Using EPA's Environmental Benefits Mapping and Analysis Program (BenMAP) for Global Health Impact Analysis

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1. Introduction

The Environmental Benefits Mapping and Analysis Program (BenMAP) is a tool for performing customized health benefits analysis. BenMAP is used by the Environmental Protection Agency (EPA) to estimate domestic health impacts of U.S. air quality regulations. Researchers in countries around the world also use BenMAP by customizing the data inputs to their country or region. As understanding of the global nature of air quality and climate change increases, new applications have arisen for health impact analysis on a global scale. However, global scale analyses also present new considerations for methods and underlying uncertainties. This document describes the data inputs necessary to run BenMAP on a global scale, using methods consistent with the traditional U.S. setup. It will then discuss considerations unique to the global scale, such as aggregation levels and valuation. Finally, major uncertainties associated with global health impact analyses are highlighted.

2. Data and Methods

Global BenMAP analyses use health impact functions to relate changes in air pollution concentrations with health outcomes. Health impact functions take into account exposed population, baseline incidence rates, pollutant concentrations, and concentration-response factors identified by the epidemiology literature (Figure 1). The method used for calculating health impacts using health impact functions is consistent with the U.S. BenMAP setup and, therefore, will not be discussed in detail here. However, the data inputs are specific to global analyses and are described below.

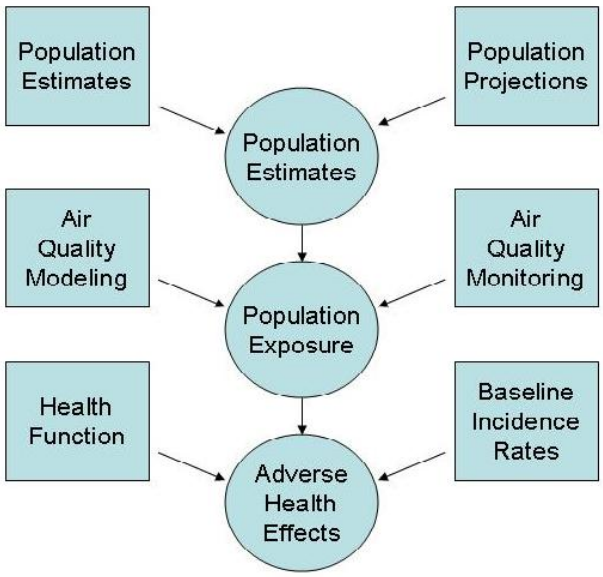

Figure 1. Flowchart of health impact assessment method used in BenMAP

2.1. Concentration-Response Factors

Concentration-Response Factors (CRFs) relate a unit change in air pollutant concentrations to a change in health endpoint incidence. They are identified by short- and long-term epidemiology studies. BenMAP can be run with the user's choice of CRF (pre-programmed or customized), though some CRFs may be better suited for use on a global scale than others. In its current version, BenMAP applies each chosen CRF to the entire geographical range included in the analysis.

Many time-series studies have associated ozone with mortality and can be used in global health analysis. It is recommended that CRFs from Bell et al., 2004, are used, because they are based on 95 large US communities and may not be subject to publication bias like the single-city studies that are incorporated into meta-analyses. Unlike ozone, the effects of $PM_{2.5}$ are most pronounced after chronic exposure. Long-term $PM_{2.5}$ health effects are demonstrated by long-term cohort studies. While three $PM_{2.5}$ cohort studies have been conducted in the U.S. (Dockery et al., 1993; Pope et al., 2002; Laden et al., 2006) and one Europe (Hoek et al., 2002), to date no cohort study has yet been conducted in a developing country.

However, several studies of short-term ozone and $PM_{2.5}$ effects in developing countries have shown similar results to North American and European short-term studies (HEI International Scientific Oversight Committee, 2004). Until more complete data for the relationship between $PM_{2.5}$ and mortality in developing countries exists, it can be assumed that mortality relationships found in the developed world are valid globally. Of the four $PM_{2.5}$ cohort studies, Pope et al., 2002, may be the most generalizeable because it had the largest sample size (approximately 500,000). Therefore, it may be the most appropriate cohort study to use for global analyses.

2.2. Baseline Incidence Rates

Baseline incidence rates at the finest resolution available should be used to calculate health impacts. At the global scale, the finest resolution is likely to be at the country-specific level. However, many countries lack the infrastructure to collect data on morbidity, and often lack medical professionals to diagnose illness in a systematic way. Until morbidity data is improved around the world, global health impact assessments should focus on mortality only.

Mortality rates are available for many countries and are made public by the World Health Organization (WHO) (http://www.who.int/healthinfo/morttables/en/). However, mortality rates are not available for all countries. Furthermore, in some cases, available country-specific mortality rates are over a decade old and obsolete in the fast-changing social and economic environments of developing countries. While country-specific rates have many data quality problems, the WHO also publishes estimated regional mortality rates for 14 world regions (http://www.who.int/choice/demography/by_country/en/index.html). The latest year available for cause-specific and age-specific mortality rates is 2002 (World Health Report 2004, Annex 2). Since some epidemiology studies include only adults of a

certain age, baseline mortality rates for the relevant population only must be used. Age-specific baseline mortality rates for countries and regions can be found on the WHO website.

Differences in total mortality rates experienced by countries and regions also present some difficulty in estimating global health impacts. As explained in section 2.1, no cohort studies to date relate $PM_{2.5}$ concentrations and mortality in developing countries. Therefore, cohort studies conducted in the U.S. or in Europe must be extrapolated across the global population, including populations in developing countries. Since baseline incidence rates and causes of total mortality vary widely between developed and developing countries, it may be inappropriate to apply U.S. and European total mortality CRFs to the developing world. Instead, it is more appropriate to assess cause-specific mortality, such as cardiopulmonary and lung cancer mortality, because they are not affected by differences in baseline mortality rates.

2.3. Pollutant Concentrations

Pollutant concentrations may be provided by global atmospheric chemistry and transport models or by global air quality monitor networks. Any global model, such as the Model of Ozone and Related Tracers (MOZART) and the Goddard Earth Observing System chemical model (GEOS-CHEM), can be used to supply pollutant concentrations. The user must create a new grid definition for each global model used in the analysis.

Similarly, any global monitoring network may be used in BenMAP, provided it has adequate sampling frequency and meets quality assurance criteria. Some monitoring networks available are:

- Clean Air Status and Trends Network (CASTNET)
- European Monitoring and Evaluation Programme (EMEP)
- Acid Deposition Monitoring Network in East Asia (EANET)
- Climate Monitoring and Diagnostics Laboratory (CMDL)
- Interagency Monitoring of Protected Visual Environments (IMPROVE)
- Aerosol Robotic Network (AERONET)

2.4. Population

Spatially-distributed population can be provided by the Landscan database operated by Oak Ridge National Laboratory or by the Center for International Earth Science Information Network (CIESIN), operated by the Earth Institute at Columbia University. These programs apportion population to very fine grid cells (30” by 30”) based on likelihood coefficients, such as proximity to roads, slope, land cover, nighttime lights, and other information. Fine resolution population data is very memory intensive and slows down BenMAP considerably. Since global health impact analyses are necessarily at a coarse resolution due to the coarseness in global modeling data and baseline incidence rates, such fine scale resolution for population is an unnecessary burden on computing memory and speed. Instead, fine resolution population data should be summed

to the larger grid resolution of the global model used for analysis before loading the data into BenMAP.

As previously mentioned, some epidemiology studies include adults of a certain age only. The exposed population, therefore, should be limited to the age group included in the epidemiology study selected to provide the CRFs for the analysis. Since Landscan and CIESIN do not provide the age structure of population in each grid cell, the fraction of the population within each age group for each of the 14 world regions should be converted to grid cells at the air quality model resolution. These fractions can then multiplied by population in each grid cell (outside of BenMAP) to obtain the correct exposed population in each grid cell. Age-specific population is available from the WHO for 2002 (World Health Organization, 2004).

3. Aggregation Levels

Global health impact analysis results may be aggregated to the country level or the continent level. However, country level aggregation may be inappropriate given the coarse grid resolution necessitated by the global air quality model. Results may also be aggregated to the 14 WHO regions. Countries included in each region can be found on the WHO website (http://www.who.int/choice/demography/by_country/en/index.html). Each aggregation level must be added to BenMAP as a grid definition.

4. Valuation

EPA often uses the Value of a Statistical Life (VSL) and other economic indicators to quantify the economic benefits of U.S. air quality regulations. Monetary quantification supports cost-benefit analysis techniques when deciding whether a regulation meets a cost-benefit test. Similar analyses using global air quality models and country-specific economic data could provide useful data on which the worldwide community can base decisions. However, uncertainties and ethical concerns surround attempts to apply valuation statistics to global health impact analyses. For example, inequity in salaries between developed and developing countries may result in vastly different VSLs around the world, causing mortalities in developing countries to be valued lower than the same number of mortalities in developed countries. Users should consider such issues when deciding whether to run the valuation step in BenMAP or whether to calculate health impacts only.

5. Sources of Uncertainty

Many uncertainties are associated with health impact analysis. Uncertainties are associated with impact functions, pollutant concentrations, mortality risk, and baseline incidence rates. These uncertainties are common for local, regional, and global health impact assessments. Since most uncertainties have previously been described in detail (PM RIA), only those that influence global health impact analysis differentially are discussed here and summarized in Table 1.

5.1. Scale

A major source of uncertainty in global health impact analysis is scale. Due to computing power constraints, global air quality models are very coarse in grid size, making it difficult to estimate actual exposure levels. Peaks in ozone and $PM_{2.5}$ concentrations that usually occur in urban areas are most likely subdued, due to averaging across the large grid cell. If captured by the model, large urban populations would be exposed to these concentration peaks, resulting in high mortalities. However, since the peak concentrations are diluted within each grid cell in global air quality models, these high urban mortalities may not be captured.

Table 1. Primary Sources of Uncertainty Affecting Global Benefits Analysis Differentially

Uncertainty	***Description***	***Possible Effect on Health Outcome***
Scale	Global air quality models have coarse grid size, causing urban peaks to be diluted	Health outcome underestimated because urban peak concentrations and populations not captured
Extrapolation of Health Impact Function Across the World	Cohort studies on PM mortality have included only U.S. and European populations and must be assumed to apply to populations across the world	Health outcome could be overestimated because median age in developing countries is much lower than that in developed countries, and the elderly are more susceptible to air pollution mortality (Schwartz, 2008). Health outcome could also be underestimated because populations in developing countries exposed to greater susceptibility factors, such as indoor air pollution and disease.
Use of Concentration Response Factors for Total PM	No PM cohort study to date has examined the effects of specific PM components on mortality. Though some PM components may have more deleterious health effects than others, relative risks are for total PM and must be applied to the total PM concentration.	Direction of effect on health outcome is unknown, but the magnitude could be great due to significant variability in PM composition around the world and between urban and rural regions.

5.2. Extrapolation of Health Impact Functions Across the World

Extrapolation of health impact functions across populations is another source of uncertainty. CRFs found in the U.S. and Europe must be assumed to apply to all other parts of the world. While some evidence exists to validate this assumption, no long-term

cohort epidemiology study of $PM_{2.5}$ and mortality has been conducted in developing countries. Differences in health status and medical care between developing and developed countries may have substantial consequences for air pollution-related mortality. For instance, the differential exposure of populations in developing countries to indoor air pollution, mainly due to wood-burning stoves and poor ventilation, may influence the susceptibility of these populations to diseases caused by outdoor air pollution. Similarly, many populations in developing countries lack access to adequate medical care, which may result in a higher rate of mortality from any particular disease. Differences in lifestyle and age structure are also likely to affect population-level health response to air pollution. For these reasons, less uncertainty is associated with estimating cause-specific mortality than with estimating total mortality. Therefore, cause-specific mortality should be calculated when possible.

5.3. Use of Concentration Response Factors (CRFs) for Total PM

Lack of CRFs for $PM_{2.5}$ components also influences uncertainty. To date, no epidemiology study has assessed mortality related to specific $PM_{2.5}$ components. However, $PM_{2.5}$ composition is drastically different throughout the world, depending largely on emissions. While particle size is a critical factor for toxicity, composition is also important. Though significant variability in $PM_{2.5}$ composition exists between countries and between rural and urban regions, all $PM_{2.5}$ components must be assumed to have the same CRFs until more data becomes available.

6. Future Directions

BenMAP is a useful tool for performing global health impact analyses with many potential applications. However, in the future, steps should be taken to reduce uncertainty, which may limit the strength of the results.

For example, the coarse resolution of global health impact analyses introduces significant uncertainty in actual exposures. To diminish the impact of such coarse resolution, data from global monitoring networks can be employed in areas where monitors are located. BenMAP's Model and Monitor Relative function allows users to anchor model results to actual observations and to calculate concentrations on a smaller grid sale through statistical methods. Another method for improving scale is to use finer scale regional models for regions with high quality data, such as the U.S., Europe, and Japan and coarse resolution global models for the rest of the world.

Extrapolation of CRFs discovered in one country to the rest of the world also presents uncertainty. As new epidemiological data for the developing world becomes available, a method for applying unique CRFs to different areas around the world should be developed. In this way, CRFs from developed countries would be applied only to populations in developed countries, and the same would be true for the developing world.

Similarly, as epidemiological studies associating $PM_{2.5}$ components with mortality become available, these data should be applied to global health impact analyses. For

example, to examine the global health impact of sulfates, a CRF specific to sulfates should be applied, rather than the CRF for total $PM_{2.5}$. Applying component-specific CRFs would lessen the impact of uncertainty due to differential $PM_{2.5}$ composition around the world.

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