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Air pollution characteristics and health risks in Henan Province, China

Fuzhen Shen[a], Xinlei Ge[a,*], Jianlin Hu[a], Dongyang Nie[a], Li Tian[b], Mindong Chen[a]

[a] Jiangsu Key Laboratory of Atmospheric Environment Monitoring and Pollution Control (AEMPC), Collaborative Innovation Center of Atmospheric Environment and Equipment Technology (CIC-AEET), School of Environmental Science and Engineering, Nanjing University of Information Science & Technology, Nanjing 210044, China
[b] Henan Institute of Meteorological Sciences, Zhengzhou 450003, China

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ABSTRACT

Events of severe air pollution occurred frequently in China recently, thus understanding of the air pollution characteristics and its health risks is very important. In this work, we analyzed a two-year dataset (March 2014 – February 2016) including daily concentrations of six criteria pollutants ($PM_{2.5}$, PM_{10}, CO, SO_2, NO_2, and O_3) from 18 cities in Henan province. Results reveal the serious air pollution status in Henan province, especially the northern part, and Zhengzhou is the city with the worst air quality. Annual average $PM_{2.5}$ concentrations exceed the second grade of Chinese Ambient Air Quality Standard (75 μg/m^3) at both 2014 and 2015. $PM_{2.5}$ is typically the major pollutant, but ozone pollution can be significant during summer. Furthermore, as the commonly used air quality index (AQI) neglects the mutual health effects from multiple pollutants, we introduced the aggregate air quality index (AAQI) and health-risk based air quality index (HAQI) to evaluate the health risks. Results show that based on HAQI, the current AQI system likely significantly underestimate the health risks of air pollution, highlighting that the general public may need stricter health protection measures. The population-weighted two-year average HAQI data further demonstrates that all population in the studied cities in Henan province live with polluted air – 72% of the population is exposed to air that is unhealthy for sensitive people, while 28% of people is exposed to air that can be harmful to healthy people; and the health risks are much greater during winter than during other seasons. Future works should further improve the HAQI algorithm, and validate the links between the clinical/epidemiologic data and the HAQI values.

1. Introduction

A number of previous studies (e.g., Cao et al., 2012; Heal et al., 2012; Jin et al., 2017; Pope and Dockery, 2006; Pope and Dockery, 2013) have demonstrated clearly that the air pollutants could pose adverse effects on human health. Along with the rapid economic development and urbanization in China, air pollution has become particularly severe lately (Zhang and Cao, 2015), it is thus important to let the public know the air pollution status and its associated health risks. In 2012, the Chinese Ministry of Environmental Protection (CMEP) issued the Ambient Air Quality Index (AQI) Technical Provisions (Trial) (HJ 633–2012) on the basis of the United States Environmental Protection Agency (US EPA) AQI, and it was implemented in the Chinese Ambient Air Quality Standard (CAAQS) (GB 3095-2012). The AQI level is determined by the concentrations of six criteria pollutants including SO_2, NO_2, CO, O_3, $PM_{2.5}$ and PM_{10}. Basically the AQI acts as a guide for government to inform the public to take proper health protection measures. Thus studies on the spatiotemporal distributions of air pollutants and/or AQI is of central importance, and a number of prior works have investigated this issue and/or their relationships with meteorological conditions in various locations of China, for example Beijing (Guo et al., 2017; Yan et al., 2016), 31 provincial capital cities (Wang et al., 2014; Zhao et al., 2016), and many other areas (e.g., He et al., 2017; Hu et al., 2014; Wang et al., 2015; Xie et al., 2015; Zhang and Cao, 2015).

Nevertheless, the AQI system may have some issues in practice, because its calculation ignores the combined health effects of exposure to multiple air contaminants. Correspondingly, Kyrkilis et al. (2007) proposed an aggregate air quality index (AAQI) and demonstrated that it could estimate the exposure more effectively than the AQI; Wong et al. (2013) developed a risk-based air quality health index (HAQI), and showed its improvement over the existing AQI for Hong Kong. Since the atmospheric pollution in China is often characterized by high concentrations of multiple pollutants rather than a single pollutant, the current AQI system may be not accurate for health risk assessment. Indeed, Hu et al. (2015) compared the AQI, AAQI and HAQI for six megacities in China, and implied that AQI likely underestimated the health risks associated with exposure to multiple pollutants, especially

* Corresponding author.
E-mail address: caxinra@163.com (X. Ge).

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when heavy pollutions occurred, although it needs to be validated by using real clinical data and epidemiological studies. Furthermore, considering the temporal and spatial heterogeneity of air pollutants under different atmospheric environments, it is worthwhile and important to conduct the health risk assessment using these novel indices for other areas. In this regard, Henan Province in China was chosen as a representative. Henan is an inland province, and is one of the most populated provinces with over 120 million people, and it is also an important economically developing region in China. On the other hand, the status of air pollution in Henan is also very serious. Public data showed that during the first half of 2015, Zhengzhou, the capital city of Henan Province, ranked as the third worst city in air quality among 74 major cities nationwide. Therefore, it is valuable to analyze and characterize the spatial and temporal distribution of air pollutants, and evaluate their health risks by comparing the three air quality indices (AQI, AAQI and HAQI) for Henan Province.

2. Methods

2.1. Monitoring sites and data sources

The locations of Henan province and the 18 cities included in this study are illustrated in Fig. 1. The 18 cities include Anyang (AY, population of 5.79 million), Hebi (HB, 5.79 million), Jiyuan (JY, 0.69 million), Jiaozuo (JZ, 3.69 million), Kaifeng (KF, 5.14 million), Luoyang (LY, 6.69 million), Luohe (LH, 2.77 million), Nanyang (NY, 11.77 million), Pingdingshan (PDS, 5.41 million), Puyang (PY, 3.9 million), Sanmenxia (SMX, 2.28 million), Shanqiu (SQ, 9.05 million), Xinxiang (XX, 6.04 million), Xinyang (XY, 8.65 million), Xuchang (XC, 4.87 million), Zhengzhou (ZZ, 7.6 million), Zhoukou (ZK, 11.36 million), and Zhumadian (ZMD, 9.01 million), covering all urban areas of the province. Total population of the 18 cities occupies ~90% population of Henan province. Monitoring data of the six criteria pollutants – daily $PM_{2.5}$, PM_{10} SO_2, NO_2, CO, and 8 h-averaged O_3 concentrations, for each city were obtained from the National Environmental Monitoring (NEM) sites established in that city. The data used for each city was the average of all NEM sites in that city, and the data ranged from March 1, 2014 to February 29, 2016. The population data of the 18 cities used for exposure assessment were referred to the 2015 Statistical Yearbook of Henan province (http://www.ha.stats.gov.cn/hntj/lib/tjnj/2015/indexce.htm).

2.2. Calculation of air quality indices

2.2.1. Air quality index (AQI)

Calculation of the AQI can refer to the Ambient Air Quality Index (AQI) technical Provisions (Trial) issued by CMEP. The AQI for each pollutant (AQI_i) is first calculated by using Eq. (1), and the maximum AQI_i of all pollutants is chosen as the overall AQI according to Eq. (2).

$$\boldsymbol{AQI_i = \frac{AQI_{i,j} - AQI_{i,j-1}}{(m_{i,j} - m_{i,j-1})} \times (m_i - m_{i,j-1}) + AQI_{i,j-1}, \quad j > 1,}$$

$$\boldsymbol{AQI_i = AQI_{i,1}\frac{m_i}{m_{i,1}}, \quad j = 1} \tag{1}$$

$$\boldsymbol{AQI = max\,(AQI_1, AQI_2 \ldots, AQI_n), \quad n = 1, \quad 2, \quad \ldots, \quad 6,} \tag{2}$$

where i represents the pollutant i; m_i is the measured concentration of i; j is the health category index; $m_{i,j}$ is the reference concentration for pollution i corresponding to the jth health category. The reference concentrations for the pollutants in different health categories are provided by CMEP, and are presented in Table S1 of the Supporting information. Within this system, the air quality is classified into six classes according to the ranges of AQI values (< 50: excellent, satisfactory; 51–100: good, acceptable; 101–150: light pollution, unhealthy for sensitive people; 151–200: moderate pollution, unhealthy; 201–300: serious pollution, very unhealthy - healthy people commonly have symptoms; > 300: very severe pollution, hazardous - healthy people have significant symptoms, and should avoid outdoor activities).

2.2.2. Aggregate AQI (AAQI)

The AAQI considers influences of all six pollutants, which can be calculated simply by using the following Eq. (3) (Kyrkilis et al., 2007; Swamee and Tyagi, 1999):

$$AAQI = \left(\sum_{i=1}^{n} (AQI_i)^{\rho}\right)^{\frac{1}{\rho}} \tag{3}$$

where ρ is an empirical constant, however the optimal ρ value is still an open question, and some previous studies (Khanna, 2000; Swamee and Tyagi, 1999) suggested a range between 2 and 3 for ρ. Hu et al. (2015) tested the mean and standard deviations of AAQI/AQI ratios using four different ρ values (i.e., 1.5, 2.0, 2.5, 3.0), and found the ratios were not very sensitive to the variations of ρ, and they used 2.0 for ρ. This value was also chosen in this study.

2.2.3. Health-risk based AQI (HAQI)

To better reflect the health risks of air pollution, the AQI should

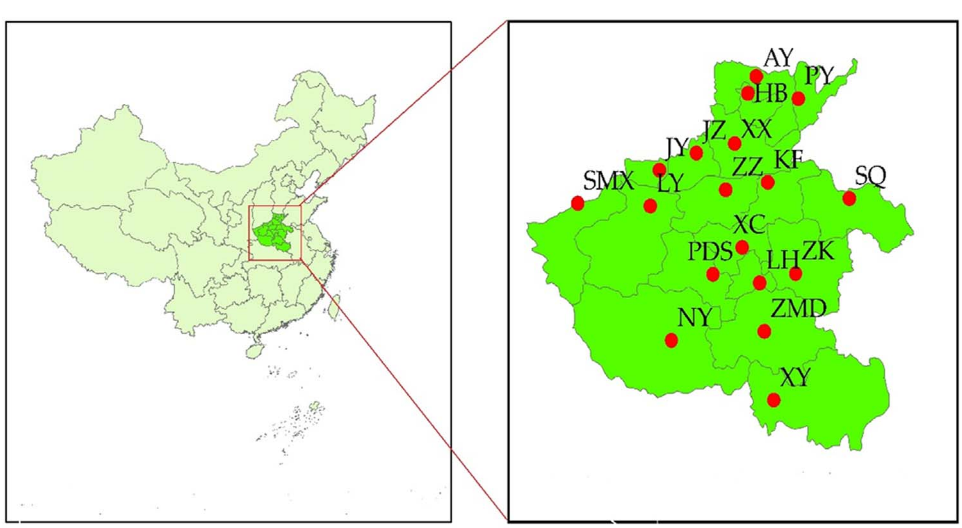

Fig. 1. Locations of Henan Province and the 18 cities included in this study.