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Field assessment of the impacts of landscape structure on different-sized airborne particles in residential areas of Beijing, China

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HIGHLIGHTS

- There were overall lower concentrations of air particles in residential environment compared with the nearby urban background.
- Different residential environments significantly varied in their reduction of the different-sized particles.
- The impacts and relative contribution of different landscape structure parameters on particle reductions differed and varied seasonally.
- Percentage of vegetation and building cover showed great impact on the levels of local airborne particles.

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ABSTRACT

In high-density metropolis, residential areas are important human living environments. Aimed at investigating the impacts of landscape structure on the levels of different-sized airborne particle in residential areas, we conducted field monitoring of the levels of TSP, PM10, PM2.5 and PM1 using mobile traverses in 18 residential areas during the daytime in winter (Dec. 2015–Feb. 2016) and summer (Jun.–Aug. 2016) in Beijing, China. The net concentration differences (d) of the four-sized particles (dTSP, dPM10, dPM2.5 and dPM1) between residential environments and nearby corresponding urban backgrounds, which can be regarded as the reduction of particle concentration in residential environments, were calculated. The effects and relative contributions of different landscape structure parameters on these net concentration differences were further investigated. Results showed that the distribution of particle concentrations has great spatial variation in urban environments. Within the residential environment, there were overall lower concentrations of the four-sized particles compared with the nearby urban background. The net concentration differences of the four-sized particles were all significantly different among the 18 studied residential areas. The average dTSP, dPM10, dPM2.5 and dPM1 reached 18.92, 12.28, 2.01 and 0.53 $\mu g/m^3$ in summer, and 9.91, 7.81, 1.39 and 0.38 $\mu g/m^3$ in winter, respectively. The impacts and relative contribution of different landscape structure parameters on the reductions of TSP, PM10, PM2.5 and PM1 in residential environments differed and showed seasonal variation. Percentage of vegetation cover (PerVC) and building cover (PerBC) had the greatest impact. A 10% increase in PerVC would increase about 5.03, 8.15, 2.16 and 0.20 $\mu g/m^3$ of dTSP, dPM10, dPM2.5 and dPM1 in summer, and a 10% increase in PerBC would decreased about 41.37, 16.54, 2.47 and 0.95 $\mu g/m^3$ of them in winter. Increased vegetation coverage and decreased building construction were found to be conducive to ameliorate airborne particle levels in residential environments. Moreover, landscape structure parameters can be served as indicators for predicting the potential particle reduction at local scale.

1. Introduction

With the rapid development of urbanization and industrialization, increasing human activities discharge large amounts of pollutants into the atmosphere. Airborne particle, the primary air pollutants of many world cities, has constituted a serious

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environmental issue (Grimm et al., 2008). Particles suspended in the air can transport pollutants over long distances and provide a matrix for atmospheric chemical reactions leading to secondary pollution. They can even influence climate change by absorbing and scattering solar radiation to aggravate the local "heat island effect" (Tai et al., 2010). Not only that, many epidemiological studies have reported that long-term exposure to airborne particle pollution is at a great risk of adverse health effects, especially for the respiratory system and cardiopulmonary function (Kappos et al., 2004; Delfino et al., 2005). The significant impact of air particulate pollution on urban ecological environment and public health all over the world has motivated research concerning how to effectively promote the removal of particulate pollution. Based on different aerodynamic characteristics, the removal methods of airborne particles with different size vary greatly (Beckett et al., 1998; Janhäll, 2015). In general, coarse particles in air are more susceptible to deposition caused by direct contact with obstacles and gravity-related sedimentation (Freer-Smith et al., 2005), and fine particles are more dependent on impaction and outward diffusion for attenuation (Hinds, 1999). This makes the concentration levels, temporal and spatial distribution, particularly the responses to influencing factors of the different-sized air particles are always different thus deserving concern.

For a long time, the previous researches on the influencing factors of airborne particles were mainly centered on the source apportionment, meteorological conditions, traffic interference, and urban land use (Dimitriou and Kassomenos, 2014; Tecer et al., 2008; Masiol et al., 2014; Karagiannidis et al., 2015; Zhang et al., 2015). The intricate impacts of urban surface landscape structure which is the composition, distribution and pattern characteristics of different underlying surface elements on ambient airborne particles attract increasing attention in recent years. For example, as one of important underlying surface elements, vegetation can effectively participate in the migration, transformation and attenuation of air particles. Not only the positive effects of absorbing, intercepting and filtering particulate matters (Yang et al., 2005; Tallis et al., 2011), the negative effects of inhibiting the near ground air exchange in some cases thus being unfavorable to upper diffusion of particles are both exist (Setälä et al., 2012; Janhäll, 2015). Percentage of vegetation cover has been demonstrated having a significant impact on the levels of air particles (Sæbø et al., 2012). Mcdonald et al. (2007) estimated that planting 25% of the unplanted area in the West Midlands would result in a 19% increase in particulate deposition and a 3% decrease of PM10 concentration. Additionally, the urban building can also affect the deposition and diffusion of airborne particles. Buccolieri et al. (2010) and Hang et al. (2012) found that the building density and height significantly influenced the airborne particle levels. Moreover, by using the landscape metrics, Weber et al. (2014) investigated the relationship between the distribution of air particles and the heterogeneous landscape structure and found that total area, area proportion and density of the underlying surface elements had excellent potential for predicting the level of ambient particles in residential areas. However, air particles were often affected by the near-ground features from diversified sources simultaneously in the highly heterogeneous urban environment. Although the influence of some certain landscape elements and their structural characteristics on airborne particles had already developed some basic achievements, few studies have provided the relative contribution of different landscape structures when they take combined action. The related researches of important guiding significance in future urban planning and design are urgently needed.

Currently, most studies concerning the relationship between underlying landscape structure and the level of air particles were launched at entire city scales, with the methods of model evaluation, remote satellite photograph and data inversion (Gupta et al., 2006; Shi et al., 2012; Guo et al., 2014). In some studies at local scale, environmental model simulation was also widely used (Buccolieri et al., 2009; Wania et al., 2012). These methods made great contributions in the field of airborne particles. However, due to the complexity of actual situation, the results obtained by these methods often have some errors. By comparison, the method of field monitoring, which can better reflect the reality, was more suitable for the local and micro scale studies (Hagler et al., 2012; Pant and Harrison, 2013; Brantley et al., 2014). In the urban environment, residential area is a typical local-scale environment. It has a very spatially heterogeneous interior environment and limited vegetation cover. Hoek et al. (2008) found that the air particulate concentration of residential, industrial and traffic area is obviously higher than other land-use types in urban environment. Since it is an elementary entity to support the daily life of urban residents, the air quality in residential environment is particularly important. Thus the research on what kind of landscape structures can effectively ameliorate the particle level in residential areas based on field monitoring is of great necessity and has more ecological and social meaning.

Given the above issues, to provide a comprehensive interpretation of the effects of local landscape structures on the levels of different-sized particles in urban residential areas, this study systematically investigated the following based on the field monitoring data: 1) the differences of TSP, PM10, PM2.5 and PM1 concentration levels among residential areas in summer and winter; 2) the quantitative relationship between multiple landscape structure parameters and the concentration reduction of four-sized particles in the residential environment; and 3) the relative importance of different landscape structure parameters for explaining the concentration reduction of TSP, PM10, PM2.5 and PM1. The results will help us to understand how the pivotal landscape structure parameters affect the levels of different-sized airborne particulates in the local environment. In the future planning and design of residential areas, giving targeted priority to controlling these key parameters will be contribute to ameliorate the particulate pollution in urban residential environments.

2. Materials and methods

2.1. Study area and measurement sites

Beijing, China (39°56′N, 116°20′E), a super metropolis in Asia, had a population of 21.51 million at the end of 2014 living within an area of 16,800 km^2 (Beijing statistical Bureau, 2014). Located in the north of the North China Plain, Beijing has a monsoon-influenced humid continental climate with hot and humid summers and cold and dry winters. The predominant wind direction in summer is southeast to northeast, and the reverse occurs during winter. Taking the statistics for 2016 as example, the annual mean temperature was 12.1 °C and mean precipitation was 680.6 mm (Beijing Meteorological Bureau, 2017). During 2016, 167 days did not meet air quality standards, accounting for 46% of the entire year. In addition, heavy pollution occurred on 39 days (Beijing Municipal Environmental Protection Bureau, 2017).

In this study, the measurements were conducted in 18 residential areas in Chaoyang District. Within the urban area of eastern Beijing, Chaoyang District is the largest district of six core districts in population (3.92 million at the end of 2014) and area (475 km^2) in Beijing (Beijing statistical Bureau, 2014), covering different urban development gradients from near downtown to urban-rural fringe and on to suburb. Its area scale, population level, and urban development pattern have adequately reached the city level and can be regarded as a representative area in the