Donkelaar et al., 2015). CTM depend on the availability and quality of the emissions inventories. This may be particularly an issue in LMIC with potentially limited information but going through a rapid economic transformation. Finally, there are also issues with the existing network of ground-level monitors. There are many countries where there is no monitoring of PM2.5, so the satellite and CTM estimates cannot be calibrated. In addition, measurement protocols and quality controls are not standardized around the world, as seen in the air quality data regularly compiled by WHO (WHO, 2016). Some of the general uncertainties created by these limitations are reduced through the combination of methods and the use of advanced statistical techniques that improve estimation accuracy and incorporate uncertainty. However, the need for carefully calibrated ground-level monitors with proper quality control is imperative for many LMIC.

The second major enhancement is the improvement in developing the CRF. For GBD 2010, IERs were developed that combine evidence from studies of ambient air pollution, second-hand smoke, household air pollution and active smoking to estimate air pollution risks over the entire global range of particulate matter exposure (Burnett et al., 2014). The studies of second hand and active smoke are particularly important since their equivalent PM2.5 concentrations are much higher than those that were associated with ambient air pollution in cohort studies. Therefore, these studies play an important role in determining the shape of the IER at higher concentrations. This non-linear function was necessitated because the naïve assumption of a linear CRF function up to highest observed concentrations would ultimately result in implausible and biologically inconsistent results (Cohen et al., 2004, Ostro, 2004). In this approach risks of AAP on mortality from ischemic