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The Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP–CE): A tool to estimate the health and economic benefits of reducing air pollution

Jason D. Sacks [a, *], Jennifer M. Lloyd [b], Yun Zhu [c], Jim Anderton [d], Carey J. Jang [e], Bryan Hubbell [f], Neal Fann [e]

[a] National Center for Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC, USA
[b] RTI International, Durham, NC, USA
[c] Guangdong Provincial Key Laboratory of Atmospheric Environment and Pollution Control, College of Environment and Energy, South China University of Technology, Guangzhou Higher Education Mega Center, Guangzhou, China
[d] Industrial Economics, Inc., Cambridge, MA, USA
[e] Office of Air Quality Planning and Standards, Office of Air and Radiation, U.S. Environmental Protection Agency, Research Triangle Park, NC, USA
[f] Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC, USA

A R T I C L E I N F O

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A B S T R A C T

A number of software tools exist to estimate the health and economic impacts associated with air quality changes. Over the past 15 years, the U.S. Environmental Protection Agency and its partners invested substantial time and resources in developing the Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP–CE). BenMAP–CE is a publicly available, PC-based open source software program that can be configured to conduct health impact assessments to inform air quality policies anywhere in the world. The developers coded the platform in C# and made the source code available in GitHub, with the goal of building a collaborative relationship with programmers with expertise in other environmental modeling programs. The team recently improved the BenMAP–CE user experience and incorporated new features, while also building a cadre of analysts and BenMAP–CE training instructors in Latin America and Southeast Asia.

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Software Availability

Software name: Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP–CE)
Developers: RTI International – Jennifer Lloyd, J. Colin Mathews, Ed Rickman, Adam Shelton, Caitlin Hulsey, John Buckley, Bill Oberkirsch, Matt Scruggs, Mark Bruhn, Aaron Parks; Industrial Economics, Inc. – Henry Roman, Jim Anderton, Yingzi Yang; South China University of Technology – Yun Zhu; Ramboll Environ – Shawn Holladay; Brigham Young University – Dan Ames, Maxim Miroshnikov
Year first available: 2013
Software required: Spreadsheet program (to view .xlsx or .csv) to view BenMAP–CE output
Programming language: C#.NET

Abbreviations: BenMAP–CE, Environmental Benefits Mapping and Analysis Program – Community Edition; CAPMS, Criteria Air Pollutant Modeling System; CIESIN, Center for International Earth Science Information Network; COI, cost-of-illness; DLLs, dynamic-link libraries; GBD, Global Burden of Disease; GIS, geographic information system; GUI, graphical user interface; IHME, Institute of Health Metrics and Evaluation; MSDE, Microsoft SQL Server Data Engine; NAAQS, National Ambient Air Quality Standards; NO_2, nitrogen dioxide; O_3, ozone; Pb, lead; PM, particulate matter; $PM_{2.5}$, particles with a nominal mean aerodynamic diameter less than or equal to 2.5 μm; SO_2, sulfur dioxide; VSL, value of a statistical life; WTP, willingness-to-pay.

* Corresponding author. National Center for Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, Mailcode B-243-01, RTP, NC 27711, USA.
E-mail address: sacks.jason@epa.gov (J.D. Sacks).

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Operating System: Tested on Windows 7 and 10 (64-bit OS is preferred); 32-bit version is available for Windows XP but performance may be impacted
Availability: Software and data can be downloaded from http://www.epa.gov/benmap. Requests for the source code, as well as comments and questions, should be sent to: benmap@epa.gov
License: GNU General Public License
Cost: Free

1. Introduction

Risk assessors, policy analysts and policy makers have long relied upon decision-support tools to assess the human health impacts of air pollution (Fann et al., 2012; Pascal et al., 2013; Guttikunda and Khaliquzzaman, 2014; Viana et al., 2015; U.S. EPA, 2009; Boldo et al., 2014). While these tools vary in complexity, sophistication, and installed base (i.e., number of users), they share a core attribute: each software program draws upon evidence reported in the air pollution epidemiology literature to calculate estimated cases of air quality-related adverse health impacts (Anenberg et al., 2016). As compared to ad-hoc solutions such as spreadsheets or statistical programs like SAS or R, these programs can be more time-efficient, transparent and reliable. As such, these programs are generally designed for a multi-disciplinary audience, feature a graphical user interface (GUI), and include some (or, in certain cases, all) of the data needed to quantify the estimated number, and often the economic value, of air pollution-related deaths and illnesses (Anenberg et al., 2016).

Over the past decade, the number of these types of tools has proliferated—due in part to the growing body of epidemiologic evidence that provides the quantitative parameters of the air pollution − health effect concentration-response relationship, as well as the increased interest among decision makers to inform public health policies by conveying the potential estimated benefits of improved air quality (Samet, 2009; Burnett et al., 2014; HEI, 2003). While carefully evaluating the features and design of each tool is beyond the scope of this manuscript, it is worth noting that these programs exist along a spectrum of complexity. For example, programs like the World Health Organization's AirQ+ and Aphekom (Improving Knowledge and Communication for Decision Making on Air Pollution and Health in Europe) are intended to be accessible to a broad class of users and make it quite easy to answer a defined set of policy questions related to city-level impacts (Pascal et al., 2013; Goudarzi et al., 2012).

By contrast, the program that is the focus of this manuscript—the Environmental Benefits Mapping and Analysis Program—Community Edition (BenMAP−CE) is a PC-based and open-source software platform designed for flexibility to perform a broad array of analyses at the local, regional, national and global scale. Below we describe the history of the BenMAP−CE software, its capabilities, and demonstrate its use through a case study.

2. Background

The approach for calculating the estimated benefits of improving air quality is well established, highly structured, and draws upon information from a number of disparate datasets, which has allowed for the development of decision-support tools that inform air quality policy decisions (NRC, 1983; EPA COUNCIL, 2010). Tools that quantify the human health impacts of air quality generally rely on four key pieces of information: (1) air quality data, (2) population data, (3) baseline rates of death or disease, and (4) a risk estimate (generally the coefficient from a statistical model that measures the response of a health effect for a one-unit change in an air pollutant concentration (e.g., per $\mu g/m^3$), which we refer to as a beta [β] coefficient) from an air pollution epidemiologic study that quantitatively characterizes the relationship between air pollution exposure and health effects. The formula for calculating an air pollution-related health impact is referred to as a health impact function (HIF). The functional form of the HIF is based on the statistical approach used in the epidemiologic study from which the beta coefficient was obtained (most often a log-linear statistical model), resulting in a HIF most commonly defined as (Eq. (1)):

$$\Delta Y = \left(1 - e^{-\beta * \Delta AQ}\right) * Yo * Pop \tag{1}$$

Where ΔY = the estimated health impact attributed to air pollution, β = the beta coefficient from an epidemiologic study, ΔAQ = defined change in air quality, Yo = baseline rate (i.e., incidence) for the health effect of interest, Pop = population exposed to air pollution. Users may calculate this function once at a national or regional scale, or may instead calculate it across multiple locations (like U.S. counties) and then sum the results. The economic value of air pollution-related cases of death and disease are quantified using either willingness-to-pay (WTP) or cost-of-illness (COI) estimates corresponding to each health outcome. These dollar unit values are multiplied by the estimated count of adverse health outcomes to yield a total economic value of the change in air quality.

The U.S. Environmental Protection Agency (EPA) began developing, applying, and deploying tools to support its risk and benefits analyses in the mid-1990's, when it first quantified the benefits of air quality policies resulting from the recently enacted Clean Air Act Amendments of 1990 (U.S. EPA, 1999). The tool the Agency initially used to quantify air pollution-related health impacts and economic benefits was called the Criteria Air Pollutant Modeling System (CAPMS) (Abt, 2000). The CAPMS tool featured a GUI and a static array of population data, baseline rates of death and disease, and beta coefficients preloaded into a database. Additionally, it was often challenging to load air quality data into CAPMS. Due in part to these limitations, the Agency transitioned to the Environmental Benefits Mapping and Analysis Program (BenMAP) in 2003 (Davidson et al., 2007).

In contrast to CAPMS, BenMAP enabled users to add and remove data, including air quality, population data, baseline rates of death and disease, and HIFs, from the tool, which it stored in the Microsoft SQL Server Data Engine (MSDE). The BenMAP tool was originally written in Delphi and included a basic Geographic Information System (GIS) that was used both to perform calculations involving data stored at varying spatial scales and display geospatial results. BenMAP also allowed users to report an audit trail, detailing the user's analytical choices and data inputs; this feature was critical for analyses supporting environmental policies, for which transparency and reproducibility were particularly important. Between 2003 and 2012 the Agency updated the tool regularly to include new air pollution data, additional beta coefficients from recently published epidemiologic studies, and economic value estimates.

Researchers applied the initial version of the program extensively to quantify the burden of air pollution and the economic value associated with improving air quality (Viana et al., 2015; Boldo et al., 2014; Kheirbek et al., 2014; Hubbell et al., 2005; Berman et al., 2012). Likewise, the Agency used the tool when predicting the health benefits associated with attaining more stringent National Ambient Air Quality Standards (NAAQS) for the criteria air pollutants (e.g., particulate matter [PM], ozone [O_3], nitrogen dioxide [NO_2], and sulfur dioxide [SO_2]) (U.S. EPA, 2012; U.S. EPA, 2015a), as well as important regulations that reduced emissions of the precursors to fine particulate matter ($PM_{2.5}$) and ozone including NO_x, VOCs, and SO_2 (U.S. EPA, 2011a; U.S. EPA,