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Source apportionment of soil-contamination in Baotou City (North China) based on a combined magnetic and geochemical approach

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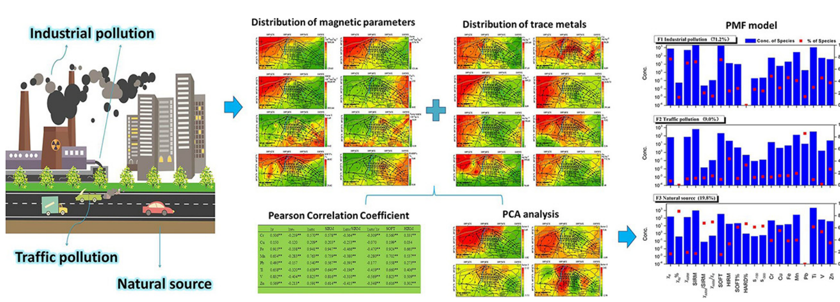
HIGHLIGHTS

- Distribution of magnetic properties and trace metals in soils is investigated.
- Relationship between magnetic parameters and trace metals is determined.
- Receptor model provides apportionment of various sources of soil pollution.
- Three sources are identified and quantified by PMF.

GRAPHICAL ABSTRACT



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ABSTRACT

We studied the magnetic properties and trace element concentrations (Cr, Cu, Fe, Mn, Pb, Ti, V, Zn) of urban topsoils from 111 urban sites in a large REE-Nb-Fe mining and smelting city, Baotou, Inner Mongolia, China. The results show that pseudo-single domain and multi-domain magnetite dominates the magnetic properties of the soil samples, and the magnetic concentration parameters show a large positive anomaly near the Baotou iron and steel works. The average contents of all trace metals exceeded their background level in soils in Inner Mongolia, except for Pb. The spatial distribution and correlation analysis show that magnetic parameters related to the magnetite concentration and Cr, Fe, Mn, Ti, V and Zn show similar trends of variation. In addition, the results of PCA show that Fe, Ti, and V are highly correlated with the magnetic particles derived from the Baotou iron and steel works, tailing dam, chromium plant, and cement plant. In contrast, Cr, Mn, Pb and Zn are derived from both the steel plant and traffic pollution. Using a PMF model, three potential pollution sources are identified: industrial pollution, including the steel works, tailing dam, cement plant and chromium plant, are reflected by χ_{lf}, χ_{ARM}, SIRM and SOFT, and they account for 71.2%; traffic pollution is reflected by Pb and Zn and accounts for 9.0%; and natural sources, reflected by χ_{fd}%, χ_{ARM}/χ, χ_{ARM}/SIRM, HARD%, S_{-300}, S_{-100} and Ti, contribute 19.8%. The results are potentially useful for developing control measures for reducing trace metal contamination in soils in Baotou city, and in addition we conclude that a combined magnetic approach and geochemical approach is an effective means for qualitative and quantitative sources apportionment of urban surface soil pollution.

1. Introduction

Soil is an important component of urban ecosystems and is subjected to the continuous accumulation of contaminants from either local point sources or diffusive pollution; thus, soils provide an

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integrated record of long-term or intermediate-term pollution (Wong et al., 2006; Morel and Heinrich, 2008). The high concentration of trace elements and organic pollutants in urban soils are a hazard to human health through resuspension - inhalation (Albanese and Cicchella, 2012; Filippelli et al., 2012), especially in the case of soil and sediments in areas of mining activity, where contributions from tailings can be a major source of toxic atmospheric dust (Hudson-Edwards et al., 2011). China's Ministry of Environmental Protection and Ministry of Land and Resources conducted a nationwide survey of soil contaminants and found that pollutant concentrations exceeding standard levels occurred in 33.4% of mines (MEPPRC and MLRPRC, 2014).

The combined use of magnetic, geochemical and mineralogical methods has been successfully applied by many researchers to assess soil, air and sediment pollution, and particulate matter originating from industrial, traffic and urban sources has been quantifying and characterized using this approach. The results indicate that trace metals released during fossil fuel combustion processes (e.g., Cu, Cr, As, Zn and Pb) are always accompanied by magnetic iron oxides, which have high adsorption capacity in relation to many trace metals (Boyko et al., 2004; Desenfant et al., 2004; Magiera et al., 2011, 2013). Technogenic magnetic particles (TMPs) are Fe-rich particles characterized by high magnetic susceptibility and therefore their presence in particulate material can be detected by using relatively rapid, non-destructive and cost-efficient magnetic methods, such as measurements of magnetic susceptibility and saturation isothermal remanent magnetization. Examples of the use of this approach are the detailed mapping of the magnetic properties of topsoils from archived samples from national soil surveys of England and Wales (Blundell et al., 2009), Austria (Hanesch et al., 2007), Bosnia-Herzegovina (Hannam and Dearing, 2008), Poland (Łukasik et al., 2016), Bulgaria (Jordanova et al., 2016), and France (Thiesson et al., 2012). Moreover, in recent years many studies have proposed the use of magnetic parameters for the semi-quantification of certain contaminants (e.g., Cu, Pb, Zn, Cr, V, Mn) or pollution assessment criteria (Pollution load index, Nemero index) (Hu et al., 2008; Zhang et al., 2011; Karimi et al., 2011; Qiao et al., 2013; Wang et al., 2013). Some researches even have combined multivariate magnetic parameter analysis to identify pollution sources (Hansard et al., 2012; Wang et al., 2014; Cao et al., 2015) and to trace the history of pollution (Ma et al., 2015; Prajith et al., 2015).

Apportioning sources of soil contaminants can help in revealing the contributions of different sources, so that appropriate control measures can be introduced. Numerous studies have focused on the identification of pollution sources, with most studies using geostatistical models and multivariate statistical analyses such as principal component analysis and cluster analysis (Li et al., 2010; Karimi et al., 2011; Long, 2013; Liu et al., 2016). However, fewer studies have been conducted on the apportion contributions of pollution sources. Unlike a chemical mass balance (CMB) model, the Positive Matrix Factorization (PMF) model is an effective source apportionment receptor model that does not require the source profiles to be determined prior to the analysis; thus, it is recommended by the United States Environmental Protection Agency (USEPA, 2014). Positive matrix factorization (PMF) is developed by Paatero and Tapper (1994); and it has been widely applied for source apportionment of pollutants in the atmosphere (Wang et al., 2016; Liang et al., 2016; Singh et al., 2017), water (Li et al., 2015; Soonthornnonda and Christensen, 2008) and in sediments (Chen et al., 2013; Comero et al., 2014). Moreover, in recent years, the PMF model has been used to identify and apportion contaminant sources in soil (Jiang et al., 2017; Liang et al., 2017; Guan et al., 2018).

In the present study, we used the PMF model to identify the sources of magnetic minerals and trace metal in soils in a typical mining city, Baotou, in Northern China. Our main objectives were: (i) to investigate the spatial distribution of pollution-derived magnetic minerals and trace metals in the soils in the study area; (ii) to ascertain the relationship between magnetic parameters and eight trace metals; and (iii) to apportion potential sources of soil contamination and quantify their contributions using a PMF model combined with geostatistical analysis.

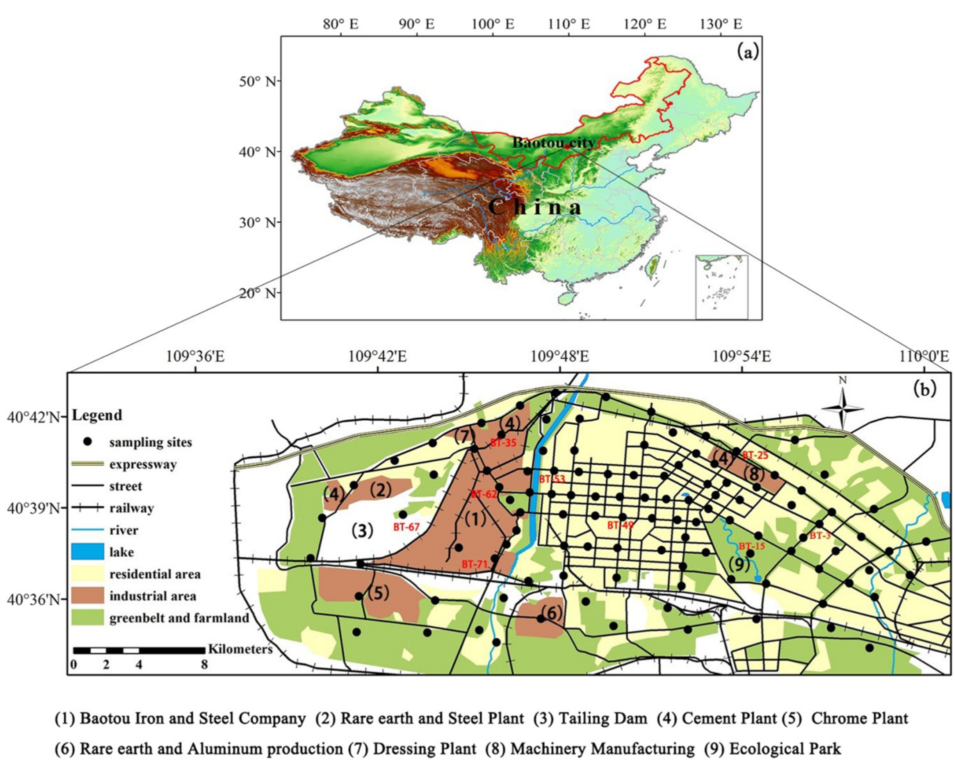

Fig. 1. Location of study area and distribution of sampling sites.