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Spatial distribution and environmental factors of catchment-scale soil heavy metal contamination in the dry-hot valley of Upper Red River in southwestern China

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ABSTRACT

The severe soil erosion in the dry-hot valley (DHV) in southwestern China may result in heavy metal pollution in the Red River. However, little is known concerning the level of contamination, spatial distribution and environmental controls of the heavy metals in the soils of the DHV. Heavy metal concentrations in agricultural soils in a typical DHV catchment were investigated. Soil samples from both the topsoil (0–20 cm) and subsoil (20–40 cm) were collected at sixty-two sites, and the soil physical and chemical properties of sand, silt, clay, and organic matter contents; soil pH; bulk density; and the concentrations of Cr, Ni, Cu, Zn, and Pb were determined. Topographic factors of slope gradient, slope aspect, elevation, and topographic wetness index at each site were calculated using DEM. Kriging and canonical correspondence analyses were used to assess the spatial distribution of and environmental controls on heavy metals. The results demonstrated that the concentrations of Cr, Ni, Cu, Zn, and Pb in the DHV were higher than most of the reported values for agricultural soils worldwide and that the DHV may constitute a potential source of heavy metal pollution in the Red River. Considering each heavy metal individually, the vertical distribution in the topsoil and subsoil was similar at all of the sampling sites. High concentrations of Cr, Ni, Zn and Pb were observed at low elevations and low slope areas, and the spatial distribution pattern of Cu was contrary to that of Cr, Ni, Zn and Pb. The concentrations of heavy metals in the topsoil were controlled by both soil and topographical factors, while in the subsoil, they were primarily controlled by soil-related factors. It is concluded that high background concentrations, uncontrolled use of chemical fertilizers, and mining are the sources responsible for heavy metal contamination in the DHV region.

1. Introduction

Soils are a key component of the terrestrial ecosystem and play a key role in food production, biochemical transformations, the cycling of elements and many recreational activities (Morgan, 2009). Due to rapid industrialization and urbanization during recent decades (Kelepertzis, 2014; Sun et al., 2010), some soils have become contaminated by heavy metals accumulated from sources such as vehicle emissions, industrial wastes, mine tailings, and the application of fertilizers and sewage sludge (Wuana and Okieimen, 2011). As a result, heavy metal contamination in soils has become an important environmental issue in recent years (Fu et al., 2014; Micó et al., 2006).

Heavy metal contamination in soils exhibits specific pollutant characteristics. Heavy metals do not decay over time and can be toxic to plants when they exceed specific thresholds. Heavy metals are present in soils at background levels from non-anthropogenic origins and can become mobile as a result of changing environmental conditions or saturation beyond the buffering capacity of soils (Facchinelli et al., 2001).

Accumulation of heavy metals in soils has the potential to inhibit soil functioning, cause toxicity to plants, contaminate the food chain, and promote heavy metal transfer to humans (He et al., 2005). Overland flow and soil erosion are increasingly recognized as important in the transfer of heavy metals from soils to surface waters. Thus, heavy metal contamination can not only affect soil ecology, agricultural production, and underground quality but also influence aquatic ecosystems and cause deformation in fish (Heredia and Cirelli, 2009).

Agricultural production plays a key role in the development of China. However, with rapid industrialization, urbanization, and increasing reliance on agrochemicals, heavy metal contamination in soils has become severe during the last two decades (Pan and Wang, 2012; Wong et al., 2002). A recent study reported that more than 16% of Chinese agricultural soils are contaminated with heavy metals (Song et al., 2013). Heavy metal contamination and the restoration of soils in China have been the subject of much attention and were important components

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in the National "12th Five-Year Plan" for environmental protection (Kelepertzis, 2014; The State Council of the People's Republic of China, 2012). In the past decade, numerous studies have been reported on the concentrations, distribution, and sources of heavy metals in Chinese soils (Shao et al., 2014; Song et al., 2013). However, most of those studies focused on urban soils (Li et al., 2013; Shao et al., 2014), and only a few addressed contamination in the agricultural soils of the dry-hot valley (DHV) region, an ecologically fragile zone with severe soil erosion in China (Zhang, 1992).

The DHV region is characterized by high temperatures (the annual mean temperature is >20 °C) and low humidity (the annual mean precipitation is <650 mm) (Wang et al., 2004). The total area of the DHV is approximately 3.2×10^4 km^2, with the largest proportion distributed in the deeply incised valleys of the Upper Red River (Fig. 1) (Ji et al., 2009; Zhang, 1992). The soils in this area have high geological background values of heavy metals (Ministry of Environmental Protection of the People's Republic of China, 1990). According to the national survey of soil elements, in this region, the background values of Pb are 1.58-fold and of Cu are 1.44-fold higher than the national average. Severe soil erosion caused by high sand content in the soils and steep slopes in the DHV (Yang et al., 2003) may contribute to heavy metal pollution in the river system (Cenci and Martin, 2004; Fu et al., 2012) because of increased sediment loads (He et al., 2007; Le et al., 2007; Miao et al., 2010). Furthermore, hydropower exploitation via the proposed cascade reservoir system in the Upper Red River (Zhai et al., 2007) may submerge parts of the DHV, making this region a potential source of heavy metal pollution in downstream agricultural products, fisheries, and river ecosystems (Phan et al., 2013; Steininger, 2003). However, little is known about the levels of contamination, spatial distribution patterns and sources of heavy metals in the agricultural soils of the DHV.

In this study, the heavy metals in the soils of a typical agricultural catchment in the DHV were studied. Our objectives were to (1) assess heavy metal concentrations, (2) characterize the spatial distribution of heavy metals, and (3) evaluate the impact of environmental factors on soil heavy metals.

2. Materials and methods

2.1. Study area

The study area was located in the Laozhai catchment on the right bank of the Yunjiang River DHV (Fig. 1) in southwestern China. The Yunjiang River, which is also known as the Red River, flows through China, Laos, and Vietnam. The river originates in the Yunnan Province, southwestern China, where it is called Yuanjiang. The Yunjiang DHV is the most concentrated and continuous DHV in China (Zhang, 1992). The area of the

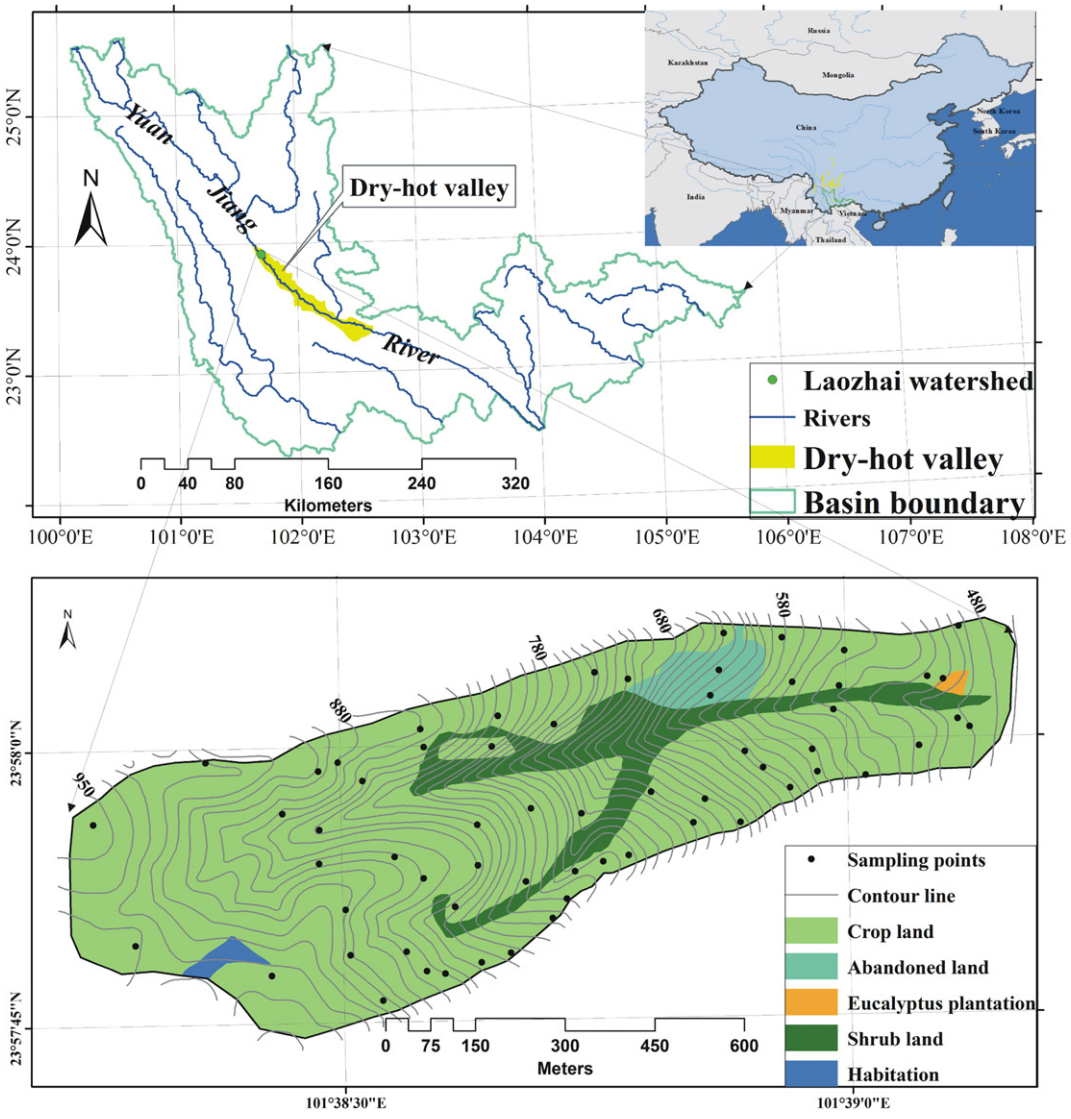

Fig. 1. Study area and spatial distribution of soil sampling sites.