The Impact of Fine Particulate Outdoor Air Pollution to Premature Mortality

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Abstract Epidemiological cohort studies have shown that the long-term exposure to $PM_{2.5}$ is associated with increased mortality from cardiorespiratory diseases and lung cancer. We use an atmospheric chemistry-general circulation model in combination with population data, country-level health statistics and pollution exposure response functions to investigate the link between premature mortality and several emission source categories, combining all aerosol types that contribute to $PM_{2.5}$. We estimate the global premature mortality by $PM_{2.5}$ at 3.15 million/year in 2010. We find that high emissions levels mainly from residential energy use have the largest impact on premature mortality in Eastern and Southeastern Asia (almost 70 % of the global), with China and India being the counties with higher mortality levels attributable. For Europe we estimate 375 thousand premature deaths (about 11 % of the global rate), and 274 thousand deaths for the Eastern Mediterranean region in 2010. In this work we assume that all particles are equally toxic.

1 Introduction

Air pollution is the largest contributor to the burden of disease from the environment. The World Health Organization (WHO) reported that in 2012 outdoor air pollution was responsible for the deaths of 3.7 million people (WHO 2009). The WHO also emphasizes that indoor and outdoor air pollution combined are among the largest health risk worldwide, both being of similar magnitude. Epidemiological studies have linked exposure to $PM_{2.5}$ pollution with several health problems, including premature mortality from cardiovascular, respiratory diseases and lung cancer, non-fatal heart and lung disorders and acute asthma. Fine particles can cause health impacts even at very low concentrations. Estimates of

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mortality attributable to outdoor air pollution and the subsequent overall costs to the society are useful to justify air quality control policies and help improve public health.

2 Data and Methodology

For this work we applied model calculated global $PM_{2.5}$ concentrations, population data, country-level baseline mortality rates and exposure response functions to a health impact function, to estimate premature mortality attributable to long-term exposure to $PM_{2.5}$. We follow the same methodology as the Global Burden of Disease for 2010 (Lim et al. 2012) applying improved exposure response functions that more realistically account for health effects at very high $PM_{2.5}$ concentrations.

2.1 Data

Model and emissions: We used the EMAC global atmospheric chemistry—general circulation model to simulate annual mean $PM_{2.5}$ concentrations. EMAC comprise sub-models that represent tropospheric and lower stratospheric processes and their interaction with oceans, land and human influences. The model has been extensively validated and the output has been tested against in situ and remote sensing observations (De Meij et al. 2012; Jöckel et al. 2006; Pozzer et al. 2012a, b, 2015; Pringle et al. 2010). We obtained results for the year 2010, applying monthly varying emissions from EDGAR—the Emission Database for Global Atmospheric Research (Pozzer et al. 2012a).

Population data: The population data were obtained from the NASA Socioeconomic Data and Applications Center (SEDAC), hosted by the Columbia University Center for International Earth Science Information Network (CIESIN), available at a resolution of 2.5 × 2.5 arc minutes (about 5 × 5 km^2) (http://sedac.ciesin.columbia.edu/), and projections by United Nations Department of Economic and Social Affairs/Population Division (UNDES 2011).

Mortality data: Baseline mortality data describe the number of deaths in a particular year for the population under consideration. These data were obtained from the World Health Organization (WHO) Statistical Information System on the country-level (WHO 2014), based on the International Classification of Diseases 10th Revision (ICD-10) classification system.

2.2 Methodology

We apply the following health impact function to estimate premature mortality related to $PM_{2.5}$:

$$\Delta\text{Mort} = y_o \text{AFPop} \tag{1}$$

$$\text{AF} = (\text{RR} - 1)/\text{RR} \tag{2}$$

$$\text{RR} = 1 + a\{1 - \exp[-b\ (X - X_o)^p]\} \tag{3}$$

where y_o is the baseline mortality rate (Giannadaki et al. 2014; Lelieveld et al. 2013, 2015) and Pop is the exposed population. AF is the fraction of the disease burden attributable to the risk factor (here $PM_{2.5}$). RR is the relative risk of certain health impacts of the population exposed to outdoor $PM_{2.5}$ air pollution. To estimate the global burden of disease attributable to $PM_{2.5}$ we applied the integrated health risk function (Eq. 3) from Burnett et al. (2014), also used by Lim et al. (2012) for the GBD in 2010.

We refer to Burnett et al. (2014), Giannadaki et al. (2014) and Lelieveld et al. (2015) for details on the exposure response models and uncertainties. X is the annual mean $PM_{2.5}$ concentration in 2010 and X_o is the background concentration below which no impact is assumed. We used mortality data from the World Health Organization (WHO 2014) for ischemic heart disease (IHD), cerebrovascular disease (CEV), chronic obstructive pulmonary disease (COPD), and lung cancer (LC) for the population above 30 year, and for acute lower respiration infection (ALRI) for children below 5 year.

3 Results

We apply the exposure response model (Eq. 1–3), to estimate the global, regional and country level premature mortality related to the long-term exposure to $PM_{2.5}$. We consider six regions worldwide, as defined by the WHO (WHO member states by region and mortality stratum, http://www.who.int/choice/demography/mortality_strata/en/).

We estimated the global burden of $PM_{2.5}$ related mortality at 3.15 million per year in 2010. The countries with the highest number of deaths are China (1.33 million), India (575 thousand) and Pakistan (105 thousand). In total counties in Eastern and Southeastern Asia contribute about 70 % to the global level. For Europe we estimated 375 thousand premature deaths (about 12 % of the global level) with Russia ranking first with 67 thousand, followed by Ukraine with 51 thousand. For European Union we estimated 173 thousand premature deaths, which contribute about 5 % to the global level, and 46 to the European toll. Apart from the most evident regions of East and Southeast Asia, where large populations are

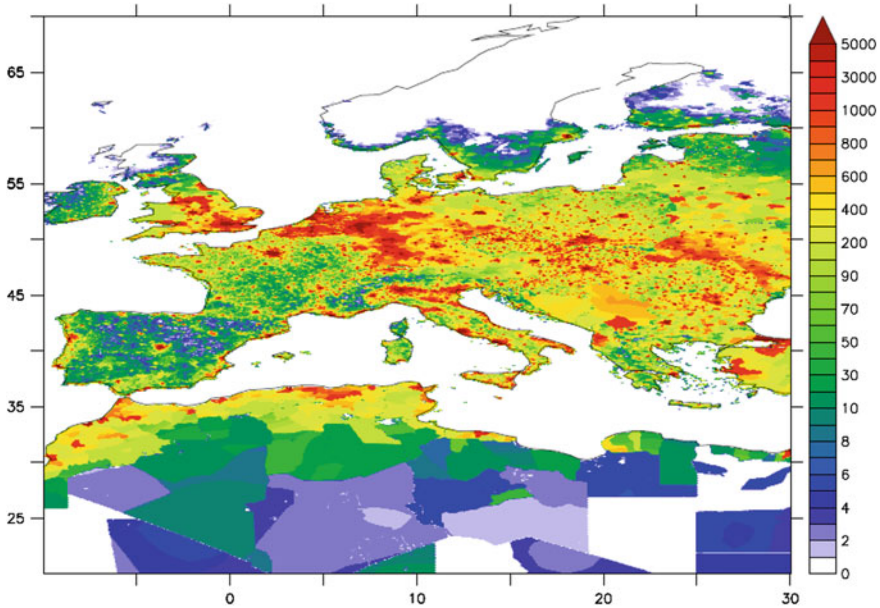

Fig. 1 $PM_{2.5}$ related mortality (in deaths/area of 100 × 100 km^2) in Europe in 2010

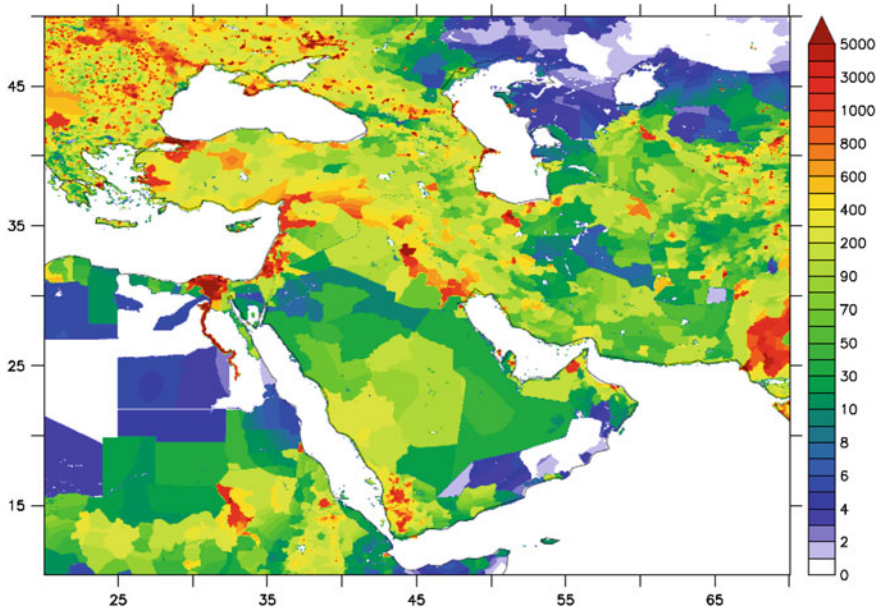

Fig. 2 $PM_{2.5}$ related mortality (in deaths/area of 100 × 100 km^2) in Eastern Mediterranean in 2010

Table 1 Premature mortality related to $PM_{2.5}$ for the regions defined by the WHO

WHO region	Year	Population ($\times 10^6$)	Mortality ($\times 10^3$)
Africa	2010	809	235
Americas	2010	930	63
Eastern Mediterranean	2010	602	274
Europe	2010	867	375
Southeast Asia	2010	1762	780
Western Pacific	2010	1812	1428
World	2010	6783	3155

exposed to high levels of air pollution, Eastern Mediterranean, a region strongly affected from air pollution transport from surrounding areas, is considered a hot spot with high risk to health due to increasing levels of ambient $PM_{2.5}$. We estimate for Eastern Mediterranean region 274 thousand premature deaths related to $PM_{2.5}$ (about 9 % of the global). For the above estimations we assume that all particles from different sources and different composition are equally toxic. Figures 1 and 2 highlight the hot spot locations in red with high rates of premature mortality due to $PM_{2.5}$ in Europe and Eastern Mediterranean respectively in 2010. Table 1 summarizes the mortality attributable to long-term exposure to $PM_{2.5}$ for the six WHO regions.

4 Conclusions

We estimated the global $PM_{2.5}$ related premature mortality in 2010 at 3.15 million with China having the higher burden, followed by India and Pakistan. In Europe the toll of premature deaths is estimated at 375 thousand, and 173 thousand in the European Union. In the sensitive region of Eastern Mediterranean our estimates give a toll of 274 thousand deaths. Our results show the urgent need to reduce air pollution levels though strict emission controls, to improve air quality and public health. This effort requires a better understanding of the relative toxicity of particles from various emissions sources. In addition, there is a strong need for developing better emission inventories and monitoring systems, especially in regions with high air pollution burden.

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