Environment International 73 (2014) 413–422

Contents lists available at ScienceDirect

Environment International

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

Spatial and temporal variations of six criteria air pollutants in 31 provincial capital cities in China during 2013–2014

Yungang Wang [a], Qi Ying [b], Jianlin Hu [c,*], Hongliang Zhang [d,*]

[a] Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, Berkeley, CA 9472 0, USA
[b] Department of Civil Engineering, Texas A&M University, College Station, TX 77843, USA
[c] Department of Civil and Environmental Engineering, University of California, Davis, Davis, CA 95616, USA
[d] Department of Civil and Environmental Engineering, Louisiana State University, Baton Rouge, LA 70803, USA

ARTICLE INFO

Article history:
Received 30 June 2014
Accepted 29 August 2014
Available online 20 September 2014

Keywords:
Spatial variation
Temporal variation
Criteria pollutants
$PM_{2.5}$
Provincial capital cities
China

ABSTRACT

Long-term air pollution data with high temporal and spatial resolutions are needed to support the research of physical and chemical processes that affect the air quality, and the corresponding health risks. However, such datasets were not available in China until recently. For the first time, this study examines the spatial and temporal variations of $PM_{2.5}$, PM_{10}, CO, SO_2, NO_2, and 8 h O_3 in 31 capital cities in China between March 2013 and February 2014 using hourly data released by the Ministry of Environmental Protection (MEP) of China. The annual mean concentrations of $PM_{2.5}$ and PM_{10} exceeded the Chinese Ambient Air Quality Standards (CAAQS), Grade I standards (15 and 40 μg/m^3 for $PM_{2.5}$ and PM_{10}, respectively) for all cities, and only Haikou, Fuzhou and Lasa met the CAAQS Grade II standards (35 and 70 μg/m^3 for $PM_{2.5}$ and PM_{10}, respectively). Observed $PM_{2.5}$, PM_{10}, CO and SO_2 concentrations were higher in cities located in the North region than those in the West and the South-East regions. The number of non-attainment days was highest in the winter, but high pollution days were also frequently observed in the South-East region during the fall and in the West region during the spring. $PM_{2.5}$ was the largest contributor to the air pollution in China based on the number of non-attainment days, followed by PM_{10}, and O_3. Strong correlation was found between different pollutants except for O_3. These results suggest great impacts of coal combustion and biomass burning in the winter, long range transport of windblown dust in the spring, and secondary aerosol formation throughout the year. Current air pollution in China is caused by multiple pollutants, with great variations among different regions and different seasons. Future studies should focus on improving the understanding of the associations between air quality and meteorological conditions, variations of emissions in different regions, and transport and transformation of pollutants in both intra- and inter-regional contexts.

1. Introduction

Air pollution in China receives increasing attention by the general public as well as scientific researchers and policy makers due to frequent occurrences of severe regional and inter-regional air pollution events. Air pollution data with high spatial and temporal resolutions are needed to accurately evaluate the health risks associated with air pollutant exposure. However, open-access air pollution data published by the Ministry of Environmental Protection (MEP) of China and local environmental protection bureaus were historically scarce. Also these data are only limited to a generalized daily Air Pollution Index (API) based on the highest of the three criteria pollutants including sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and inhalable particles (PM_{10}, particulate matter with aerodynamic diameter less than 10 μm). Although concentrations of other air pollutants have been reported in scientific literature for a few urban regions such as the Pearl River Delta (PRD) (Louie et al., 2005), the Beijing metropolitan area (Zhang et al., 2012b) and some other major cities (Han et al., 2010; Peng et al., 2013; Wang et al., 2014a; Wang et al., 2014b), it is difficult to extrapolate these data to other regions due to complex terrain, meteorological conditions and emission distributions (Li et al., 2014). Even for the highly instrumented regions such as PRD, continuous data with high temporal resolution were generally unavailable (Ying et al., 2014; Zhang et al., 2012a). These data are useful for exposure assessments and investigation of pollution formation/transport mechanisms using statistical methods or air quality models. It is also difficult to scientifically assess and for the public to perceive the effectiveness of proposed air pollution measures without detailed records of the spatial and temporal variations of air pollutant concentrations.

A number of previous studies on temporal and spatial variations of concentrations of air pollutants in China have been reported, but detailed observational data were scarce. Some of them are limited within one single city. For example, Zhao et al. (2014) used fine particles

* Corresponding authors.
E-mail addresses: jjlhu@ucdavis.edu (J. Hu), hlzhang@lsu.edu (H. Zhang).

http://dx.doi.org/10.1016/j.envint.2014.08.016
0160-4120/

($PM_{2.5}$, particulate matter with aerodynamic diameter less than 2.5 μm) and PM_{10} data collected at 30 sites in Beijing during the winter and the spring of 2012 and 2013 and applied the ordinary Kriging interpolation to show that PM concentrations were lower in the north near the mountain areas and higher in the south in urban areas. West part of the urban area experienced higher concentrations than the east part of the city. Peak PM concentrations occurred in January. PM concentrations in Beijing are negatively correlated with wind speed and positively correlated with relative humidity. Analyses with larger spatial coverage have also been reported. For example, Qu et al. (2010) studied spatial and temporal distribution of PM_{10} reconstructed from reported API records from 2000 to 2006 in 83 cities. It was found that PM_{10} concentrations were highest in cities in northern China and lowest in southern China. A decreasing trend was observed for northern cities but no significant changes were detected for cities in other regions. Consistent with other studies, PM_{10} concentrations peaked in the winter and were the lowest in the summer.

Studies on spatial and temporal distribution of multiple criteria pollutants have also been reported. Chai et al. (2014) reported a study on the spatial and temporal variations of the 6 criteria pollutants in 26 cities in China using data collected between August 2011 and February 2012. 16 cities had data for all six criteria pollutants while the remaining 10 cities only had data for SO_2, NO_2 and PM_{10}. All pollutants except ozone (O_3) showed higher concentrations during winter months and lower concentrations in the summer. Carbon monoxide (CO) and SO_2, as well as $PM_{2.5}$ and PM_{10}, were much higher in northern cities, but O_3 and NO_2 did not show significant differences between northern and southern cities. Ji et al. (2012) conducted a more detailed analysis of two severe regional PM events in northern China during October and November 2009 using PM_{10}, SO_2 and NO_x data collected at 24 sites and $PM_{2.5}$ data collected at 5 sites. It was found that high PM_{10} events were regional instead of being isolated within large cities. The $PM_{2.5}$/PM_{10} ratio increased during high PM events. Analyses of synoptic weather patterns and back trajectories showed that light wind, elevated temperature in surface inversion and low mixing height caused by low pressure systems were responsible for the weak dilution of primary pollutants and enhanced secondary PM formation. Although these studies provide valuable insights, none of them covers a full-year $PM_{2.5}$ data and few of them include cities in less economically developed areas such as the northwest and southwest of China.

The objective of this study is to examine the temporal and spatial variations of $PM_{2.5}$, PM_{10}, CO, SO_2, NO_2, and 8 h O_3 in China based on the one-year (March 2013 to February 2014) officially released data for 31 provincial capital cities. The air quality attainment conditions of these cities are studied and the leading factor for days that exceed the ambient air quality standards is determined. Inter-correlation of different pollutants is studied to provide a more comprehensive understanding of the current status of air pollution in China.

2. Methods

To evaluate the overall air quality status in China, we analyzed one-year long ambient monitoring data of $PM_{2.5}$, PM_{10}, CO, SO_2, NO_2, and 8 h O_3 in the 31 provincial capital cities in China (except Taipei, Hong Kong, and Macau). To contrast the regional difference of air quality, the 31 cities were further categorized into three general regions, i.e., North, South-East, and West. The cities are listed in Table 1 and their locations are shown in Figure S1. The 31 capital cities have a total population of 231 million in 2013, accounting for 17% of the total population in China.

The real-time hourly concentrations of SO_2, NO_2, $PM_{2.5}$, PM_{10}, CO, and O_3 in the 31 capital cities were downloaded from the publishing website of China National Environmental Monitoring Center (http://113.108.142.147:20035/emcpublish/). In January 2013, MEP started to publish hourly air quality data of the six criteria pollutants at individual monitoring site for 74 major cities through the website. This database is essential for providing a more detailed picture of the extent of the current air pollution situations in China. 8 h O_3 concentrations in this analysis were calculated based on hourly O_3 concentrations. One-year data from March 1st, 2013 to February 28th, 2014 were included in this study. All the measurements were conducted at the national air quality monitoring sites located in each city. Multiple air quality monitoring (AQM) sites (4–17) were set up in each city as shown in Table 1. The monitoring sites have been designed as a mix of urban and background sites, with most of the sites in urban area, and a few in suburban and rural areas as background sites.

Table 1
Regional category, population, available AQM sites and number of non-attainment days of the 31 provincial capital cities.
Source: http://data.stats.gov.cn/workspace/index?m=csnd.

	Region category	Population (million)	# of AQM sites	# of non-attainment days[a] Mar 1, 2013–Feb 28, 2014
Shijiazhuang (SZ)	North	10.05	8	261/303
Jinan (JN)	North	6.09	8	239/312
Tianjin (TJ)	North	9.93	15	199/341
Beijing (BJ)	North	12.97	13	182/345
Zhengzhou (ZZ)	North	10.73	9	171/299
Taiyuan (TY)	North	3.66	9	136/307
Huhehaote (HT)	North	2.3	8	132/312
Shenyang (SY)	North	7.25	12	106/307
Changchun (CC)	North	7.57	10	98/330
Haerbin (HB)	North	9.94	12	97/321
Wuhan (WH)	South-East	8.22	10	193/306
Hefei (HF)	South-East	7.11	10	149/320
Changsha (CS)	South-East	6.61	10	144/331
Nanjing (NJ)	South-East	6.38	9	126/304
Nanchang (NC)	South-East	5.08	9	105/305
Shanghai (SH)	South-East	14.27	11	100/342
Hangzhou (HZ)	South-East	7.01	11	99/321
Nanning (NN)	South-East	7.14	8	94/307
Guangzhou (GZ)	South-East	8.22	12	89/329
Haikou (HK)	South-East	1.62	5	21/311
Fuzhou (FZ)	South-East	6.55	6	16/320
Xi'an (XA)	West	7.96	13	185/315
Chengdu (CD)	West	11.73	9	184/332
Chongqing (CQ)	West	33.42	17	140/339
Lanzhou (LZ)	West	3.22	5	140/300
Wulumuqi (WQ)	West	2.58	7	123/307
Xining (XN)	West	1.98	4	112/295
Guiyang (GY)	West	3.75	10	64/332
Yinchuan (YC)	West	1.67	6	61/301
Lasa (LS)	West	0.5	6	17/304
Kunming (KM)	West	5.43	7	14/319

[a] The first numbers in the last column represent the total number of non-attainment days (>Grade II standards), and the second numbers represent the total number of days with valid data.

At each site, automated monitoring systems were installed and used to measure the ambient concentration of SO_2, NO_2, O_3 and CO. According to China Environmental Protection Standards HJ 193-2013 (http://www.es.org.cn/download/2013/7-12/2627-1.pdf), and HJ 655-2013 (http://www.es.org.cn/download/2013/7-12/2626-1.pdf), the $PM_{2.5}$ and PM_{10} continuous monitoring system consists of the sample collection unit, the sample measurement unit, the data collection and transport unit, and other accessory equipment. The micro oscillating balance method and the β absorption method are both used to measure $PM_{2.5}$ and PM_{10}. The continuous monitoring systems for NO_2, SO_2, O_3 and CO consist of the sampling unit, the calibration device, the analytical instrument, and the data collection and transport unit. NO_2, SO_2 and O_3 are measured using the chemiluminescence method, the ultraviolet fluorescence method, and the UV-spectrophotometry method, respectively. CO is measured using the non-dispersive infrared absorption method and the gas filter correlation infrared absorption method.

The values from the monitoring sites at each city are automatically reported to the China National Environmental Monitoring Center and published after being validated through Technical Guideline on Environmental Monitoring Quality Management HJ 630-2011 (http://kjs.mep.gov.cn/hjbhbz/bzwb/other/qt/201109/