Pollution, fractionation, and mobility of Pb, Cd, Cu, and Zn in garden and paddy soils from a Pb/Zn mining area

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Abstract This study was conducted to investigate the pollution load index, fraction distributions, and mobility of Pb, Cd, Cu, and Zn in garden and paddy soils collected from a Pb/Zn mine in Chenzhou City, China. The samples were analyzed using Leleyter and Probst’s sequential extraction procedures. Total metal concentrations including Pb, Cd, Cu, and Zn exceeded the maximum permissible limits for soils set by the Ministry of Environmental Protection of China, and the order of the pollution index was Cd > Zn > Pb > Cu, indicating that the soils from both sites seriously suffered from heavy metal pollution, especially Cd. The sums of metal fractions were in agreement with the total contents of heavy metals. However, there were significant differences in fraction distributions of heavy metals in garden and paddy soils. The residual fractions of heavy metals were the predominant form with 43.0% for Pb, 32.3% for Cd, 33.5% for Cu, and 44.2% for Zn in garden soil, while 51.6% for Pb, 40.4% for Cd, 40.3% for Cu, and 40.9% for Zn in paddy soil. Furthermore, the proportions of water-soluble and exchangeable fractions extracted by the selected analytical methods were the lowest among all fractions. On the basis of the speciation of heavy metals, the mobility factor values of heavy metals have the following order: Cd (25.2–19.8%) > Cu (22.6–6.3%) > Zn (9.6–6.0%) > Pb (6.7–2.5%) in both contaminated soils.

Keywords Pollution index · Fractionation distribution · Heavy metal · Leleyter and Probst’s sequential extraction · Mobility · Contaminated soils

Introduction

Soil contamination with heavy metal is a worldwide environmental concern and leads to bioaccumulation of toxic elements in the food chain, destroys the function and balance of ecosystem, and causes human health problems. Both natural
and anthropogenic activities are releasing heavy metals into soil environment. Solid waste disposal, sludge applications, vehicular exhaust, wastewater irrigation, industrial activities, and metal mining are the major sources of soil contamination with heavy metals (Singh et al. 2005; Khan et al. 2008). Heavy metals such as Pb, Cd, Cu, and Zn are considered the most toxic elements in the environment and included in the US Environment Protection Agency (EPA) list of priority pollutants (Cameron 1992). It is undoubtedly important to know the total metal concentrations for the purpose of evaluating the level of soil contamination. However, many previous studies have shown that the toxicity and mobility of these pollutants depend strongly on their specific forms or binding state (Ahumada et al. 1999; Cornelis 2002; Moćko and Waclawek 2004; Abul Kashem et al. 2007). For this reason, the chemical speciation analysis of heavy metals in soil is increasingly important and attracting more attention. To determine the chemical species of heavy metals in soil, a large number of single and multiple sequential extraction procedures, which use a series of reagents to separate the soil metals into different fractions, have been developed (Tessier et al. 1979; Shuman 1985; Rauret 1998; Leleyter and Probst 1999). Although the sequential extraction methods suffer from non-selectivity and trace element redistribution among phases during extraction, they are still suggested for evaluating the mobility and potentially bioavailable metal fractions in contaminated soils (Gómez Ariza et al. 2000; Kabala and Singh 2001; Abollino et al. 2002; Parat et al. 2003; Pueyo et al. 2003; Banat et al. 2005; Hu et al. 2006). In some research work, consistent correlations between specific metal fractions and plant metal contents were found. Similarly, heavy metals in the water/acid soluble and exchangeable fractions are considered to be the most mobile and available forms present in the soils, followed by the carbonate phase (Tessier et al. 1979; Ahumada et al. 1999; Howari and Banat 2001). The iron and manganese oxide fractions are relatively stable under normal conditions, which are otherwise reduced in acidic conditions (Tessier et al. 1979; Banat et al. 2005). The organic phase is a relatively stable phase in nature, but it can be mobilized under strong oxidizing conditions due to organic matter degradation, leading to a release of the soluble metal (Tessier et al. 1979). The residual fractions are entrapped within the crystal structure of the minerals and represent the least mobile fraction.

The present study was conducted to investigate the pollution load index and properly understand the distributions and mobilities of the selected metals (Pb, Cd, Cu, and Zn) in garden and paddy soils collected from a Pb/Zn mine in Chenzhou, China. The samples of garden and paddy soils were analyzed for total metal concentrations and the pollution load indices were calculated to know the degree of contamination. The fractions of Pb, Cd, Cu, and Zn in both types of soils were determined with Leleyter and Probst’s sequential procedure (1999), which is a new, modified method for studying the availability of heavy metals in soils, containing seven fractions such as soluble with water, exchangeable, carbonates, manganese oxides, amorphous iron oxides, crystalline iron oxides, and organic matters, while the residual fraction (eighth fraction) was also added in this study.

Materials and methods

Site description

The study area is a Pb/Zn mine site (25°48′N, 113°02′E) located about 10 km east of Chenzhou city in Hunan province, China. In this area, the mining activities of heavy metals have been conducted for 500 years and mine tailings have been piled up around the sites. On 25th August, 1985, the big tailing pool dam of Pb/Zn mine collapsed because of heavy rainfall. In that disaster, 85 persons were killed, and both sides of the Dong river channel were covered with about a 15-cm-thick layer of toxic tailings. After the accident, some emergency soil clean-up measures were quickly carried out in some places, and a major portion of the contaminated soil surface was mechanically removed. Nevertheless, most of the contaminated farmlands are still cultivated presently. There were some previous studies on heavy metal pollution in soils and plants around this area (Liao et al. 2005a, b; Liu et al. 2005; Zeng et al. 2005).