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Urbanization strategy and environmental changes: An insight with relationship between population change and fine particulate pollution

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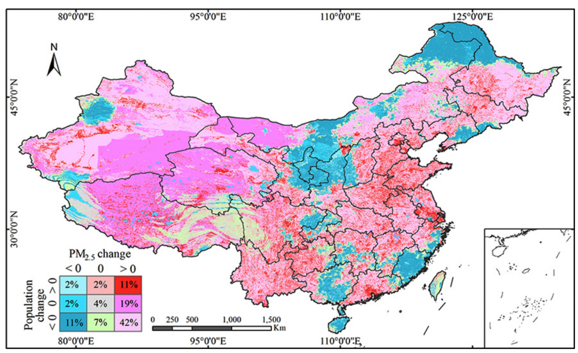
HIGHLIGHTS

- Urban population density increase/decrease with $PM_{2.5}$ concentration increase.
- Rural population decrease but $PM_{2.5}$ concentration increase.
- Population and $PM_{2.5}$ concentration increased rapidly in China's major cities.
- 723 million people was exposed to $PM_{2.5}$ pollution in 2014.
- 105 million people were added in the $PM_{2.5}$ pollution exposure since 2000.

GRAPHICAL ABSTRACT



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ABSTRACT

Fine particulate ($PM_{2.5}$) pollution, along with the rapid urbanization process, has been given much attention in China during the recent decades. However, the relationships between urban population dynamics and $PM_{2.5}$ changes have not been well examined. We therefore analyzed their relationship using full-coverage remotely sensed $PM_{2.5}$ and population density data. The results showed that 1) both population density and $PM_{2.5}$ concentration increased rapidly from 2000 to 2014, especially in East and Central China, as well as China's high population density urban areas and the major cities; 2) A total of 723 million people was exposed to $PM_{2.5}$ pollution in 2014, an increase of 105 million from 2000; 3) most of the urban areas exhibited population density increase/decrease with $PM_{2.5}$ concentration increase, while a total of 42% of China's territory, mainly in East and Central China's rural areas were found to have population decrease but $PM_{2.5}$ concentration increase. We hope the results in this work can serve as an example to other countries in designing their urbanization strategy by paying more attention to environmental degeneration accompanying rapid development.
Capsule abstract: Most of urban areas were observed to have population density increase/decrease along with $PM_{2.5}$ concentration increase.

1. Introduction

Population-environment systems (PES) have long been of concern to researchers from varied fields aiming to provide ways for sustainable development (de Sherbinn et al., 2007). Population size and growth are the most important indicators in PES. By adding in certain conditions, the population size and growth can be transformed to population

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dynamics, which contain more information beyond the population size and growth. These conditions can be fertility, mortality and migration. As a special type of migration, urbanization introduces varying magnitudes of population migration, especially in rapidly developing low- and mid-income countries (e.g. China and countries in Africa). Urbanization in low- and mid-income countries is generally associated with rapid economic development that not only has improved the material wealth and living standards, but also caused a number of environmental problems, e.g. soil, water, and air pollution, due to the increase in human activities in high-density populated areas (Han et al., 2015a). Exploring the nuances of urbanization in terms of population migration along with environmental change would benefit not only the research community but also could provide information to policy-makers on sustainable ways to simultaneously benefit urban development and environmental protection.

Rapid developing low- and mid-income countries provide a good example for understanding the interaction between rapid urbanization and environmental dynamics. In the past century, most of the high-income countries have finished their rapid urbanization and successfully recovered their environment. Their urban environments have been improving, although some cities are still growing faster. However, most of the mid- and low-income countries only started their urbanization in the last several decades of the twentieth century (Cohen, 2004; Bai et al., 2014). Among those mid- and low-income counties, China is a typical example, with a variety of urbanization speeds and complex impacts on the environment (Zhu and Jones, 2010; Skeldon, 1999). In East China, particularly the eastern and southeastern coast of China, urbanization started in the very beginning of the "Reform and opening-up" policy at the end of the 1970s, then, accelerated after 2000. Such rapid urbanization in East China has changed people's lives, meanwhile creating negative environmental impacts, e.g. heavy urban and regional air pollution. However, moderate and low urbanization could be observed in central and west China, with various consequences for the environment (Liu and Xu, 2014).

In recent decades, along with rapid urbanization, urban and regional air pollution, with fine particulate matter ($PM_{2.5}$) as the major pollutant, has skyrocketed and attracted increasing attention from both authorities and the public (Han et al., 2014; Peng et al., 2016). $PM_{2.5}$ pollution is not like the conventional pollutants sulfur dioxide (SO_2) and nitrogen dioxide (NO_2), which exist in the open atmosphere for only a short period (Zhang et al., 2015). $PM_{2.5}$ can stay in the urban and regional near-surface atmosphere for several days during stable meteorological conditions (Lin et al., 2015; Han et al., 2015b). It can affect the heart and lungs and cause serious health effects, and change the urban micro-meteorological and thermal environment through the reduction of solar radiation. Many studies have employed $PM_{2.5}$ records derived from remote sensing, ground measurements, and computer modeling in the fields of health risk estimation, pollutant spatio-temporal pattern illustration, public exposure estimation, and analysis of socio-economic driving forces. As the increasing $PM_{2.5}$ pollution was associated with rapid urbanization, which could introduce intensive human activities that emit massive amounts of pollutants, the relationship between $PM_{2.5}$ and urbanization has also attracted increasing concern (Han et al., 2014; Han et al., 2015a; Han et al., 2016; Li et al., 2016; Larkin et al., 2016).

The previous studies on urbanization and $PM_{2.5}$ pollution have mainly focused on examination of $PM_{2.5}$ patterns in urban and nearby areas, driving-force examination, and the contribution of urbanization-derived population migration to the total population exposure to $PM_{2.5}$ pollution. However, those studies lacked consideration of the changes in both urban population and $PM_{2.5}$, and using this information to guide urbanization strategy and its accompanying environmental changes. Thus, the objectives of this research were to combine the changes of urban and rural population against the background of China's rapid urbanization along with the spatial-temporal dynamics of $PM_{2.5}$ concentrations, and based on which to promote/improve the understanding between urbanization variation and air quality dynamic. We hope the results of this research can provide an example to other countries with rapid urban growth, or on the way to the growth, to enable better design of their urbanization strategy, to balance economic growth with environmental protection.

2. Materials and methodology

2.1. Social economic records, population density records and related urban classification standards

Energy structure indicators including consumption of raw coal, crude oil, natural gas and others from 1997 to 2012, dust and smoke emission from living and industrial sources from 1999 to 2010, and vehicle amount and its private portion in Beijing, Tianjin and the whole China from 1997 to 2012 were obtain from the online data source center of National Bureau of Statistics of the People's Republic of China, available at http://www.stats.gov.cn/tjsj/.

The ORNL LandScan™ population distribution product was used in this research. This product was made utilizing the LandScan (2000 and 2014)™ High Resolution global Population Data Set copyrighted by UT-Battelle, LLC, operator of Oak Ridge National Laboratory under Contract No. DE-AC05-00OR22725 with the United States Department of Energy. The product has an approximately 1 km resolution at global scale. We used a subset of the product that covered China in 2000 and 2014 in this research.

The urban population density classifications were set based on the spatio-temporal change of population density in China as: <1000 persons/km^2 indicates rural areas, 1000–2000 persons/km^2 indicates low-density populated urban areas (MW), 2000–4000 person/km^2 indicates medium-density populated urban areas (MG), and >4000 persons/km^2 indicates high-density populated urban areas (LG) (Mao et al., 2015).

2.2. $PM_{2.5}$ concentration dataset and air quality guidelines

The $PM_{2.5}$ concentration dataset was obtained from the atmospheric composition analysis group at Dalhousie University (Available at http://fizz.phys.dal.ca/~atmos/martin/). The dataset was compiled using a combined geophysical-statistical method with information from satellites, models and monitors, providing a 0.01° × 0.01° grid at global scale for each year from 1998 to 2014 (van Donkelaar et al., 2016). The result improved the accuracy of directly derived satellite $PM_{2.5}$ concentrations and enhanced the spatial resolution to approximately 1 km, so that it can be directly combined with the LandScan population density data. In this research, we used a subset of the dataset that covered China in 2000 and 2014.

The World Health Organization's (WHO) annual air quality standard was used in this research (WHO, 2006). The standard has four levels: the air quality guideline (AQG; 10 μg/m^3), and three interim targets (IT-1: 35 μg/m^3; IT-2: 25 μg/m^3; IT-3: 15 μg/m^3). We further set two times IT-1, 70 μg/m^3, for the concentrations beyond 35 μg/m^3, since there was no additional level for high $PM_{2.5}$ concentrations.

2.3. Analysis and statistical units: pixel, prefecture and province boundary, and China's regionalization system

Pixel-based analysis was carried out in this research, as both population density and $PM_{2.5}$ concentration datasets have an approximate 1 km spatial resolution. The Chinese prefecture, with boundaries obtained from National Geomatics Center of China (http://ngcc.sbsm.gov.cn/), was set as the basic statistical unit to better indicate the regional urbanization strategy and its relationship with air quality changes. Further province and regional analyses were carried out with the support of province boundaries from the National Geomatics Center of China (http://ngcc.sbsm.gov.cn/). China's regionalization system was also used, with East China, which is the most developed area that covers