Environment International 113 (2018) 42–49

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

Impacts of air pollution wave on years of life lost: A crucial way to communicate the health risks of air pollution to the public

Jing Huang, Xiaochuan Pan, Xinbiao Guo, Guoxing Li*

Department of Occupational and Environmental Health Sciences, Peking University School of Public Health, Beijing, China

ARTICLE INFO

Handling Editor: Yong Guan Zhu

Keywords:
Air pollution wave
Years of life lost
Durational effect
Risk communication

ABSTRACT

Limited studies have explored the impacts of exposure to sustained high levels of air pollution (air pollution wave) on mortality. Given that the frequency, intensity and duration of air pollution wave has been increasing in highly polluted regions recently, understanding the impacts of air pollution wave is crucial. In this study, air pollution wave was defined as 2 or more consecutive days with air pollution index (API) > 100. The impacts of air pollution wave on years of life lost (YLL) due to non-accidental, cardiovascular and respiratory deaths were evaluated by considering both consecutive days with high levels of air pollution and daily air pollution levels in Tianjin, China, from 2006 to 2011. The results showed the durational effect of consecutive days with high levels of air pollution was substantial in addition to the effect of daily air pollution. For instance, the durational effect was related to an increase in YLL of 116.6 (95% CI: 4.8, 228.5) years from non-accidental deaths when the air pollution wave was sustained for 4 days, while the corresponding daily air pollution's effect was 121.2 (95% CI: 55.2, 187.1) years. A better interpretation of the health risks of air pollution wave is crucial for air pollution control policy making and public health interventions.

1. Introduction

Air pollution is a well-known public health hazard (GBD 2016 Risk Factors Collaborators, 2017). The associations between high concentrations of air pollutants and increased mortality have been found in numerous epidemiological studies (Chen et al., 2012a, 2012b; Chen et al., 2017; Dehbi et al., 2017; Dockery et al., 1993; Pope 3rd et al., 2015; Pun et al., 2017). However, most of the studies focused on the impact of a specific pollutant, and few have evaluated the impact of exposure to sustained high levels of air pollution on mortality. In addition, whether sustained high levels of air pollution increase the mortality risk beyond that associated with single days of high levels of air pollution is unknown. The disease burden related to sustained high levels of air pollution is even more unclear. However, information about the impacts of sustained high levels of air pollution on disease burden is crucial for air pollution control policy making and public health interventions, especially in highly polluted regions of the world.

Due to rapid urbanization and industrialization, China is now experiencing severe and persistent air pollution. Although the government has put special effort into reducing air pollution, air pollution control is a long-term process, and the air pollution levels in mega cities such as Beijing and Tianjin still exceed the World Health Organization's air quality guideline levels (Ministry of Environmental Protection of the People's Republic of China, 2016). Thus, understanding the impacts of sustained high levels of air pollution is crucial given that the frequency, intensity and duration of sustained high levels of air pollution, such as haze, has been increasing in recent decades in China (Guo et al., 2014; Huang et al., 2014).

In our study, the impacts of sustained high levels of air pollution on the disease burden from non-accidental, cardiovascular and respiratory deaths were evaluated in Tianjin, China, from 2006 to 2011. We quantified the durational effect of consecutive days with high levels of air pollution while also considering the effect of daily air pollution.

Because ambient air pollution is a complex mixture of particles and gaseous pollutants (Yu et al., 2013), we used a comprehensive index, the air pollution index (API), to reflect the daily air pollution level. The daily API data was provided by the Chinese government, documenting the ambient air quality information during the period before 2012. It is a comprehensive index reflecting the air quality status in terms of the particulate matter with aerodynamic diameter ≤10 μm (PM_{10}), sulfur dioxide (SO_2) and nitrogen dioxide (NO_2). API ≤ 100 indicates excellent or good air quality, while API > 100 indicates different levels

Abbreviations: API, air pollution index; CO, carbon monoxide; ER, excess risk; ICD-10, International Classification of Diseases, 10th version; NO_2, nitrogen dioxide; PM_{10}, particulate matter with aerodynamic diameter ≤10 μm; SO_2, sulfur dioxide; WHO, World Health Organization; YLL, years of life lost

* Corresponding author at: Department of Occupational and Environmental Health Sciences, Peking University School of Public Health, 38 Xueyuan Road, Haidian District, Beijing 100191, China.

E-mail address: liguoxing@bjmu.edu.cn (G. Li).

https://doi.org/10.1016/j.envint.2018.01.022
Received 2 November 2017; Received in revised form 7 January 2018; Accepted 22 January 2018
0160-4120/

of air pollution (Ministry of Environmental Protection of the People's Republic of China, 2008). In this study, sustained high level of air pollution was defined as air pollution wave with 2 or more consecutive days with daily API > 100.

In addition, compared with conventional epidemiological studies on air pollution, which always use mortality as the health outcome endpoints, in our study, we used the indicator of years of life lost (YLL) to estimate the disease burden related to air pollution wave. YLL is an important indicator that considers both death counts and life expectancy at death, assigning higher weights to deaths that occur at younger ages (Guo et al., 2013; Liang et al., 2018; Wang et al., 2012; Yang et al., 2016). Compared with mortality, it is more accurate to measure premature death and excess mortality. In this sense, exploring the relationships between air pollution wave and YLL may provide additional information for policy making and resource allocation. Furthermore, the effect modifications of demographic factors were explored in our study.

2. Materials and methods

2.1. Study site and population

The study site was in Tianjin, which is the third largest metropolis in China, and the city is an important industrial city in northern China. The study area included 11 urban and suburban districts of Tianjin, which covered 3340 km^2. The population was approximately 12.0 million people during the study period (Tianjin Statistical Information Site, 2006–2011).

2.2. Death data and the corresponding YLL

The death records of the population were restricted to the permanent residents in the 11 urban and suburban districts in Tianjin and were classified by the International Classification of Diseases, 10th version (ICD-10). The mortality data of non-accidental deaths (ICD-10: A00-R99), cardiovascular deaths (ICD-10: I00-I99) and respiratory deaths (ICD-10: J00-J99) from Jan 1st 2006 to Dec 31th 2011, were obtained from the Center for Public Health Surveillance and Information Service of China Centers for Disease Control and Prevention. The information of death date, age and gender were also available in the database.

The corresponding YLL of each death was calculated by matching the death age and gender to the World Health Organization (WHO) life table for China during 2006–2011 (Supplemental data, Table S1). Daily YLL were the sum of the YLL of all deaths on the same day. In addition, the sums of daily YLL were stratified by age (> 65 years and ≤65 years), and gender (male and female).

2.3. Air pollution and meteorological data

Daily API data of were also obtained from the Tianjin Environmental Monitoring Center during the study period. The data were collected from the 12 fixed monitoring sites distributed in the 11 urban and suburban districts of Tianjin. According to the Ministry of Environmental Protection of China, API value is calculated by using the linear interpolation method, as presented in the following equations (Ministry of Environmental Protection of the People's Republic of China, 2008). In the equation, API_i is the index for pollutant i (PM_{10}, SO_2, or NO_2). C_u and C_l are the upper and lower breakpoints, respectively, of the measured concentration of the pollutant i, and the API_u and API_l are the upper and lower limits, respectively, of the corresponding index (Supplemental data, Table S2), C_i is the observed concentration of pollutant i. API is the maximum of API_i.

$$API_i = \frac{API_u - API_l}{C_u - C_l} \times (C_i - C_l) + API_l$$

$$API = max(API_i)$$

Meteorological data including daily temperature and relative humidity were obtained from the National Meteorological Information Center of China in the same study period.

2.4. Statistical analysis

We evaluated the durational effect of 2 or more consecutive days with API > 100 after adjusting for daily API. A dummy variable was used for the air pollution wave days and non-air pollution wave days, with 1 for the air pollution wave days, when daily API > 100 lasted for 2, 3 or 4 days, and 0 for the non-air pollution wave days, when the API ≤ 100.

A generalized additive model was applied to explore the associations between the air pollution wave and the daily YLL, while accounting for the effect of daily API. A similar method was used in an East Asian study that explored the effects of both the sustained high levels of particulate matter and the daily PM_{10} (Kim et al., 2018). This model allows nonparametric smoothing functions to account for the effect of fluctuations in confounding factors, such as seasonal variation and meteorological conditions, on daily YLL.

$$Y_t = \alpha + \beta_1 duration_t + \beta_2 API_{t-i} + s(time_t, df = 7^* number\ of\ years) + factor(DOW_t) + s(temp_{t-i,}\ df = 3) + s(humid_{t-i}, df = 3)$$

In the above equation, t refers to the day of observation, and Y_t refers to the observed daily YLL on day t; i refers to lags; $s(\ )$ refers to the penalized smoothing functions; df refers to the degrees of freedom; α is the intercept; $duration_t$ refers to the air pollution wave on day_t; API_{t-i} is the API value on day_{t-i}; $time_t$ refers to the seasonality using the days of calendar time, and the degrees of freedom was set to 7*number of years (Li et al., 2016); DOW_t is the day of the week on day_t; $temp_{t-i}$ and $humid_{t-i}$ refers to the mean temperature and the mean relative humidity on day_{t-i}, respectively. The degrees of freedom for temperature and relative humidity were set to 3, according to the parameters in previous studies (Guo et al., 2011; Liu et al., 2014b). The effect of daily air pollution was estimated as changes in YLL related to the median daily API during air pollution wave days. The durational effect was evaluated for each additional consecutive day with API > 100. In addition, we validated the model fit by checking the residuals to ensure that the autocorrelations had been successfully removed.

We also used a second approach to capture the characteristics of the durational effect. In the above equation, the variable (*duration*) was replaced by $f(duration)$. The function f, denoting the durational effect in terms of sustained air pollution wave days, is specified in two ways as follows: through a step function (strata breaks: 2&3) or through quadratic splines with 3df (1 knot at 3 day). Both the quadratic splines and step function were from the dlnm package in R software.

To explore the modification effects of demographic factors including age and gender, a similar analysis was performed in different subgroups. The differences between subgroup effect estimates were tested by calculating the 95% confidence interval (CI) as shown below:

$$(\beta_1 - \beta_2) \pm 1.96\sqrt{SE_1^2 + SE_2^2}$$

where β_1 and β_2 are the estimates for the two subgroups (e.g., old and young; males and females), and SE_1 and SE_2 are their respective standard errors.

To make a comparison with the results of YLL, we also assessed the impacts of air pollution wave on daily non-accidental, cardiovascular and respiratory death counts. The independent variable, relevant degrees of freedom and lag structure in the model were similar to those in the model of YLL, except a log link was used because the daily death counts followed a Poisson distribution. The results were presented as changes in excess risk (ER) of daily death counts due to the durational effect and the effect of the daily air pollution.