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Spatial variation in the flux of atmospheric deposition and its ecological effects in arid Asia

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ABSTRACT

Atmospheric deposition is one of the key land surface processes, and plays important roles in regional ecosystems and global climate change. Previous studies have focused on the magnitude of and the temporal and spatial variations in the flux of atmospheric deposition, and the composition of atmospheric deposition on a local scale. However, there have been no comprehensive studies of atmospheric deposition on a regional scale and its ecological effects in arid Asia. The temporal and spatial patterns, composition of atmospheric deposition, and its potential effects on regional ecosystems in arid Asia are investigated in this study. The results show that the annual deposition flux is high on the Turan Plain, Aral Sea Desert, and Tarim Basin. The seasonal deposition flux also varies remarkably among different regions. The Tarim Basin shows higher deposition flux in both spring and summer, southern Mongolian Plateau has a higher deposition flux in spring, and the deposition flux of Iran Plateau is higher in summer. Multiple sources of elements in deposited particles are identified. Calcium, iron, aluminum, and magnesium are mainly derived from remote regions, while zinc, copper and lead have predominantly anthropogenic sources. Atmospheric deposition can provide abundant nutrients to vegetation and consequently play a role in the succession of regional ecosystems by affecting the structure, function, diversity, and primary production of the vegetation, especially the exotic or short-lived opportunistic species in arid Asia. Nevertheless, there is not much evidence of the ecological effects of atmospheric deposition on the regional and local scale. The present results may help in further understanding the mechanism of atmospheric deposition as well as providing a motivation for the protection of the ecological environment in arid Asia.

1. Introduction

Arid Asia stretches from the Great Xing'an Mountains to the Caspian Sea, and has a land area of 1.3×10^7 km^2 and an annual mean precipitation of < 500 mm (Fig. 1). This region has the largest population (approximately 330 million people) among all the arid regions of the world. The soil types from north to south are Kastanozems, Calcisols, Arenosols and Cambisols (Food and Agriculture Organization Soil Classification; Deckers et al., 1998). Arid Asia has highly heterogeneous landscapes, including gravel desert (e.g., Ala Shan Gravel Desert), sand desert (e.g., Taklimakan Desert), desert steppe (e.g. Otindag Sandy Land), steppe (e.g., Golodnaya Steppe), and cultivated land (e.g., Indus River Plain). The soil is infertile, and the output and input of nutrients may profoundly affect the basic soil properties, thus the growth and succession of vegetation (Dong et al., 2000; Okin et al., 2004; Shen et al., 2016).

In arid areas, dry deposition which proceeds via the gravitational settling of particulates from the atmosphere and their turbulent mixing, is the main route of aerosol dust deposition (Tegen and Fung, 1994; Zhao et al., 2003). Arid Asia is one of the main source regions for global atmospheric aerosols and total suspended particulates (Ginoux et al., 2001; Zender et al., 2003; Kim et al., 2017), and approximately 30%–80% of the suspended particulates will redeposit in the source regions due to gravity (Zhang, 2001; Zhao et al., 2003; Chen et al., 2014). The deposition of particulates can alter the physical and chemical properties of soils, especially the cycling and status of nutrients in the surface soil (Reynolds et al., 2006; Rizzolo et al., 2017). For example, atmospheric deposits rich in various nutrients can remedy the loss of nutrients in surface soil by erosion, and consequently affect the growth and community structure of vegetation (Gillette and Dobrowolski, 1993; Li et al., 2009; Zhao et al., 2011; Yan et al., 2013). Previous studies have focused on the magnitude of dust emissions,

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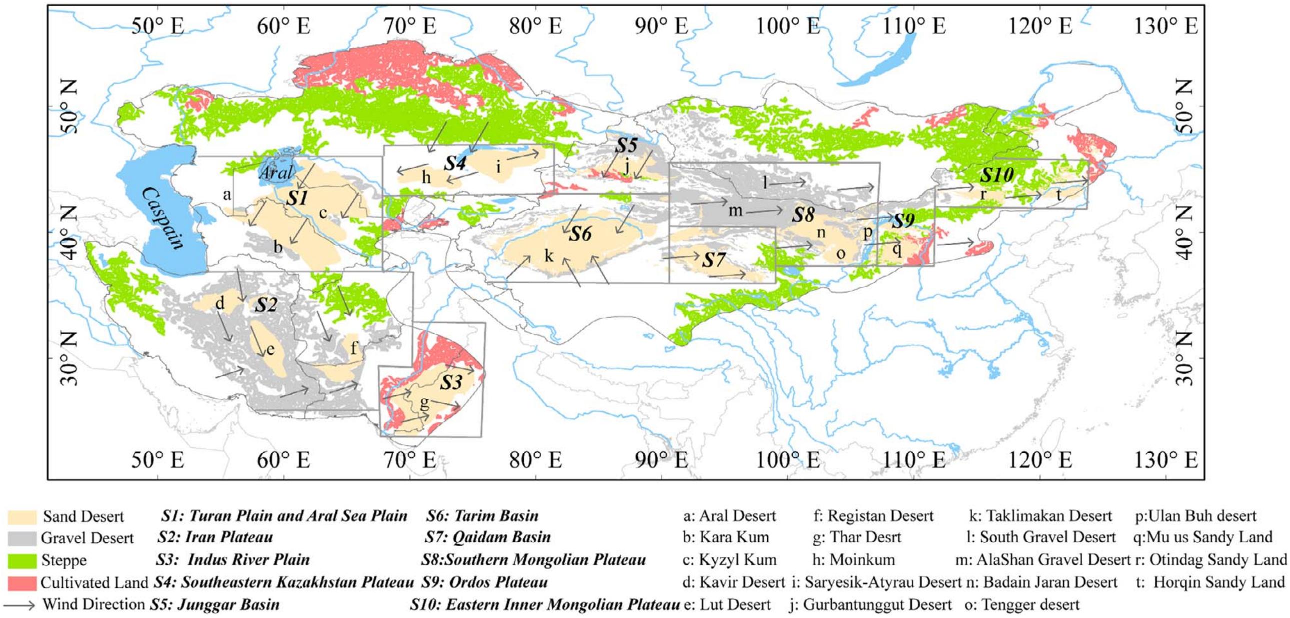

Fig. 1. Map of arid Asia and the main atmospheric deposition/dust aerosol source regions (Notes: S refers to the main dust deposition source; land cover classification is from GLCNMO: https://globalmaps.github.io/glcnmo.html and http://westdc.westgis.ac.cn/data/122c9ac2-53ee-4b9a-ae87-1a980b131c9b).

temporal and spatial variations in dust emissions, and the effects of dust emissions on human health and the environment in the distant dust source areas and ecosystems of arid Asia (Crouvi et al., 2010; Pullen et al., 2011; Martino et al., 2014; Aciego et al., 2017). There have been few reports on the deposition flux, regional variation, and the ecological effects of atmospheric deposition in arid Asia. Previous studies have mainly been focused on the local scale, including 1) the deposition flux (Zhang and Kang, 1999; Groll et al., 2013; Wang et al., 2013a); 2) the adverse environmental effects of atmospheric deposition, especially white and salt sandstorms and heavy-metal contamination (Orlovsky et al., 2005; Indoiu et al., 2012; Abdollahi et al., 2013); and 3) the different characteristics of atmospheric deposition according to special weather conditions (Li, 2008; Muhammad, 2009; Lyu et al., 2010). There has been no study of atmospheric deposition on a regional or larger scale in arid Asia. Therefore, this paper analyzed the temporal and spatial variations in atmospheric deposition and its ecological effects in arid Asia based on an intensive review of literature. This study aims to increase the understanding of the potential distribution characteristics of atmospheric deposition and its ecological effects in the arid Asia, as well as providing a motivation for the protection of the ecological environment in arid Asia.

2. Methods

2.1. Deposition flux of dustfall

Atmospheric dustfall refers to particulate matter in the air with an aerodynamic diameter of > 10 μm, which falls naturally to the ground surface under the force of gravity (Liu et al., 2004; Zhang et al., 2010). The deposition flux of dustfall is usually defined as the weight of settled particulate matter per unit area per month (Wang, 2003; Groll et al., 2013). Although the monitoring of dustfall is relatively simple, its measurement is subject to many external influences, including the physical properties (e.g., shape and materials) of the collector (Sanderson et al., 1963; Patel and Pandey, 1986), the sampling medium (Goossens and Offer, 1994; Qian and Dong, 2004), the place of the dustfall collector (McTainsh et al., 1997; Zhang and Dong, 2013), the sampling location (Evyatar and Tsoar, 1999; Liu et al., 2004), and meteorological conditions (Wiggs et al., 2003; Lyu et al., 2010). The raw data of deposition flux of dustfall cannot be directly compared due to the influences of the aforementioned factors. Therefore, standardization or calibration is essential to enable the comparison in deposition flux of dustfall obtained by various methods under different circumstances.

The most important factor which influences the deposition flux of dustfall is the sampling medium (McTainsh et al., 1997). The dustfall is usually collected by three methods: the dry method, the wet method, and the marbles method. The three methods differ in the treatment of the bottom of the collectors. Mediums at the bottom of the collectors are nothing (clean surface; dry method), free water or glycerol surface (wet method), or 1–2 layers of marbles (marbles method), respectively. It has been reported that the wet method collected the maximum dustfall, followed by the marbles method, and the dry method captured the least dustfall (Goossens and Offer, 1994; Hu, 2002; Zhang and Dong, 2013). Linear correlations have been observed among the three methods (Goossens and Offer, 1994; McTainsh et al., 1997; Hu, 2002; Wang, 2003; Qian and Dong, 2004; Zhang and Dong, 2013). In this study, the wet method is treated as the standard method, and linear regression equations are obtained are to calibrate the dry method and the marbles method (Fig. 2). To assess the goodness of fit of the linear regression equations, statistical indicators: the coefficient of determination (R^2), the mean absolute error (MAE) and root mean squared error (RMSE) are calculated as follows:

$$R^2 = \frac{\left(\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})\right)^2}{\sum_{i=1}^{n}(x_i-\bar{x})^2\sum_{i=1}^{n}(y_i-\bar{y})^2} \tag{1}$$

$$\mathrm{MAE} = \frac{\sum_{i=1}^{n}|x_i-y_i|}{n} \tag{2}$$

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(x_i-y_i)^2}{n}} \tag{3}$$

where x_i refers to the deposition flux of the dry or marbles method, y_i refers to the deposition flux of the wet method, $\bar{x}$ refers to the mean deposition flux of the dry or marbles method, $\bar{y}$ refers to the mean deposition flux of the wet method, n refers to the number of data.

In this study, the unit of deposition flux is defined as g m^{-2} (the sum of deposition flux in 12 months for annual mean deposition flux, and the sum of deposition in 3 months for seasonal deposition flux, see Appendix A and B).