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Detection and differentiation of pollution in urban surface soils using magnetic properties in arid and semi-arid regions of northwestern China

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ABSTRACT

Increasing urbanization and industrialization over the world has caused many social and environmental problems, one of which drawing particular concern is the soil pollution and its ecological degradation. In this study, the efficiency of magnetic methods for detecting and discriminating contaminates in the arid and semi-arid regions of northwestern China was investigated. Topsoil samples from six typical cities (i.e. Karamay, Urumqi, Lanzhou, Yinchuan, Shizuishan and Wuhai) were collected and a systematic analysis of their magnetic properties was conducted. Results indicate that the topsoil samples from the six cities were all dominated by coarse low-coercivity magnetite. In addition, the average magnetite contents in the soils from Urumqi and Lanzhou were shown to be much higher than those from Karamay, Yinchuan, Shizuishan and Wuhai, and they also have relatively higher χ_{lf} and $\chi_{fd}\%$ when compared with cities in eastern China. Moreover, specific and distinctive soil pollution signals were identified at each sampling site using the combined various magnetic data, reflecting distinct sources. Industrial and traffic-derived pollution was dominant in Urmqi and Lanzhou, in Yinchuan industrial progress was observed to be important with some places affected by vehicle emission, while Karamay, Shizuishan and Wuhai were relatively clean. The magnetic properties of these latter three cities are significantly affected by both anthropogenic pollution and local parent materials from the nearby Gobi desert. The differences in magnetic properties of topsoil samples affected by mixed industrial and simplex traffic emissions are not obvious, but significant differences exist in samples affected by simplex industrial/vehicle emissions and domestic pollution. The combined magnetic analyses thus provide a sensitive and powerful tool for classifying samples according to likely sources, and may even provide a valuable diagnostic tool for discriminating among different cities.

1. Introduction

In recent years, there has been a renewed interest in the use of magnetic techniques for the investigation of anthropogenic contaminants, reconstruction of pollution history, and tracing and separating pollution sources. Currently, carrier of contaminants such as soils (Blaha et al., 2008; Blundell et al., 2009a, b), street dusts (Kim et al., 2009; Xia et al., 2011), river sediments (Zhang et al., 2011; Wang et al., 2013a), peat bog (Hutchinson and Armitage, 2009; Marx et al., 2010), atmospheric particles (Muxworthy et al., 2001; Xia et al., 2008), tree rings (Zhang et al., 2008) and tree leaves (Hoffman et al., 2012; Shaltout et al., 2013) have been investigated, and have been proven to be suitable targets for the application of magnetic proxy methods to detect heavy metal (HM) pollution. Soil, as an interface between earth, air and water, is a key component of ecosystem and is non-renewable, but is ample in availability and convenient to sample and measure.

A great deal of importance has been attached to the use of magnetic parameters in urban soil pollution studies. Previous studies have shown that urban airborne ferrimagnetic particulates are dominated by anthropogenic sources, such as the burning of fossil fuels (Flanders, 1994; Ďurža, 1999; Basavaiah et al., 2012), iron and steel industries (Hu et al., 2008; Zhang et al., 2011), metal smelters (Flanders, 1999; Kapička et al., 1999; Jordanova et al., 2013) and vehicle emissions (Hoffmann et al., 1999; Goddu et al., 2004; Maher et al., 2008). Several studies (e.g. Lecoanet et al., 2003; Blundell et al., 2009a, b; Zhang et al., 2011) have shown that magnetic measurements may serve as a simple, fast, inexpensive,

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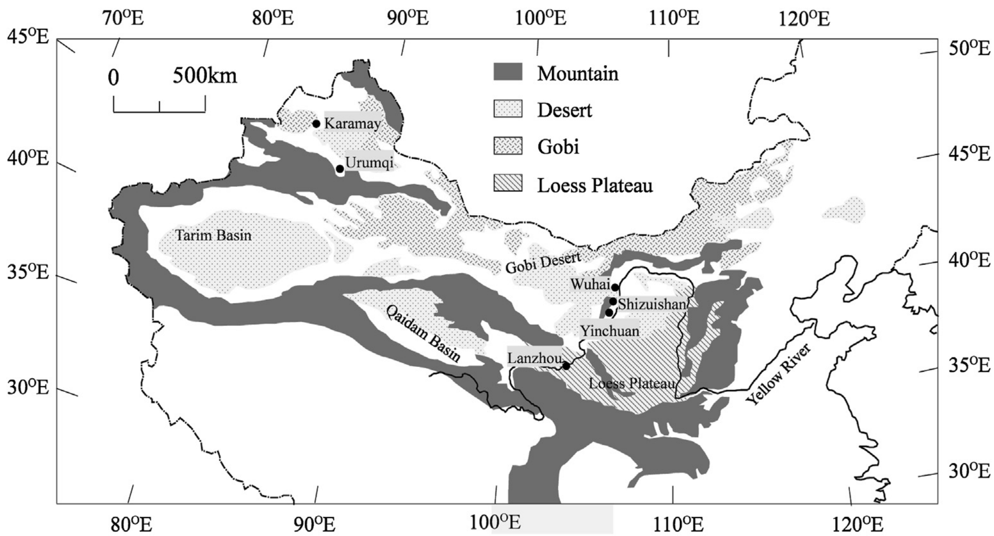

Fig. 1. Sketch map of the study area. Black dot means the sampling sites.

and nondestructive tool for pollution screening and monitoring. Low field magnetic susceptibility measurements have been successfully applied to delineate the anthropogenic pollution range (Petrovský et al., 2001; Hanesch and Scholger, 2002; Canbay et al., 2010; Karimi et al., 2011), even on large scales such as those of the Ukraine and Britain (Hay et al., 1997; Jeleńska et al., 2004; Blundell et al., 2009a, b). Moreover, in recent years, the use of magnetic parameters as proxies for quantifying/semi-quantifying the contents of certain contaminants in soils have been demonstrated (Canbay et al., 2010; Wang et al., 2013b), suggesting that the method is a promising alternative to conventional chemical analysis.

It is worth noting that although some soil samples were collected from industrial areas, influences from different magnetic backgrounds and other multiple pollution sources, such as traffic emissions, are still difficult to avoid. Hanesch and Scholger (2005) studied the influence of soil types on magnetic susceptibility and concluded that differences among soils could cause a large variation in magnetic properties. In the case of an area containing different types of soil, it may be difficult to discriminate pollution signals from the natural background by means of magnetic susceptibility mapping alone. Therefore, how to distinguish the contributions of different pollution sources from magnetic background on a large scale of cross-contamination is a pressing and meaningful question.

Numerous studies regarding magnetic characters in topsoil have been performed throughout the world, such as the UK (Blundell et al., 2009a,b), France (Lecoanet et al., 2001, 2003), Germany (Fürst et al., 2009), Italy (Imperato et al., 2003; Chianese et al., 2006), Austria (Hanesch and Scholger, 2002, 2005; Blaha et al., 2008), the Czech Republic (Kapička et al., 1999, 2001), Poland (Basavaiah et al., 2012), the Ukraine (Jeleńska et al., 2004), Morocco (Baghdadi et al., 2012), Egypt (Khalil, 2012), Argentina (Chaparro et al., 2004), Iran (Dankoub et al., 2012), India (Meena et al., 2011), Nepal (Gautam et al., 2005), and eastern China (Lu and Bai, 2006; Zheng and Zhang, 2008; Jiang et al., 2012; Wang et al., 2013b). However, much less attention has been placed on northwestern China, which is one of the world's most well known arid/semi-arid regions. This region is situated in a climatic transition zone between the Asian monsoons and westerly airflow. The annual precipitation is generally less than 400 mm, and gradually reduces from the east to the west. Gobi deserts, deserts and mountains are widespread in these arid and semi-arid areas, with some oases scattered throughout. As a result of this particular location, the area is quite fragile, and restoration would be difficult if it was polluted. With the transfer of high energy consumption and heavy pollution industries to northwestern China, heavy metal pollution is gradually widespread in northwestern cities. Frequent pollution incidents not only seriously threaten human health but also urban ecosystem. It is urgent to develop simple and time-efficient methods for determining and distinguishing soil contaminations in these regions.

In this paper, the spatial variations of the magnetic properties were studied using surface soil samples collected from six typical cities in the arid and semi-arid regions of northwestern China (Fig. 1). These six cities have diverse function areas and different soil types. The main objectives of this study are as follows: (a) to estimate and contrast soil pollution among these cities through the application of a fast and inexpensive method; (b) to characterize the anthropogenic magnetic particles in topsoil samples; and (c) to discriminate the contributions of different pollution sources. The study is thus a contribution to the potential use of magnetic measurements, as well as their application for evaluating and distinguishing large-scale anthropogenic soil pollution in an arid and semi-arid urban environment.

2. Methods

2.1. Sampling methods

The arid and semi-arid regions of northwestern China is topographically diverse, consisting of the northern section of the vast Tibetan plateau, basins and mountains to the north of the Tibetan Plateau, the southern edge of the Mongolian Plateau, and the western extremity of the Loess Plateau (Fig. 1). Karamay and Urumqi are located in Xinjiang Uyghur Autonomous Region. Karamay is a relatively small city located near the Gurbantunggut Desert. Urumqi is located on the southern edge of the Junggar Basin, and is surrounded by highlands on three sides. The city is seriously polluted due to large amount of coal dust and motor vehicle emissions. Lanzhou is located at the intersection among the Tibet Plateau, Alxa Plateau and Loess Plateau. The long-term inversion related to this trough-shaped topography, large amount of emissions from coal-fired factories and vehicles, and large input of desert dust from the highly frequent dust events lead to poor air quality in the valley city. Yinchuan and Shizuishan are located on the Ningxia Plain. Yinchuan is a well-known historical and cultural city, which possesses reasonable urban planning, with wide and clean roads. Shizuishan is also a relatively small city bordering on Wuhai city (Fig. 1). Wuhai is located on the edge of the Ulan Buh Desert, which is one of the cities with the least precipitation in Inner Mongolia autonomous region. In summary, Karamay and Wuhai are characterized by Gobi desert; Urumqi and Lanzhou consist of wide-