Atmospheric Environment 182 (2018) 171–178

Contents lists available at ScienceDirect

Atmospheric Environment

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

Global distribution and evolvement of urbanization and $PM_{2.5}$ (1998–2015)

Dongyang Yang[a,b], Chao Ye[a,*], Xiaomin Wang[c], Debin Lu[a,b,d], Jianhua Xu[a,b,**], Haiqing Yang[a,b]

[a] School of Geographic Sciences & Institute of Eco-Chongming, East China Normal University, Shanghai 200241, China
[b] Research Center for East-West Cooperation in China, East China Normal University, Shanghai 200241, China
[c] School of Geography, Beijing Normal University, Beijing 100875, China
[d] Department of Tourism and Geography, Tongren University, Tongren, Guizhou Province 554300, China

ARTICLE INFO

Keywords:
$PM_{2.5}$
Urbanization
Bivariate spatial association
Environmental Kuznets Curve

ABSTRACT

$PM_{2.5}$ concentrations increased and have been one of the major social issues along with rapid urbanization in many regions of the world in recent decades. The development of urbanization differed among regions, $PM_{2.5}$ pollution also presented discrepant distribution across the world. Thus, this paper aimed to grasp the profile of global distribution of urbanization and $PM_{2.5}$ and their evolutionary relationships. Based on global data for the proportion of the urban population and $PM_{2.5}$ concentrations in 1998–2015, this paper investigated the spatial distribution, temporal variation, and evolutionary relationships of global urbanization and $PM_{2.5}$. The results showed $PM_{2.5}$ presented an increasing trend along with urbanization during the study period, but there was a variety of evolutionary relationships in different countries and regions. Most countries in East Asia, Southeast Asia, South Asia, and some African countries developed with the rapid increase in both urbanization and $PM_{2.5}$. Under the impact of other socioeconomic factors, such as industry and economic growth, the development of urbanization increased $PM_{2.5}$ concentrations in most Asian countries and some African countries, but decreased $PM_{2.5}$ concentrations in most European and American countries. The findings of this study revealed the spatial distributions of global urbanization and $PM_{2.5}$ pollution and provided an interpretation on the evolution of urbanization-$PM_{2.5}$ relationships, which can contribute to urbanization policies making aimed at successful $PM_{2.5}$ pollution control and abatement.

1. Introduction

Many regions of the world have seen a rapidly increased urbanization in the last few decades, simultaneously, $PM_{2.5}$ pollution with its negative health impacts on humans have been one of the major social problems globally (Butt et al., 2017; World Health Organization, 2014). Urbanization transformed the natural and social-economic factors within the rural-urban territorial system and affected local $PM_{2.5}$ pollution, and even the development of megacities and urban agglomerations could produce implications on the distribution of global $PM_{2.5}$ concentration (Gurjar et al., 2016; Seto et al., 2017). The development level and speed of urbanization showed obvious disparities between different countries or regions, along with which was the regional disparities of $PM_{2.5}$ concentration. $PM_{2.5}$ pollution has been an unprepared challenge that many countries faced, while urbanization is projected to continue to present an accelerated growth in the near future (Alhowaish, 2015; World City Report, 2016). Hence, it is urgent to grasp the relationship between urbanization and $PM_{2.5}$ pollution from a global perspective, which can contribute to urbanization policies making to control and reduce air pollution and achieve the global urban sustainability goals.

Although urbanization theoretically has the potential to transform living conditions, including services, income, and health, toward better, it also concentrated and increased pollution sources. $PM_{2.5}$ pollution is therefore one of the environmental changes caused by the transitions of urban components, including industry, motor vehicles, building yard et al., during the process of urbanization (Timmermans et al., 2017). The absolute numbers of urban dwellers increased 77 million per year between 2010 and 2015, and in 2015, the proportion of the world's urban population has reached to 54 percent (4 billion) according to World Cities Report in 2016 (World City Report, 2016). While, less than 20% of people living in urban areas that the $PM_{2.5}$ concentrations met the WHO Air Quality Guideline (AQG) level (10 $\mu g/m^3$), and approximately half of the population in monitored cities were exposed to air pollution that was at least 2.5 times higher than the WHO recommended level (World Health Organization, 2016). Inevitably, serious and long-term additional health risks come with the air pollution.

Researchers from multiple disciplines have conducted numerous

* Corresponding author. School of Geographic Sciences & Institute of Eco-Chongming, East China Normal University, Shanghai 200241, China.
** Corresponding author. Research Center for East-West Cooperation in China, East China Normal University, Shanghai 200241, China.
E-mail addresses: yeover@163.com (C. Ye), Jhxu@geo.ecnu.edu.cn (J. Xu).

https://doi.org/10.1016/j.atmosenv.2018.03.053
Received 5 January 2018; Received in revised form 7 March 2018; Accepted 23 March 2018
Available online 24 March 2018

studies on both the issues of $PM_{2.5}$ and the issues of urbanization. Firstly, the development of air monitoring sites and atmospheric remote sensing has had a great progress in recent years, which provided substantial data sources for researches on $PM_{2.5}$ pollution. Relevant studies mainly involved several aspects, including the spatial and spatio-temporal distribution, the source apportionment, and the influencing factors of $PM_{2.5}$ (Gummeneni et al., 2011; Hao and Liu, 2016; Heimann et al., 2015; Lu et al., 2017; Yang et al., 2017). Prior studies contributed to understanding the spatiotemporal variations, chemical compositions, and driving mechanism of $PM_{2.5}$ pollution. Secondly, urbanization was one of the hot topics for many disciplines, such as geography, economics, demography, etc., which absorbed long-term concern from governments and scholars. The basic aspects of urbanization, including increasing population, transformational industrial structure, and expanded urban space, has been widely discussed (Wei and Ye, 2014; Ye et al., 2017). Besides, dramatic transitions of these socio-economic elements within urbanization posed environmental disruption and pollution in many cities all over the world (Bekhet and Othman, 2017; Cao et al., 2014; Hu et al., 2013; Wei and Ye, 2014). Urban development, accompanied by the exacerbated environmental problems, triggered a number of studies on the relationship between urbanization and environment (Cui et al., 2015; Zhao et al., 2016). However, existing researches approved that the relationship between $PM_{2.5}$ pollution and urbanization get less attention except a few researches which have examined the relationship between $PM_{2.5}$ pollution and urbanization in some cities over the last few decades (Cavalcante et al., 2017; Han et al., 2016; Tuo et al., 2013). Especially, few studies were conducted to research the relationship between $PM_{2.5}$ pollution and urbanization from a global perspective.

Therefore, this study examined the spatiotemporal variation of urbanization and $PM_{2.5}$ pollution and their evolution relationship using global data on urbanization and $PM_{2.5}$ concentrations from 1998 to 2015. The findings in this study would be useful to identify the relationship between urbanization and $PM_{2.5}$ globally, assist in the urbanization policy-making to improve air quality and the realization of development goals of urban sustainability.

2. Context and literature review

As one of major environmental and social issues, $PM_{2.5}$ pollution was seen increasing concern from multidisciplinary researchers. Researches on source apportionment of $PM_{2.5}$ have proved that coal and biomass combustion, transport, and industry were the general sources (Chowdhury et al., 2007; Huang et al., 2014; Marcazzan et al., 2003; Timmermans et al., 2017; Wang et al., 2015). And researches have also documented that social-economic factors, including economic growth, industrial production, thermal power generation, building construction et al., drove increases in $PM_{2.5}$ concentrations in many cities in the world (de Miranda et al., 2012; Guan et al., 2014; Hao and Liu, 2016; Li et al., 2016; Rao et al., 2017). Urban was the concentrated space of these social-economic factors and characterized by these factors, urbanization which transformed the socio-economic factors, would inevitably affect $PM_{2.5}$ pollution. While, urbanization presented different modes, levels, and speeds in different countries and regions, and not all the urbanization deteriorated $PM_{2.5}$ pollution. The power from environmental regulation, technical improvement, and capital could promote the improvement of air pollution (Liu et al., 2015; Rao et al., 2017; Walsh, 2014; Wang et al., 2010; Wang and Hao, 2012).

Hence, $PM_{2.5}$ pollution should be related to the level and development speed of urbanization, as they were respectively the reflection of the development state of urban components and their transforming speed. In this aspect, Northman first proposed an S-curve to depict the general process of urbanization and urban development mode in mid-1970s (Northam, 1975), which provided a theoretical basis for understanding the transitions on population, industry, and development speed within the urbanization process (Antrop, 2000; Chen et al., 2014; Pannell, 2002). Northman's S-curve interpreted the process of urbanization as a triple transitional process of initial stage (urbanization rate < 30%), acceleration stage (30% < urbanization rate < 70%), and terminal stage (urbanization rate > 70%). In the initial stage of urbanization, the industrial productivity was low, industry could just provide limited employment opportunity and transferred the surplus labor force slowly. Urbanization rate could reach 30 percent after several decades, even a hundred years of development. In the accelerating stage, urbanization rate rose from 30% to 70%, the industrial productivity enhanced and transferred a large rural population into urban population. Urbanization rate could pass 50% in a short time, and then went up to 70%. In the third stage, the increase in the urban population tends to be slow and even stagnant, industry transferred to tertiary industry.

It was worth noting that the Environmental Kuznets Curve (EKC) hypothesis, early verified by Panayotou (1993), Selden and Song (1994), Grossman and Krueger (1995), and others, contributed to understanding the relationship between economic growth and environmental pollution. EKC described that environmental pollution would experience a process of pollution increase, reaching a "turning point", and pollution reduction along with the economic growth. Given that urbanization was partly a comprehensive representation of economic development, EKC has also been widely used to examine the relationship between urbanization and the issues of environmental pollution and emissions in recent decades (Bekhet and Othman, 2017; He et al., 2017; Li et al., 2012; Zhao et al., 2016).

Northman's S-curve is a generalization of urbanization process. Given the diversity of urbanization across the world and the potentially drastic changes in the accelerating stage of urbanization, we redivided the urbanization process into four sub-processes: initial stage (urbanization rate < 30%), transition stage (30% < urbanization rate < 50%), climbing stage (50% < urbanization rate < 65%), and terminal stage (urbanization rate > 65%) according to the S-curve. This paper would examine the spatiotemporal profiles of $PM_{2.5}$ in these different urbanization stages, and inspect the evolution of urbanization-$PM_{2.5}$ relationships according to the EKC.

3. Data and methods

3.1. Data

$PM_{2.5}$ data is a published global $PM_{2.5}$ concentration dataset obtained from Atmospheric Composition Analysis Group at Dalhousie University (http://fizz.phys.dal.ca/~atmos/martin/?page_id=140). This dataset provides global $PM_{2.5}$ concentrations from 1998 to 2015 with a geographical range of from 54.995°S to 69.995°N and from 179.995°W to 179.995°E. The spatial resolution is 0.1° * 0.1°. It is the ground-level $PM_{2.5}$ estimated by combining Aerosol Optical Depth (AOD) with the GEOS-Chem chemical transport model and subsequently calibrated by using the geographically weighted regression method based on monitoring data of $PM_{2.5}$ (Boys et al., 2014; Van Donkelaar et al., 2016). This dataset has good accuracy ($R^2 = 0.81$) with the largest coverage and longest time span and has been used in many researches at national or regional scale (Lu et al., 2017; Luo et al., 2017; Ma et al., 2016; Pinault et al., 2016).

The percentage of urban population in the total population was regarded as urbanization rate. Data on the percentage of urban population in total population from 1998 to 2015 for all countries were obtained from the World Bank (https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?view=chart). This dataset included the urban population (% of total) in 217 countries (or regions and cities), but it was null in individual countries (or regions) or in individual years. Given the data integrality and to match the vector maps of global countries, a total number of 197 countries or regions were extracted and used to analyze in this study. Data on industrial added values (million US dollars) and annual percentage growth rate of GDP (%)