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## Short communication

## Mortality and air pollution in Beijing: The long-term relationship



Guiqian Tang<sup>a</sup>, Pusheng Zhao<sup>b</sup>, Yinghong Wang<sup>a</sup>, Wenkang Gao<sup>a</sup>, Mengtian Cheng<sup>a</sup>,  
Jinyuan Xin<sup>a</sup>, Xin Li<sup>c</sup>, Yuesi Wang<sup>a,\*</sup>

<sup>a</sup> State Key Laboratory of Atmospheric Boundary Layer Physics and Atmospheric Chemistry (LAPC), Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China

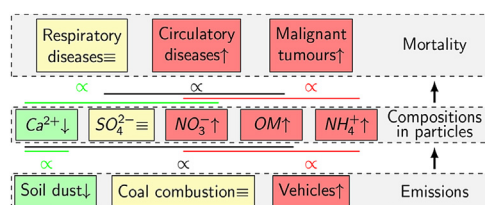
<sup>b</sup> Institute of Urban Meteorology, Chinese Meteorology Administration, Beijing 100089, China

<sup>c</sup> Mentougou District Government, Beijing 102300, China

## HIGHLIGHTS

- Coal combustion was key factor for mortality from malignancies from 1949 to 1965.
- Total suspended particle concentration and dust fall decreased after 1980.
- Secondary inorganic ions in the wet depositions increased after 1980.
- Vehicular emissions were the key factors for mortality after 1980.

## GRAPHICAL ABSTRACT



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## ABSTRACT

Since the 1980s, air pollution has become a major problem in northern China. Exposure to the extremely high concentrations of aerosols and trace gases might lead to important human health outcomes, including respiratory, cardiovascular and cerebrovascular diseases and malignant tumours. In this study, we collected data on mortality, visibility and the concentrations of certain air pollutants in Beijing from 1949 to 2011. Our goal was to investigate the mortality trends of different types of diseases and the relationship between mortality and air pollution. Based on the chemical compositions in particles and satellite formaldehyde, we found that mortality due to circulatory diseases was correlated with sulphate, nitrate and formaldehyde, whereas respiratory diseases were correlated with calcium, sulphate and nitrate, and malignant tumours was correlated with ammonium, nitrate and formaldehyde with an 11-year lag. The different responses to different air pollutants for different diseases are primarily a result of energy usage.

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## 1. Introduction

In recent years, northern China has experienced severe air pollution problems (Ji et al., 2012; Wang et al., 2014; Tang et al., 2012, 2015b; Pan et al., 2016a; Sun et al., 2016). In fact, satellite and ground observations show that the concentrations of aerosols

and gaseous pollutants have become extremely high in northern China over the last decades (Richter et al., 2005; Zhang et al., 2006; Tang et al., 2009; Xin et al., 2011; Liu et al., 2014; Zhuang et al., 2014; Ma et al., 2016).

Beijing is a megacity located in the rapidly developing Beijing-Tianjin-Hebei region of northern China. The population increased from 8.8 million in 1980 to 20.2 million in 2011 within an area of 16,800 km<sup>2</sup>, making it one of the largest and most densely populated cities in northern China (Beijing Municipal Bureau of Statistics, 2012). The number of civil motor vehicles also

\* Corresponding author.

E-mail address: [wys@mail.iap.ac.cn](mailto:wys@mail.iap.ac.cn) (Y. Wang).

increased from 16.2 million in 1984 to 498.3 million in 2011 (Beijing Municipal Bureau of Statistics, 2012). The usage of coal increased from 17.3 Mton in 1980 to 27.4 Mton in 2007 but decreased to 23.6 Mton in 2011 (Beijing Municipal Bureau of Statistics, 2012). However, the usage of gasoline, kerosene, diesel and natural gases respectively increased from 0.8 Mton, 0.9 Mton, 0.6 Mton and 0.3 billion cubic metres in 1998 to 3.9 Mton, 4.2 Mton, 2.4 Mton and 4.3 billion cubic metres in 2011 (Beijing Municipal Bureau of Statistics, 2012). In summary, the usage of energy increased from 27.1 Mton (the standard coal equivalent) in 1986 to 70.0 Mton in 2011.

This rapid increase in fossil fuel usage in this urban area has led to increased pollutant emissions (e.g., aerosols and trace gases) (Wang et al., 2010; Lu et al., 2010). The history of airborne materials impacting health has been reviewed elsewhere (Brimblecombe, 1999). High concentrations of aerosol particles are believed to induce oxidative damage to human DNA, resulting in significant effects on human health (Lave and Seskin, 1970; Vineis and Husgafvel-Pursiainen, 2005; Peluso et al., 2005). The high levels of ozone that usually occur together with high aerosol pollution events generate additional health problems (Abbey et al., 1999; Jerrett et al., 2005). Although the biological mechanisms involved may not be fully understood, there is statistical evidence that air pollution is a considerable risk factor for respiratory morbidity and cardio-pulmonary mortality (Cohen et al., 2005; Cao et al., 2011). Air pollution is also associated with the incidence of lung cancers (Nesnow and Lewtas, 1981; Cohen, 2000; Zhao et al., 2006) because particles released by diesel engines, for example, are believed to have mutagenic and carcinogenic properties (Pope et al., 1995, 2002).

In this study, we first illustrate the mortality and visibility in Beijing from 1949 to 2011 using statistical data and long-term observations. Next, we clarify the relationship between visibility and mortality by using a combined approach that incorporates the energy usage, wet deposition and satellite data to evaluate the main factors driving the variations in the causes of deaths in Beijing from 1949 to 2011. Finally, the above results are used to identify strategies for controlling mortality from the main causes of deaths in Beijing.

## 2. Data and methodology

To achieve the above described goals, several types of data were utilised to analyse the relationship between air pollution and mortality in Beijing. First, we described the mortality patterns related to the top 4 diseases, including respiratory, cardiovascular, cerebrovascular and malignant tumour diseases. Statistical data from 1949 to 1990 were acquired from the *Annals of Beijing: Annals of Health* (Beijing local Chronicles compilation committee, 2003), whereas the mortality data were obtained from the Beijing Statistical Yearbook (Beijing Municipal Bureau of Statistics, 2012). The causes of death were coded according to the International Classification of Diseases, 9 (ICD-9).

Because the concentrations of particles were not available for this long-term period, other parameters had to be used instead of the concentration of particles. A previous study indicated that optical extinction is mainly due to particles and accounts for more than 90% of the total extinction coefficient in Beijing (Liu and Shao, 2004). Therefore, the optical extinction coefficient (OEC) is a good indicator of the concentrations of particles, as applied in the previous study (Tie et al., 2009). In the present study, we derived the OEC from observations of visibility using the following equation:  $b_{\text{ext}} = 2.99/v$ , in which  $b_{\text{ext}}$  is the OEC and  $v$  is visibility (Seinfeld and Pandis, 1998). Amongst the visibility data, data between 1949 and 1979 from the Beijing Meteorology station (ID: 54511) were obtained from Qiu (1986), whereas the visibility data for 21 sites in

Beijing from 1980 to 2011 were obtained from the Chinese Meteorology Administration (Zhao et al., 2011). The visibility was observed manually at 00, 06, 12, and 18 UTC. It is well known that mortality is correlated with the population age structure. To remove the influence of population ageing on mortality, we also obtained age-specific population and mortality data from the Beijing Statistical Yearbook (Beijing Municipal Bureau of Statistics, 2012) and from Wei et al. (2009).

After the relationship between the OEC and mortality for different diseases was clarified using the above analysis, the usage of energy in Beijing over the past 60 years (Beijing Municipal Bureau of Statistics, 2010) was used to illustrate the reasons for the variations in the causes of deaths from different diseases. Particulate matter (PM) is comprised of several types of air pollutants, including elemental carbon (EC), organic carbon (OC), water soluble ions and elements, amongst others (Wang et al., 2014). Because the concentrations of the particle chemical compositions were not available throughout the long-term period, the chemical compositions of the wet depositions (including nitrate ( $\text{NO}_3^-$ ), sulphate ( $\text{SO}_4^{2-}$ ), ammonium ( $\text{NH}_4^+$ ), chloride ( $\text{Cl}^-$ ) and calcium ( $\text{Ca}^{2+}$ )) and space-based formaldehyde (HCHO) data from 2 satellite data sources (SCIMACHY and GOME) were used in this analysis instead of the chemical composition of the inorganic and organic particles. The chemical compositions of the wet depositions from 1980 to 2011 were specifically obtained from the Beijing Environmental Quality Report (Beijing Municipal Environmental Protection Bureau, 1983–2011), whereas the space-based HCHO data were obtained from the TEMIS website (<http://www.temis.nl/index.php>).

To verify the effects of energy usage on mortality, we applied an overdispersed Poisson generalised additive model (GAM) to explore the relationship in Beijing. This method has been widely used in previous studies (Li et al., 2013) and can be described as follows:

$$\text{Log } E(Y) = \beta X \quad (1)$$

Where  $E(Y)$  is the mortality in each year;  $\beta$  is the regression coefficient and  $X$  is the matrix of the independent variables, which included the concentrations of air pollutants, temperature and relative humidity, amongst other variables. Considering the different pathways between cancer and respiratory or circulatory diseases, different lags were applied to check the effects of the air pollutants on mortality from malignant tumours. All confidence intervals (CIs) were estimated at the 95% level. Matlab software version 2012a was used for the analysis.

## 3. Results and discussion

### 3.1. Mortality and the OEC

In this section, we present the mortality attributable to the top 4 diseases to understand the variations in the causes of deaths from 1949 to 2011 (Fig. 1). Deaths from malignant tumours increased significantly from 1949 to 1964, with a slope of 4.8 deaths per 100,000 individuals per year ( $R = 0.95$ ), and then remained constant from 1973 to 2004. After 2004, deaths from malignant tumours increased again, with a slope of 13.3 deaths per 100,000 individuals per year ( $R = 0.99$ ). Deaths from circulatory system problems displayed a slightly different pattern compared to mortality from malignant tumours, increasing significantly between 1949 and 1978, with a slope of 6.5 deaths per 100,000 individuals per year ( $R = 0.96$ ), and then decreasing slowly, from 323.9 to 220.8 deaths per 100,000 individuals per year, between 1979 and 1989. Subsequently, the number of deaths related to circulatory system

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