Quantifying public health benefits of environmental strategy of PM$_{2.5}$ air quality management in Beijing–Tianjin–Hebei region, China

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ABSTRACT

In 2013, China issued "Air Pollution Prevention and Control Action Plan (Action Plan)" to improve air quality. To assess the benefits of this program in Beijing–Tianjin–Hebei (BTH) region, where the density of population and emissions vary greatly, we simulated the air quality benefit based on BenMAP to satisfy the Action Plan. We estimate PM$_{2.5}$ concentration using Voronoi spatial interpolation method on a grid with a spatial resolution of 1 km × 1 km. Combined with the exposure–response function between PM$_{2.5}$ concentration and health endpoints, health effects of PM$_{2.5}$ exposure are analyzed. The economic loss is assessed by using the willingness to pay (WTP) method and human capital (HC) method. When the PM$_{2.5}$ concentration falls by 25% in BTH and reached 60 μg/m$^3$ in Beijing, the avoiding deaths will be in the range of 3175 to 14,051 based on different functions each year. Of the estimated mortality attributable to all causes, 3117 annual deaths were due to lung cancer, 1924–6318 annual deaths were due to cardiovascular, and 343–1697 annual deaths were due to respiratory. The avoided cases of cardiovascular mortality had the estimated monetary values ranged from 673 to 13,325 million CNY based on WTP method and from 161 to 529 million CNY based on HC method. The avoided cases of respiratory mortality had the estimated monetary values ranged from 120 to 3579 million CNY based on WTP and from 29 to 143 million CNY based on HC. The avoided cases of lung cancer mortality had the estimated monetary value of 261 million CNY based on HC.

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Keywords: BenMAP, Air pollution, Health benefits, PM$_{2.5}$, Beijing–Tianjin–Hebei

Introduction

It is noted that the air pollution situation in China is serious, especially the high PM$_{2.5}$ and PM$_{10}$ concentrations in the ambient air of a number of regions. Beijing–Tianjin–Hebei (BTH) is one of the most air polluted regions in China. In 2014, the annual average PM$_{2.5}$ concentration was 93 μg/m$^3$ in BTH, about 6.2 times higher than the China’s Class I standard (15 μg/m$^3$) and 2.7 times higher than the China’s Class II standard (35 μg/m$^3$). Urban air pollution is recognized as a serious problem since it is not only imposing a severe threat to the public health but also affecting the economic burden.

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Hence, it is necessary to develop an effective air quality management strategy to address the challenging air pollution problem. The Chinese government has sought to balance environmental and public health concerns against the economic growth. In recent years, China has implemented a number of air quality control measures that are expected to lead to a future reduction in fine particle concentrations and an ensuing positive impact on public health. For example, the “Air Pollution Prevention and Control Action Plan (hereinafter referred to as Action Plan)” issued in September 2013 was one of these measures. According to this Plan, in force till the year of 2017, the \( \text{PM}_{2.5} \) concentrations in a number of cities should be reduced more than 10% compared to those of 2012, and the numbers of good air quality days (Air Quality Index, AQI < 100) would increase annually (China State Council, 2013). Specifically, \( \text{PM}_{2.5} \) levels in Beijing–Tianjin–Hebei, Yangtze River Delta and Pearl River Delta will be cut by 25%, 20% and 15%, respectively, and the annual \( \text{PM}_{2.5} \) concentration in Beijing will be kept around 60 \( \mu \text{g/m}^3 \) in 2017. To achieve these goals, the supporting assessment methods and the implementation details for the Action Plan were issued in 2014.

\( \text{PM}_{2.5} \) may seriously affect human health because it is able to penetrate deeply into the lung with its small size, and the various chemicals that absorbed on its surface (Rd and Dockery, 2006). A large number of time-series studies of mortality have been published in the past 20 years, but only a few cohort studies have been reported. Epidemiological cohort studies, both in Europe (Cesaroni et al., 2013) and in North America (Turner et al., 2011), have estimated the long-term health risk of being exposed to air pollution. The study in North America showed that long-term exposure to \( \text{PM}_{2.5} \) was associated with an increase in non-accidental mortality (hazard ratio (HR) = 1.04 (95% CI: 1.03, 1.05) per 10 \( \mu \text{g/m}^3 \) \( \text{PM}_{2.5} \)). Ischemic heart diseases (HR = 1.10 (95% CI: 1.06, 1.13) per 10 \( \mu \text{g/m}^3 \) \( \text{PM}_{2.5} \)) was found to have the strongest association with the \( \text{PM}_{2.5} \) concentration, followed by cardiovascular diseases and lung cancer. The study in Europe examined the association between mean long-term ambient \( \text{PM}_{2.5} \) concentrations and lung cancer mortality in a 26-year prospective study among a large cohort of non-smokers. Each 10 \( \mu \text{g/m}^3 \) increase in \( \text{PM}_{2.5} \) concentration was associated with a 15%–27% increase in lung cancer mortality. The Harvard Six Cities study reported a 14% increase in long-term all cause mortality for every 10 \( \mu \text{g/m}^3 \) increase in fine particle concentration (Lepelule et al., 2012). Recent European cohort study (Raaschou-Nielsen et al., 2013) has reported an increase of long-term mortality even at fine particle levels below the ambient air quality standards. In China, several time-series studies and cross-sectional mortality studies were conducted in cities including Shanghai, Beijing, Tianjin, Xi’an, Wuhan, Taiyuan and Anshan (Kan et al., 2007; Guo et al., 2009, 2010; Huang et al., 2012; Wong et al., 2008; Zhang et al., 2008; Chen et al., 2010). Results of these studies were in accordance with those reported from the developed countries.

Quantifying the benefits of air quality programs is an important step in evaluating the efficacy of regulations, comparing alternative strategies, and communicating to the public the importance of these efforts. The U.S. EPA’s BenMAP is a windows-based computer program that uses Geographic Information System (GIS)-based data to estimate the health impacts and monetary value when populations experience changes in air quality (US EPA, 2015). Because BenMAP does not model air quality changes, data must be input into BenMAP as modeling data or generated from air pollution monitoring data. Models such as Community Multiscale Air Quality (CMAQ) were used to simulate air pollutant exposure concentrations in several studies (Ding et al., 2016; Wang et al., 2015; Voorhees et al., 2014; Fann et al., 2012; Chae and Park, 2011; Boldo et al., 2014; Sonawane et al., 2012). In this study, we attempted to simulate the air quality surface based on monitoring data. There are some international public released papers using BenMAP-CE to address the health benefit due to air quality improvement in China.

This study took Chinese health impact functions, applied monitored air quality data, and estimated the numbers of avoided cases of mortality and economic benefit for BTH, assuming the Action Plan was completed. The findings of this study can provide scientific basis for implementation of air pollution control strategies.

### 1. Materials and methods

#### 1.1. Study area

The region of BTH is located in northern China, and includes two municipalities (Beijing, Tianjin) and one province (Hebei). Hebei Province includes Chengde, Qinhuangdao, Tangshan, Langfang, Zhangjiakou, Baoding, Cangzhou, Shijiazhuang, Handan, Hengshui, Xingtai, and is located at the east of the Taihang Mountains and at the north of the Yellow River. The BTH region has a monsoon climate of medium latitudes, which has dry and windy spring, hot and rainy summer and dry-cold winter. It covered 2.3% of the Chinese territory, while 15% of the population and 11.7% of the total motor vehicle numbers in China. The major industries in Hebei are iron, steel, coke and cement. In addition, BTH is also one of the regions with the worst air pollution in the world.

#### 1.2. Data collection

The \( \text{PM}_{2.5} \) concentration data were collected from the air pollution monitoring network operated by China National Environmental Monitoring Centre (CNEMC) in 2014. The measurement method used for air quality assessment-complies with those recommended in China National Ambient Air Quality Standard (No. GB3095-2012). The quality assurance (QA) and quality control (QC) procedures are implemented at CNEMC according to relevant Chinese rules and regulations. There were 90 \( \text{PM}_{2.5} \) monitoring sites in study area (Fig. 1), including 12 sites in Beijing, 28 sites in Tianjin and 50 sites in Hebei Province. The population data with 1 km resolution were obtained from the Center for International Earth Science Information Network (Columbia University et al., 2005). Fig. 1 shows the spatial distribution of the population. The baseline mortality of BTH was obtained from China Statistical Yearbook and China Health Yearbook. The health endpoints included all...
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