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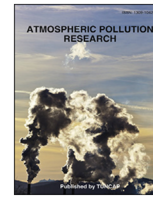

Modeling spatiotemporal distribution of PM_{10} using HJ-1 CCD data in Luoyang, China

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A B S T R A C T

Previous studies have proved that the statistical models between satellite-retrieved aerosol optical depth (AOD) and ground-level PM_{10} provide a feasible and effective way to obtain the extensive and continuous spatial distribution of ground-level PM_{10}. The two-year annual mean PM_{10} was 119.9 ± 66.5 μg/m^3 from 2014 to 2015, which significantly exceeded the annual WHO IT-1 standard for PM_{10} (70 μg/m^3), and the mean AOD was 0.56 ± 0.21 in Luoyang. Statistical models were proposed using a combination of HJ-1 (Environment Satellite 1) CCD (charge-coupled device) AOD and PM_{10} acquired at monitoring sites. The fitting analysis of PM_{10} and AOD shows that PM_{10} agrees well with AOD, and the linear regression model is the most accurate one. By the land-use function analysis of PM_{10} hotspots using Google Earth, it is apparent that the prevalence of industrial or bare soil areas is the key factor in determining anthropogenic pollutant emissions. In view of the small HJ-1 data available for analyzing and the limitation of dark target algorithm in the season with sparse vegetation cover, further investigation should be conducted for a more accurate understanding of the PM_{10} monitoring. Despite the limitations of this work, the results prove the feasibility of retrieving remote sensing images for monitoring regional aerosol pollution, together with ground-level data. The combination of satellite images, ground monitoring and Google earth can help to better understand the spatial distributions and sources of PM on a regional scale.

1. Introduction

Along with rapid industrialization and urbanization over the past two decades, China has experienced unprecedented economic growth, which has led to a severe particulate matter (PM) pollution problem (Huang et al., 2015; Li et al., 2016; Yue et al., 2015). The PM_{10}, one of the major components of atmospheric pollution, is an indicator of air quality in urban areas (Zhao et al., 2013). Several epidemiologic researches have shown that PM_{10} is closely linked with increased morbidity and mortality rates, particularly associated with cardiopulmonary disease (Bravo and Bell, 2011). Therefore, understanding the spatial distribution characteristic of PM_{10} in the urban areas is imperative (Ozel and Cakmakyapan, 2015).

At present, PM_{10} monitoring is based on ambient PM_{10} concentration data from ground monitoring sites. The point measurements from ground observations are limited in spatial distribution of air pollution and unavailable on large spatial scale (Wang and Christopher, 2003). The satellite-derived aerosol optical depth (AOD) represents the total integrated extinction of a column of aerosols (Zong et al., 2015). The AOD is commonly used to provide an extensive and fast monitoring of PM distributions (Arvani et al., 2016; Chang et al., 2014; Kumar et al., 2007; Mao et al., 2012). Several models have been used to establish statistical models between remotely sensed AOD and ground-level PM, including linear models (Kim et al., 2013; Nordio et al., 2013; Xin et al., 2014), nonlinear models (Hutchison et al., 2005), and multiple regression analyses (You et al., 2016; Zheng et al., 2016). These

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results suggest that AOD can provide reasonable satellite-based evaluations of low-level PM_{10} concentrations. Satellite observations offer larger-scale spatial coverage of air pollution than do in situ observations, and many studies have proved their great potential for retrieving global indirect estimates of ground PM (Kim et al., 2013; Lee et al., 2012). Satellite observations can complete ground PM_{10} monitoring networks, particularly in regions containing a limited number of PM_{10} monitoring sites.

In urban environmental monitoring, requirements for high temporal resolution and medium to high spatial resolution have been increasing (Xue et al., 2008). Small satellites and constellations have been widely (and increasingly) used for urban environmental monitoring due to their low volume, low mass, and low power consumption (Xue et al., 2008). The HJ-1A/B satellites, which were launched successfully on September 6, 2008, carry two charge-coupled device (CCD) cameras on each satellite – one infrared multispectral (IRS) camera on HJ-1B and one hyperspectral imager (HSI) on HJ-1A. The excellent image quality, stable radiation properties, moderate temporal resolution (two days), high spatial resolution (30 m), high revisiting frequency, and wide coverage characteristics make the HJ-1 data suitable for atmospheric monitoring (Wang et al., 2010). In fact, HJ-1 data are highly useful in atmospheric environmental monitoring and remote sensing studies (Li et al., 2012; Ye et al., 2016). It is challenging but worthwhile to retrieve high spatial and temporal resolution AOD from small satellite images for air quality assessment.

Under conditions of rapid urbanization and industrialization, China has experienced severe air pollution. High ground-based PM concentrations indicate poor air quality resulting from rapid urbanization processes and industrialization. Models developed in previous studies in China associating AOD with ground-level PM_{10} showed promise (Meng et al., 2016). However, further analyses of the spatial structure of satellite-retrieved high PM_{10} concentrations and PM_{10} hotspots have been scarce and limited and require further investigation. Luoyang, which is a major city that is representative of other highly industrialized cities in China, was investigated in this study, and the relationship between HJ-1 CCD AODs and daily PM_{10} was explored. Specifically, a statistical model to infer the spatial PM_{10} distribution of daily PM_{10} based on satellite AOD of Luoyang has been established. The results of this study indicates that using recent satellite data with high resolution AOD data, it becomes feasible to investigate the possible statistical relationship between space-borne AOD measurements and ground-level PM concentrations. Then, the high values of PM_{10} have been extracted. And by the analysis of their spatial distribution in Google Earth, it can be concluded that there is a remarkable similarity between the distribution of PM_{10} hotspots and industrial activity and bare land.

2. Material and methods

2.1. Study area

Luoyang is representative of a typical highly industrialized city in China and includes many energy-intensive industries (such as

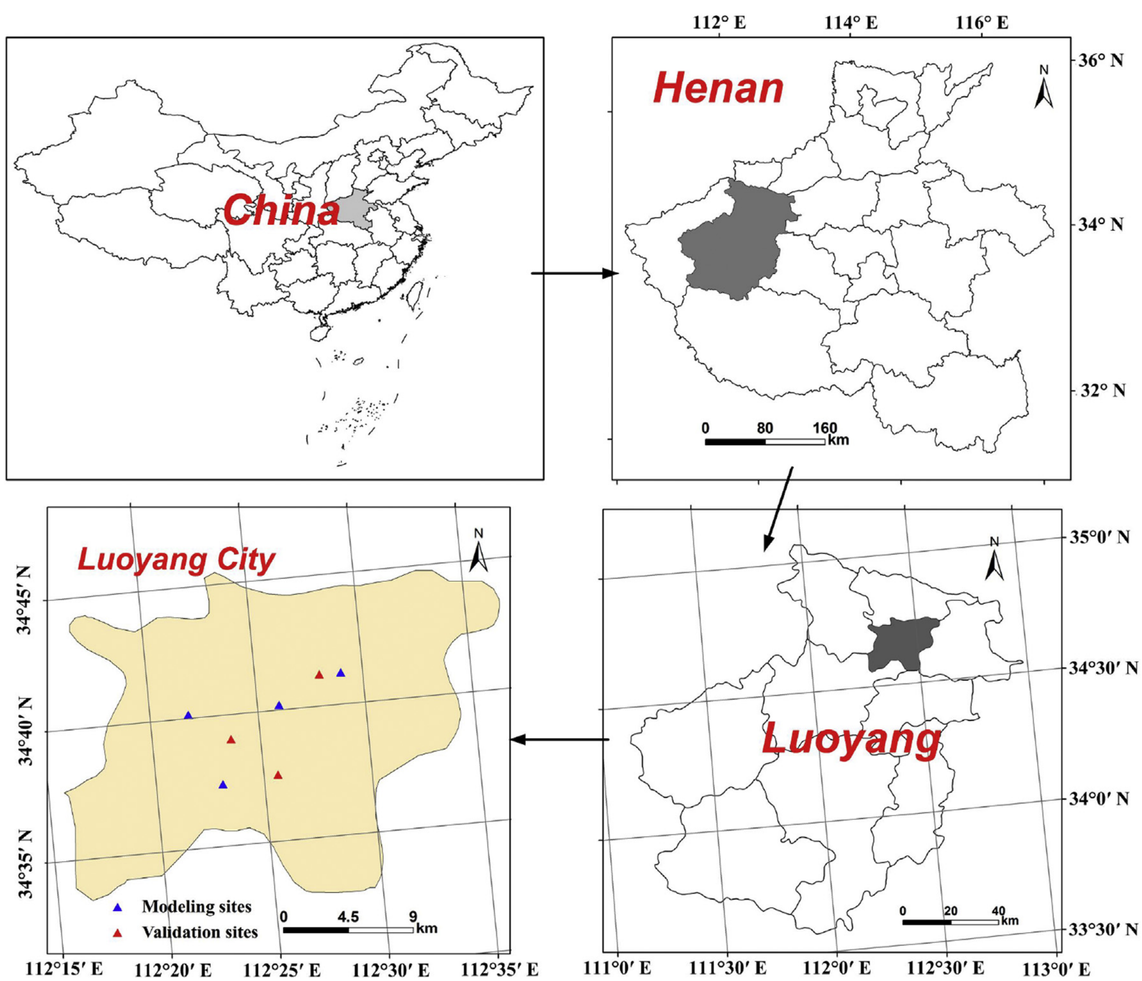

Fig. 1. The study area and the positions of the seven monitoring stations.