

Quantitative contributions of the major sources of heavy metals in soils to ecosystem and human health risks: A case study of Yulin, China

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ABSTRACT

Quantifying source-oriented risk can identify primary pollution sources to help alleviate risks to ecosystems and human health posed by soil heavy metals. Taking Yulin National Energy and Chemical Industry Base as an example, ecosystem and human health risk assessments of each identified source category were quantitatively calculated by combining the Potential Ecological Risk (*RI*) and Total Carcinogenic Risk (*Total-CR*)/Total Hazard Index (*Total-HI*) assessment models with the positive matrix factorization (PMF) receptor model. In this work, an analysis of the Geoaccumulation Index (*I_{geo}*), Contamination Index (*P_i*), *RI*, *CR* and *HI* of heavy metals (As, Cr, Cu, Zn, Cd, Pb, Hg and Mn) identified universal ecosystem risks and both carcinogenic and noncarcinogenic health risks in most sites. Source apportionment results indicated that the dominant source of heavy metals in the soil was coal-related activities (52.5%), followed by industrial activities (22.0%), traffic activities (13.2%) and agricultural activities (12.3%). The source-oriented quantitative risk assessment results showed that coal-related activities are the greatest contributor to *RI* and *Total-HI*, while industrial activities are the largest source of *Total-CR*, which should be controlled, to reduce the carcinogenic health risk posed by exposure to heavy metals.

1. Introduction

Heavy metals such as Hg, Cr, and Cd and metalloids such as As have attracted great environmental concern due to their abundance, persistence, and toxicity (Bing et al., 2016; Salam et al., 2016). The toxicity of heavy metals has been proven to cause several human diseases (Wei et al., 2016). For instance, excessive intake of Pb can damage nervous and immune systems and chronic exposure to Cd has the potential risks of lung cancer and bone fracture (Zhang et al., 2012). Soil is a repository of surface runoff, wastewater discharge and atmosphere pollutants accumulated via dry and wet deposition (Gulan et al., 2017). Most soil polluted heavily by metals is due to heavily-polluting factories, mining exploration, coal combustion, traffic emissions, sewage runoff, and agriculture activity (Li et al., 2014; Wu et al., 2016). Heavy metals are nonbiodegradable pollutants that can accumulate in the soil (Wei et al., 2016) and eventually enter the human food chain (Karamanis et al., 2009; Pentari et al., 2006). Therefore, it is essential to evaluate metal concentration distributions, identify their sources and understand the environmental risks of heavy metals in soils to protect ecological systems and human health.

The quantitative identification of potential sources of heavy metals in soils is of great importance to controlling the priority pollutants (Liu

et al., 2017; Vu et al., 2017). The source apportionments for heavy metal concentrations in soils have been analyzed by receptor models, such as principal component analysis-multiple linear regression (PCA-MLR) model and positive matrix factorization (PMF) model, which are based on assumptions of significant correlations of compounds derived from the same sources (Bai et al., 2016; Jiang et al., 2017; Liang et al., 2017a; Liu et al., 2017; Wang et al., 2016a; Yang et al., 2017).

Heavy metal risk assessment approaches include single element pollution indices (such as enrichment factor, contamination index and geoaccumulation index) and multielement pollution indices (such as nemerow pollution index, potential ecological risk and health exposure risks). These assessment approaches are employed to study the risks to ecological and human health posed by heavy metals (Bing et al., 2016; Fang et al., 2012; Jiang et al., 2017; Li et al., 2017, 2014; Vu et al., 2017). Health exposure risks, including total carcinogenic risk and total hazard index (non-carcinogenic risk), are widely used to comprehensively evaluate the potential risks to human health associated with exposure to multiple heavy metals (Jiang et al., 2017; Li et al., 2017; Peng et al., 2017).

Substantial research has been conducted for the ecological and human health risk assessments of heavy metals in soil sampling sites (Islam et al., 2017; Kowalska et al., 2016, 2018; Mazurek et al., 2016; Vu et al., 2017).

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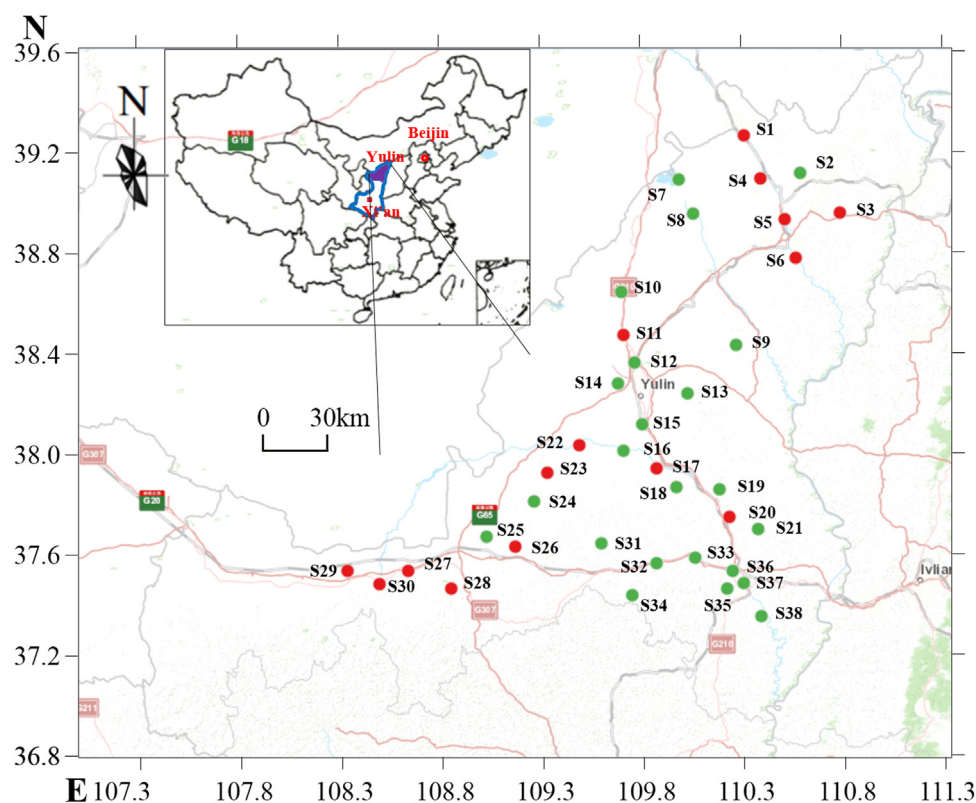


Fig. 1. Map of the study region and sampling sites (red sites near the non-sensitive land and green sites on the sensitive land).

Current research concerning the risk of heavy metals in soils only focuses on the receptor risk, ignoring the source-oriented risk. However, the constituents of heavy metals differ due to source activity, land use, and initial composition, hence causing the metals to exert different distribution patterns and risk levels (Chen and Lu, 2018; Guan et al., 2018; Hu et al., 2018; Liang et al., 2017a). Thus, the greatest contributing source of the total heavy metal concentration does not necessarily contribute the most to risk (Peng et al., 2017; Thurston et al., 2011).

Receptor risk assessment and source-oriented risk analysis are essential for controlling the priority source. The analysis of ecosystem and human health risks of source is conducive to our understanding of the contribution of various source categories to the increasing knowledge of potential adverse effects due to heavy metals in soil. The method established in this work can be applied to derive quantitative source-oriented risk assessment and manage the priority control contaminant sources for protecting ecological environment and human health.

Located in northwestern China, the Yulin Region houses an energy chemical industry base that is based on coal, oil and other resources (Lei et al., 2012). Agricultural production is well-developed in this area, with high applications of chemical fertilizer and pesticides. Therefore, this area is highly exposed to various heavy metal sources. Until recently, no environmental data on evaluating the level of metals and the risk assessment for soil pollution in this region had been published.

The objectives of this study were as follows: (i) to investigate the concentration distribution of heavy metals as well as the ecological and human health risks in the study region; (ii) to apportion sources of heavy metals using PMF models; and (iii) to quantitatively and spatially identify source contributions to ecosystem and human health risks, combining the PMF model with the Potential Ecological Risk (RI) and Human Health Exposure Risk assessment models. This study's results will help in alleviating or controlling ecosystem and human health risks

posed by exposure to the heavy metals in soils by controlling the anthropogenic sources that cause these risks.

2. Methods and models

2.1. Study region

The Yulin National Energy and Chemical Industry Base is located in Shaanxi Province (Fig. 1), which is one of the priority desertification development regions in northern China. Because the region's natural landscape is divided into the northern Mu Us Sandy Land area (mainly dominated by fine sand soil and sandy loam soil) and the southern Loess Plateau area (mainly dominated by loess loam soil) with the Ming Great Wall as the boundary, its ecosystem is very fragile and highly sensitive to environmental influences (Zha et al., 2008; Zhang et al., 2003). In 2015, the grain sown area was 654 thousand hectares. The region is abundant in mineral resources, including large reserves of coal, gas, salt and petroleum. Approximately 30 years ago, a coal chemical and petrochemical industrial complex base was developed and became the mainstay of the local economy (WU Chengzhong and SHU Shiguang, 2014). The presence of several highways with heavy traffic enormously influences the environment of this area (Fig. 1). This area currently has a total of 91 national key monitoring companies in operation, including a million tons of coal oil industry, a petroleum refinery, and a number of coal mining and coking, petroleum natural gas exploitation, thermoelectricity generation, and manufacture industries. In recent years, possible adverse health effects for humans living in areas with such industry bases have become an increasing concern (Bhuiyan et al., 2010; Li et al., 2018; Liang et al., 2017a; Tang et al., 2018). It is therefore necessary to assess the various inorganic and organic pollutants in the area and apportion their respective sources and risks for

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