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Dominant factor affecting Pb speciation and the leaching risk among land-use types around Pb-Zn mine

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ABSTRACT

Soil lead (Pb) pollution around the mining area has severely threaten human health. However, Pb leaching risk in soils with different land uses and which is the proper land use are still unknown. In this work, Pb speciation characteristics and the dominant soil factors affecting Pb speciation in three land uses (farmland, woodland, and grassland) surrounding the Pb-Zn mine in Feng Country, Shaanxi province were investigated. Moreover, the Pb leaching risk and associated determining factors were evaluated by the combination of leached Pb concentration and structural equation model (SEM). The results showed that farmland presented the highest total Pb content (410.1 mg kg^{-1}) among three land use types. The reducible fraction of Pb (Fe-Mn oxides bound) was the major speciation ($> 50\%$) in all tested soils of three land-use types. Soil total phosphorus (TP), water content (WC), and pH play major role in regulating Pb speciation. Though soil biological properties, like microbial communities, catalase, and microbial biomass nitrogen (MBN) exhibited distinct responses to three different land uses, they showed minor influence on Pb speciation. More interestingly, SEM analysis indicated that Pb leaching risk was directly linked with bacteria abundance, total Pb content, clay content, and C/N. Grassland presented the higher predicted Pb leaching concentration (85.03 mg kg^{-1}), compared with that in woodland, suggesting that grassland was the worst land-use type to buffer the Pb toxicity. Woodland could be recommended as the proper native land use to alleviate environmental risk. Overall, our results demonstrated the dominant factor to regulate Pb speciation and pointed out the proper land-use in relieving Pb leaching risk around Pb-Zn mine. These finding provides the new strategies to the remediation and management of metal-contaminated soil.

1. Introduction

Soil pollution by lead (Pb) in the mine tailings and surrounding area has been the focus due to the high health risk (Li et al., 2014). Pb, which is emitted from smelters in flue gases or incorporated into solid wastes, would reach the soil and result in significant contamination at local-to-regional scale. However, these large area of polluted soil was still utilized in various land-use types, such as woodland, farmland, grassland, etc. (Wei and Yang, 2010). Land-use types can affect soil quality to regulate Pb bioavailable and biotoxicity (Marzaioli et al., 2010). Thus, it is necessary to investigate Pb mobilization in soil with different land uses and find out the key factors that determine Pb biotoxicity. Furthermore, the evaluation of environmental risks under different land use patterns and the seeking of safe land use type are of great significance to human health.

As it is known, the toxicity and mobility of Pb in soil were not only affected by the total concentration, but also by its geochemical speciation i.e. exchangeable, iron-manganese oxide-associated, organic-associated and residual forms. Exchangeable fractions are considered to be bioavailable; oxide- and organic matter-bound fractions may be potentially bioavailable; while the residual fraction is mostly not available to either plants or microorganisms (Rodriguez et al., 2009). These fraction distributions are affected by complex environmental factors, like soil properties, plant species, and microbiological processes, which were mainly determined by land use types (Li et al., 2009). Wang et al. (2008) have concluded that soil particle-size distribution was significant different under 5 land-use types (woodland, shrub land, grassland, terrace, and abandoned slope farmland). Subsequently, Marzaioli et al. (2010) proved that several physical, chemical and biological parameters in soils were affected by different land use

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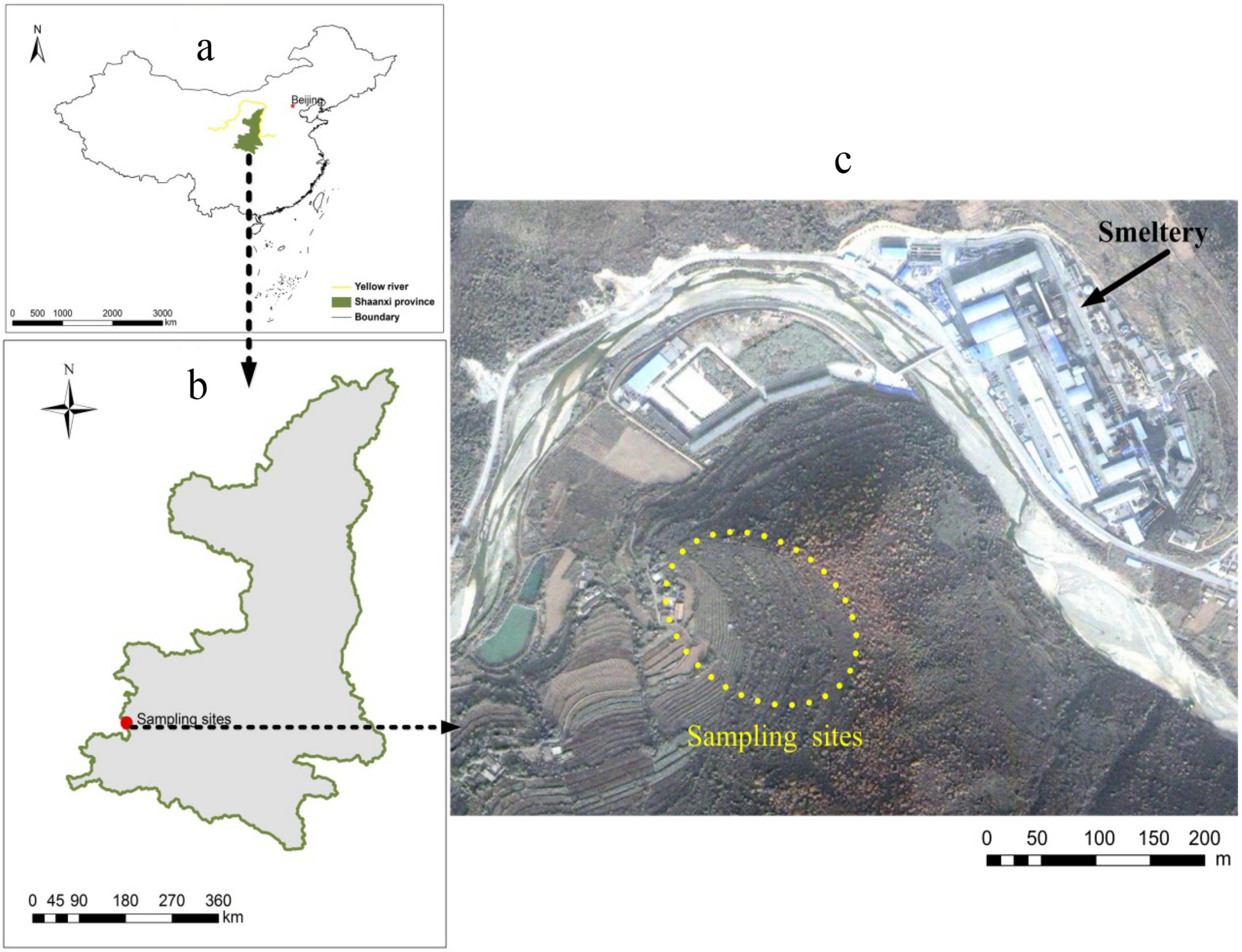

Fig. 1. Map of sampling area. a and b show the map of China and Shaanxi province, respectively. c shows the specific sampling area which is marked with the yellow dots. The smeltery was marked by black arrow. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

types (i.e. permanent crops, grazing lands, shrublands, coniferous and mixed forests). They also concluded that different land uses led to distinct heavy metal contents (chromium, copper, and zinc) in soils. Total Pb content in classical garden was reported to be almost twice than in other land use types (business area, public green space, residential area, and roadside area) (Xia et al., 2011). Zheng et al. (2005) also stated that Pb in greenbelt and orchard were significantly higher than those in other land use types (paddy field, vegetable field, and wheat field). Moreover, land use type could change the distribution of diethylene triamine pentacetate acid (DTPA) exactable form of heavy metals in the soils through affecting soil organic matter (Mahmoudabadi et al., 2015). Metals (except Ni) mobility decreased in the following order: wetland > dryland ≥ paddy field > forest land (Zheng et al., 2016).

Thus, it is believed that land-use type influence on Pb speciation should be considered in the Pb contamination evaluation systems. Limited relevant studies have been carried out and proved that heavy metals i.e. Cd, Cu, Pb and Zn had distinct concentration among several land uses (Wei and Yang, 2010; Xia et al., 2011; Zheng et al., 2005). However, these primary studies focused only on total Pb contamination with neglecting of Pb speciation distribution. Therefore, the dominant soil properties under different land uses regulating Pb speciation and toxicity are still unknown, which hinders the effective strategies to the remediation and management of Pb-contaminated soil around Pb-Zn mine. Moreover, in most previous studies of evaluating Pb biotoxicity, stimulated Pb polluted soils by artificial addition were employed. For example, the effects of plant species coexistence on soil biotoxicity under Pb pollution were studied by adding 200 and 500 mg Pb [applied as $Pb(NO_3)_2$] into 1 kg dry weight soil (Gao et al., 2010). Another study of Pb effects on soil biotoxicity was undertaken with brown soil in a greenhouse by adding different $Pb(NO_3)_2$ contents for a period of 10 weeks. (Pan and Yu, 2011). Zheng et al. (2017) also carried out the study of Pb influence on soil enzymes by supplementing $Pb(Ac)_2$ as the simulated Pb pollution in a plastic vessel for 15 days. These short-term and simulated Pb pollution results may obtain some unrealistic conclusions due to the different Pb pollution sources, which underestimate or overestimate the Pb exposure risk. Besides, in studies referring to the actual Pb pollution, the biotoxicity evaluation mainly depended on plant accumulation and limited microorganisms. For example, a study was designed to investigate the potential human health risks associated with the consumption of okra vegetable crop contaminated with toxic heavy metals. The crop was grown on a soil irrigated with treated wastewater. It was concluded that the okra tested was not safe for human use, especially for direct consumption by human beings. (Balkhair and Ashraf, 2016). Some native wild plant species were used to assess the Pb toxicity. The examination of Pb content in them showed