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Effect of windblown dust from local and regional sources on the air quality of the central district in Jinan, China

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ABSTRACT

Windblown dust is a major source of PM_{10} in Jinan, China. The aim of this study was to evaluate the effect of windblown dust on the air quality of the central district in Jinan, which has high population density. In this study, PM_{10} emissions from the suburbs of Jinan (local source) were estimated using the Wind Erosion Prediction System (WEPS) model; and the PM_{10} emissions from Shandong province, excluding Jinan (regional source), were estimated based on an empirical formula. In this study, the heating period includes January, February, November, and December; the non-heating period includes June, July and August; and the sand period includes March, April, May, September, and October. The WEPS-simulated annual PM_{10} emission was 9.90×10^4 tons (3.22×10^4 tons during the heating period, 5.53×10^4 tons during the sand period, and 1.16×10^4 tons during the non-heating period) in suburban Jinan in 2012. The PM_{10} emission was 9.17×10^5 tons in Shandong province, excluding Jinan, in 2012. Good correlations between the PM_{10} concentrations of windblown dust simulated by the chemical mass balance (CMB) model and the PM_{10} concentrations of windblown dust from local and regional sources were shown in this study. R^2 were equal to 0.95, 0.92, 0.96 and 0.92, respectively, for the entire year, the heating, non-heating and sand period. For the entire year, the contributions of windblown dust from the local sources, regional sources, and long-range dust transport sources to PM_{10} were 73.0%, 12.8%, 14.2%, respectively. The windblown dust was mainly from local area. The contribution of the regional source was the greatest in the sand period, and the contribution of long-range dust transport was greatest in the heating period.

1. Introduction

In recent years, particulate matter with an aerodynamic diameter of less than or equal to 10 μm (PM_{10}) has become a principle air pollutant in major cities in China. With the rapid economic development, population expansion and urbanization, the Beijing-Tianjin-Hebei (BTH) region has been experiencing a severe air pollution problem (Pu et al., 2015). PM_{10} has adverse effects on the human respiratory system and may result in chronic obstructive pulmonary disease and asthma (Mott et al., 2005). It has been shown that soil dust is a major source of atmospheric particulates (Korcz et al., 2009; Vautard et al., 2005). Saxton (1995) reported that windblown dust from croplands was the major non-compliant source for PM_{10} within the Columbia Plateau region of the Pacific Northwest. In China, soil dust with the mass concentration of 37 μg m^{-3} (24%) was the second greatest PM_{10} contributor in Tianjin in the spring of 2002, and the greatest source of PM_{10} was resuspended dust (39%) (Bi et al., 2007). Among the six primary sources (soil dust, secondary aerosols, domestic combustion, waste incineration, traffic emission and industrial emission) of PM_{10} identified in suburban Changsha in 2008, soil dust accounted for 57.7% of the amount of PM_{10} emitted into the atmosphere (Li et al., 2010). Likewise, the contributions of soil dust were 17% and 15% of the total PM_{10} emitted from the region of Hangzhou and Jinan in the year of 2006 and 2000, respectively (Bao et al., 2010; Feng et al., 2004).

Windblown dust threatens soil productivity, air quality and visibility in many arid and semiarid regions of China. The high winds related topsoil loss results in the suspension of particulates in the atmosphere, thus impairs the air quality (Chandler et al., 2004; Kielgaard et al., 2004; Pulugurtha and James, 2006; Zobeck and Pelt, 2006; Sharratt and Edgar, 2011; Zhang et al., 2011; Cesari et al., 2012). In Jinan, windblown dust is a major regional source of particulate matter in the atmosphere, especially during the dry seasons when the soil is vulnerable to windblown dust.

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Field monitoring to obtain a regional inventory of PM_{10} emissions would require a large investment of effort and equipment. Alternatively, models can be used to conduct regional assessments of PM_{10} emissions. 3D simulations have been used to determine the aerosol optical properties and direct radiative effects of dust particles using RegCM4.1 model for Saharan dust transports over through Turkey (Agacayak et al., 2015).

Although the characteristics and source apportionment of PM_{10} in Jinan have been addressed by many previous studies (Feng et al., 2004; Bi et al., 2007; Zhao et al., 2006), an attempt to identify the effects of local windblown dust and regional windblown dust on the air quality of central area has not been performed. This knowledge is potentially useful in the development of skillful air pollution prediction tools to foster better local air quality management.

The aims of this study were 1) to establish the PM_{10} emission inventory of windblown dust from regional source based on empirical formula; 2) to establish the PM_{10} emission inventory of windblown dust from local source based on WEPS; 3) to assess the effect of windblown dust on air quality using Model3/CMAQ; and 4) to validate the findings using source apportionment results from Chemical Mass Balance (CMB).

2. Materials and methods

2.1. Study area

Jinan (36.4°N; 117.0°E) is located in northwestern Shandong Province, China. It borders Mount Tai to the south and the Yellow River to the north. The land slopes downward gradually from south to north. Jinan is the capital of Shandong Province with seven districts and three counties. Typically, there are four distinct seasons in Jinan, with a long winter and summer and a relatively short spring and autumn. The annual average temperature is 13–14 °C, and the annual average precipitation is 654 mm. The total population of Jinan was 6.81 million at the end of 2012. Jinan covers an area of 8177 km^2 including 3257 km^2 of urban settlement. The central district (CD) includes Lixia (LX) and parts of the Tianqiao (TQ), Huaiyin (HY), Shizhong (SZ), and Licheng (LC) districts; the boundary of the CD is an expressway. The rural area includes Shanghei (SH), Jiyang (JY), Zhangqiu (ZQ), Changqing (CQ), Pingyin (PY) and parts of the Tianqiao (TQ), Huaiyin (HY), Shizhong (SZ), and Licheng (LC) districts (see Fig. 1). In this study, Shandong province, excluding Jinan, is considered to be the regional source region (the gray area in Fig. 1), and Jinan, excluding the central district, is considered to be the local source region (the red area in Fig. 1).

2.2. Establishing the PM_{10} emission inventory of the windblown dust from regional source based on empirical formula

In 2015, Ministry of Environmental Protection of China issued "Technical guide for establishing particulate matter emission inventory of fugitive dust" (Ministry of Environmental Protection of China, 2015). In this guide, the PM_{10} emissions rate Q_{zr} was estimated by only considering the natural windblown dust, without considering the influence of external disturbance. The Q_{zr} was calculated according to Eq (1). All parameters used blow are from the "Technical guide for establishing particulate matter emission inventory of fugitive dust".

$$Q_{zr} = \frac{0.504 \times E_Q \times B_Q \times \mu^3 \times K_Q \times L_Q \times V_Q}{P_Q^2} \quad (1)$$

where the unit of Q_{zr} is tons ha^{-1} a^{-1}. E_Q is the soil erosion index and is taken as 331 tons ha^{-1} a^{-1}, B_Q is the PM_{10} content of soil erosion dust

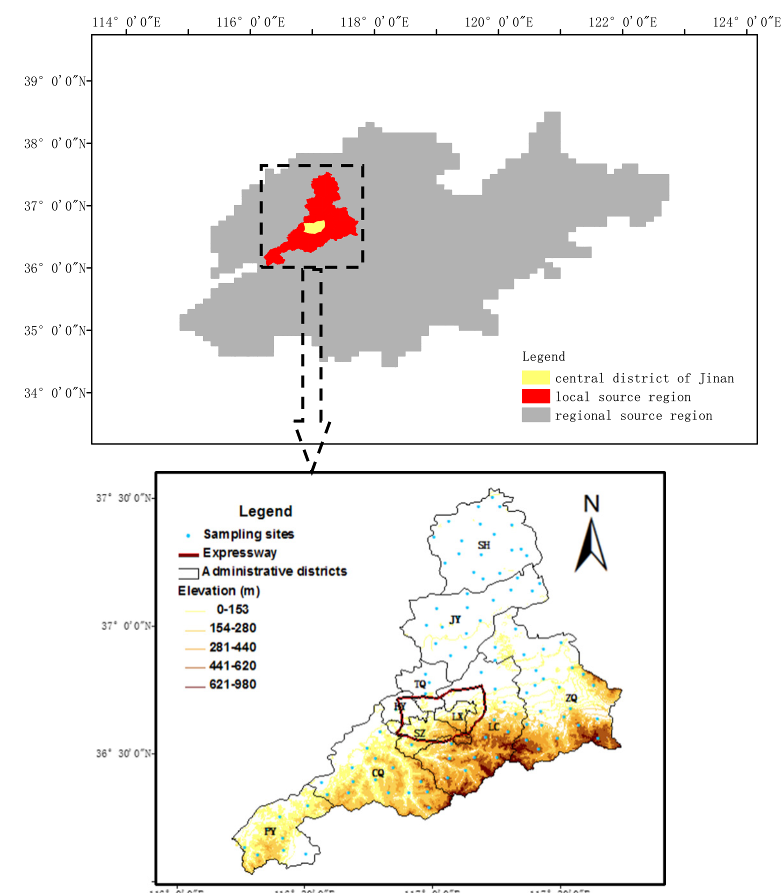

Fig. 1. The sampling site distribution in suburban of Jinan.