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National pattern for heavy metal contamination of topsoil in remote farmland impacted by haze pollution in China

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ABSTRACT

The influence of haze pollution on heavy metal transport into farmland topsoil has received little attention. This study reports on heavy metal concentrations in topsoil from remote farmland in China as well as the spatial similarity and correlation to such heavy metals in atmospheric particulate matter (APM). Heavy metal concentrations in topsoil from remote farmland significantly increased over time. Moreover, stations in the mid-eastern region of China accounted for greater than 55% of total stations that exhibited higher concentrations in 2010 than 2005. This spatial trend was consistent with changes observed in APM where mass concentrations of heavy metals were also found to be higher in the mid-eastern region of China. Heavy metals in APM have already likely caused contamination in remote farmland topsoil, particularly in the mid-eastern region of China. This is primarily due to long-range transport and deposition of APM owing that no pesticides or fertilizers have been used in the remote farmland stations selected and no industries were situated nearby. Regarding the large-scale, severe haze pollution occurring in China today, it is urgent to ascertain the accumulation of heavy metals in farmland topsoil resulting from APM as well as its subsequent potential mechanisms and ecological risks.

1. Introduction

There has been great concern over China's air quality in the past decade in the face of the country's rapid economic development. Haze pollution is considered to be the most serious environmental air issue in China today due to its adverse public health effects (Chen et al., 2013b; Huo et al., 2015; Tie et al., 2009; Yao et al., 2014) as well as its negative impacts on remote ecosystems (Chameides et al., 1999; Zhang et al., 2013) and the climate at large (Solomon et al., 2007; Tainio et al., 2013). Severe haze pollution in China has been concentrated in megacity clusters in the North China Plain, regions within the Yangtze River Delta (YRD), the Pearl River Delta (PRD), and the Sichuan Basin (Jiang et al., 2015; Zhang et al., 2012), all of which are located close to developed regions, in particular the mid-eastern region of China.

Haze is an important indicator of high concentrations of atmospheric particulate matter (PM) (Cheng et al., 2013). Atmospheric PM sources are abundant in China (Chen et al., 2014; Schleicher et al., 2011). These include anthropogenic sources such as vehicle traffic, various industries, the burning of fossil fuels for heating and cooking, construction sites, and resuspension processes related to urban surfaces. On the other hand, geogenic particles contribute to the overall mass concentration of airborne particles, such as minerals transported from arid and semi-arid regions or those originating from bare soils within or surrounding cities. Different sources and the mixing of particles of different origins pose a great challenge for the comprehensive assessment of haze pollution.

Atmospheric PM is composed of a mixture of complex materials. Many hazardous and toxic materials like heavy metals can be absorbed into atmospheric PM due to its extensive surface area. Heavy metals are non-degradable and can accumulate within the human body, damaging the nervous system and internal organs. They can also contribute to cardiovascular diseases, reproductive impairments, and cancer (Li et al., 2014; Raghunath et al., 1999; Waisberg et al., 2003). At the same time, heavy metals in atmospheric PM have a major impact on regional and global cycles as a result of deposition (Boquete et al., 2014; Chen et al., 2013a).

Because soil is the primary terrestrial repository of contaminants, soil compartments have typically been used to determine the deposition of such atmospheric contaminants (Xing et al., 2004; Zhang et al., 2013). Predictably, concentrations of certain heavy metals in farmland topsoil may be influenced by atmospheric deposition that directly transports such metals through bulk and throughfall deposition, leading to severe haze pollution, high concentrations of atmospheric PM, and increased heavy metal concentrations in topsoil (Daresta et al., 2015; Zhang et al., 2013). Negative impacts on plant growth and productivity will result (Daresta et al., 2015). Subsequently, human health could be affected through the food-chain, resulting from the enhanced accumulation and transport of metals in plant material (Peralta-Videa et al.,

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2009; Seth et al., 2012). In spite of this, this issue is not being taken seriously even though it is an obvious ecological risk to farmlands. Previous studies have reported on the basic concepts of heavy metals in atmospheric PM and the deposition of atmospheric heavy metals throughout China (Tan and Duan, 2013; Yang et al., 2011; Zhang, 2011b) . Nevertheless, little information is available with regards to the effects of heavy metals in farmland topsoil on a national scale.

China has greater than 1.8 billion hectares of farmland dedicated to food production.

In particular, remote farmlands provide considerable ecological and organic grown food produce where even slight heavy metal contamination could cause severe impairment in food quality. As it relates to haze pollution, it is of particular importance to understand the broad trends pertaining to heavy metals in topsoil in remote farmlands to verify whether topsoil quality has been influenced by haze pollution. Therefore, the objectives in this study were 1) to identify temporal and spatial variation of heavy metal contamination in remote farmland topsoil on a national scale; 2) to evaluate the temporal and spatial profile of haze pollution and its heavy metal constituents in atmospheric PM; and 3) to explore heavy metal contamination of soil caused by haze pollution, based on the extensive relationship that exists between heavy metals, atmospheric PM, and remote farmland topsoil. Results from this study can provide insight into the contribution of haze pollution on heavy metals in farmland topsoil in China and throughout the world.

2. Materials and methods

2.1. Heavy metal soil dataset

Heavy metals in this study consisted of lead (Pb), arsenic (As), chromium (Cr), cadmium (Cd), copper (Cu), and zinc (Zn). Data related to heavy metals in remote farmland topsoil were collected from China's Soil Scientific Database (http://www.soil.csdb.cn/), which is derived from 15 agricultural ecosystem stations scattered throughout China and operated by the Chinese Academy of Sciences (Fig. 1). The 6 stations located within the western region of China are CLD, LSA, ASA, CWA, YGA, and HJA. The remaining 9 stations are all located in the mid-eastern region of China. In order to minimize any potential impact of agricultural cultivation, soil observation fields devoid of any pesticides or fertilizers were selected as sampling sites from which surficial topsoil with an area of 10 cm were sampled in 2005 and 2010 to analyze heavy metal concentrations (Committee, 2007). Since the Chinese Ecosystem Research Network Scientific Committee has established uniformly strict regulations regarding analytical methods to test heavy metals in soils (2007), data quality is guaranteed.

Due to the geographically rural location, no industries were situated near sample stations (roughly within 50 km). At the same time, the various crops and soil types of all selected stations have been tabulated in Table 1 as well as the differing average precipitation observed from 2005 to 2010.

2.2. Atmospheric heavy metal dataset

Studies have been conducted on heavy metals in atmospheric PM over different regions in China but have rarely been explored comprehensively as a whole picture throughout China. When collecting data related to heavy metals in atmospheric PM, this study gave preference to those studies in literature based upon long-term observations that mostly focused on internationally and domestically peer-reviewed publications and Chinese theses from the Science Citation Index and the China Knowledge Resource Integrated Database. In total, 29 publications were selected based upon the following four criteria: 1) sample time took place between 2001 and 2010; 2) atmospheric PM included TSP (total suspended particles), PM10 (particles less than 10.0 μm in

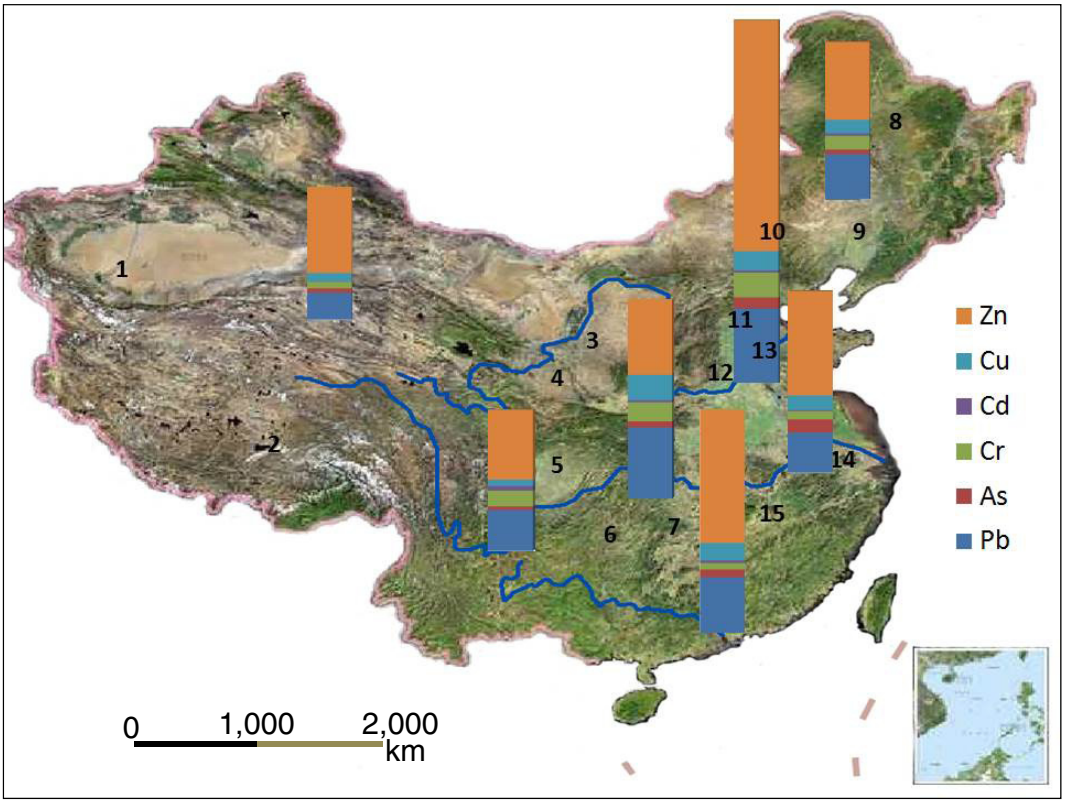

Fig. 1. Sketch location of the 15 selected agriculture ecosystem stations throughout China (1-CLD, 2-LSA, 3-ASA, 4-CWA, 5-YGA, 6-HJA, 7-TYA, 8-HLA, 9-SYA, 10-NMD, 11-LCA, 12-FQA, 13-YCA, 14-CSA, and 15-YTA) and average concentrations of heavy metals in atmospheric PM throughout China. The total heavy metals in atmospheric PM in Northwestern China, Southwestern China, Central China, Northeastern China, North China, Region of the Yangtze River Delta, and Region of the Pearl River Delta was 748.75, 787.97, 1115.34, 884.02, 2028.62, 1011.89, and 1251.81 ng m^{-3}, respectively.