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Characterizing multi-pollutant air pollution in China: Comparison of three air quality indices

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ABSTRACT

Multi-pollutant air pollution (i.e., several pollutants reaching very high concentrations simultaneously) frequently occurs in many regions across China. Air quality index (AQI) is used worldwide to inform the public about levels of air pollution and associated health risks. The current AQI approach used in China is based on the maximum value of individual pollutants, and does not consider the combined health effects of exposure to multiple pollutants. In this study, two novel alternative indices – aggregate air quality index (AAQI) and health-risk based air quality index (HAQI) – were calculated based on data collected in six megacities of China (Beijing, Shanghai, Guangzhou, Shjiazhuang, Xi'an, and Wuhan) during 2013 to 2014. Both AAQI and HAQI take into account the combined health effects of various pollutants, and the HAQI considers the exposure (or concentration)-response relationships of pollutants. AAQI and HAQI were compared to AQI to examine the effectiveness of the current AQI in characterizing multi-pollutant air pollution in China. The AAQI and HAQI values are higher than the AQI on days when two or more pollutants simultaneously exceed the Chinese Ambient Air Quality Standards (CAAQS) 24-hour Grade II standards. The results of the comparison of the classification of risk categories based on the three indices indicate that the current AQI approach underestimates the severity of health risk associated with exposure to multi-pollutant air pollution. For the AQI-based risk category of 'unhealthy', 96% and 80% of the days would be 'very unhealthy' or 'hazardous' if based on AAQI and HAQI, respectively; and for the AQI-based risk category of 'very unhealthy', 67% and 75% of the days would be 'hazardous' if based on AAQI and HAQI, respectively. The results suggest that the general public, especially sensitive population groups such as children and the elderly, should take more stringent actions than those currently suggested based on the AQI approach during high air pollution events. Sensitivity studies were conducted to examine the assumptions used in the AAQI and HAQI approaches. Results show that AAQI is sensitive to the choice of pollutant irrelevant constant. HAQI is sensitive to the choice of both threshold values and pollutants included in total risk calculation.

1. Introduction

China has been experiencing serious air pollution problems in recent decades due to the rapid industrialization and urbanization, and increasing energy consumption. Numerous studies have demonstrated associations between air pollution and various health effects (e.g., Brunekreef and Forsberg, 2005; Burnett et al., 2000; Dockery, 2001; Dominici et al., 2005; Le Tertre et al., 2002). Recognizing the severity of the air pollution situation and the dense population in China, Chinese scientists have recently started air pollution-health effects studies (e.g., Cao et al., 2012; Chen, 2007; Chen et al., 2013; Guo et al., 2013; Kan and Chen, 2002; Kan and Gu, 2011). The results of these studies confirmed that air pollution threatens public health in China. Therefore, it is important to inform the public about the levels of air pollution and associated health risks so that people can take measures to protect their health.

Air pollution levels are determined by the concentrations of a complex mixture of air pollutants. Currently SO_2, NO_2, CO, O_3, $PM_{2.5}$ and PM_{10} are defined as the six criteria pollutants around the world in quantifying air pollution levels. The concentrations among the pollutants can be different by orders of magnitude, and their unit-concentration health effects are significantly different as well. Therefore, it is difficult for the general public to use the concentrations directly to characterize the levels of air pollution. Alternatively, the use of an index ranging from good to unhealthy is more understandable

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for the general public, and becomes the most common way to interpret air pollution levels in many countries and regions (Shooter and Brimblecombe, 2005). Such indices were firstly developed in early 1970's (Babcock, 1970), and have been evolving since then. Currently, Air Quality Index (AQI) is the most used index worldwide.

The most commonly used index is the United States Environmental Protection Agency (US EPA) AQI. The AQI ranges from 0 to 500 and is calculated based on the concentrations of the six criteria pollutants. For a given location on a given day, a sub-AQI for every pollutant is calculated, and the maximum of all the sub-AQIs is defined as the overall AQI. It indicates "unhealthy" air quality when AQI is greater than 100. This method has been criticized because it does not appropriately represent the combined health effects of exposure to multiple pollutants. A few studies have been conducted to develop alternative approaches that take into account the combined health effects of various pollutants. Swamee and Tyagi (1999) proposed to combine the sub-AQIs to form an Aggregate AQI (AAQI). Kyrkilis et al. (2007) followed this idea and developed an AAQI for the area of Athens, Greece. The results indicate that the AAQI estimates the air pollution exposure more effectively than the US EPA AQI. Another novel alternative AQI approach is based on the health risk associated with exposure to multiple air pollutants (Cairncross et al., 2007; Sicard et al., 2012; Stieb et al., 2008; Wong et al., 2013). The health-risk based AQI (HAQI) considers the established exposure (or concentration)-response relationships. HAQI has shown improvement over the existing AQIs in various countries and regions. Currently, Canada is using the Air Quality Health Index approach that is based on the approach proposed by Stieb et al. (2008).

The Chinese Ministry of Environmental Protection (MEP) adopted the US EPA AQI approach and developed the Chinese AQI system in 2012 (MEP, 2012a). Wong et al. (2013) developed a HAQI for Hong Kong, but no studies have been conducted to investigate the differences between the AQI, AAQI, or HAQI approaches in designating air pollution severities in mainland China. In a recent study, the spatial and temporal distributions of six criteria pollutants in China were revealed (Wang et al., 2014), making it possible for the first time to investigate how effective different AQI approaches in characterizing the severity of multiple-pollutant air pollution in China. In this study, AAQI was defined based on the sub-AQI of individual pollutant and HAQI was developed using the exposure-response relationships from the health studies in China. Both HAQI and AAQI were compared with the MEP's AQI in different seasons and locations. Health implications of the three indices under different pollution situation were also investigated. Hypotheses in each approach were discussed and future research needs to establish an optimal index that can provide the general public with the accurate information for the purpose of health protection were highlighted.

2. Methods

2.1. Study areas and data source

Six representative cities (Beijing, Shanghai, Guangzhou, Shijiazhuang, Xi'an, and Wuhan) were selected for comparative analyses of AQI, AAQI, and HAQI in China. The locations of the six cities are shown in Fig. 1. Beijing, Shanghai, and Guangzhou are located in the North China Plain, the Yangtze River Delta, and the Pearl River Delta, respectively. These regions have become hot spots of air pollution studies in China due to dense population, more developed economy, and frequent pollution events. A recent study investigating the air pollution status in China during 2013–2014 revealed that Shijiazhuang, Wuhan, and Xi'an are the most heavily polluted provincial capital cities in the North, South-East, and West China, respectively (Wang et al., 2014). The six cities located

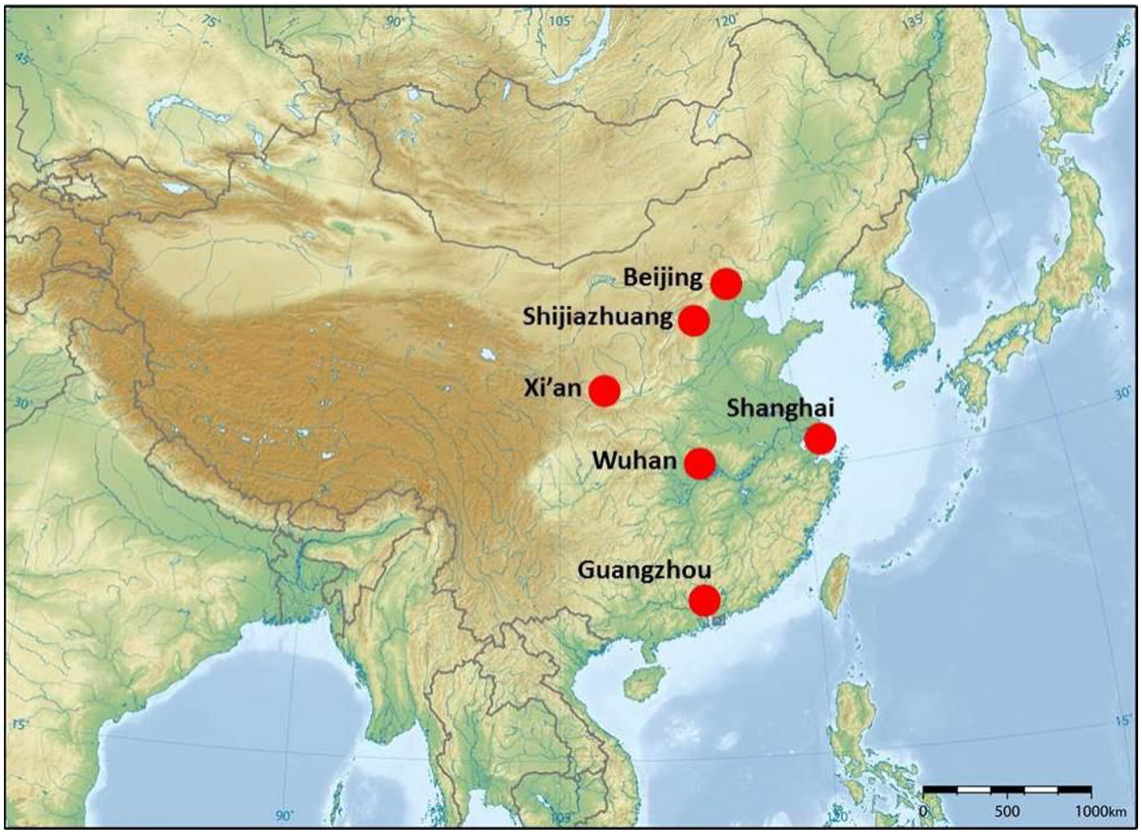

Fig. 1. Location of the six cities focused in the study. Beijing, Shanghai, and Guangzhou are the biggest and most developed cities located in the North China Plain, the Yangtze River Delta, and the Pearl River Delta, respectively. Shijiazhuang, Wuhan, and Xi'an are the most heavily polluted provincial capital cities in the North, South-East, and West China, respectively.