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Multivariate and geostatistical analyses of the spatial distribution and source of arsenic and heavy metals in the agricultural soils in Shunde, Southeast China

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ABSTRACT

An extensive survey was conducted in the study to determine the spatial distribution and possible sources of As and heavy metals in the agricultural soils in the Shunde, a representative area in the Pearl River Delta, China. A total of 238 topsoil samples were collected (0–20 cm) from the study area. The levels of Cd, Co and Ni were then analyzed by inductively coupled plasma mass spectrometry, while the content of Cr was determined by inductively coupled plasma optical emission spectrometry, and As and Hg concentrations were analyzed by atomic fluorescence spectrophotometry. The results showed that the mean concentrations of As, Cd, Co, Cr, Hg and Ni are 16.08, 0.60, 16.76, 78.87, 0.38 and 33.45 mg/kg, respectively. The concentrations of Cd and Hg were far higher than their background values of Pearl River Delta topsoil, and in the study area, 2.10%, 90.86%, 43.27% and 18.07% samples for As, Cd, Hg and Ni were higher than the guideline values of the Chinese Environmental Quality Standard for Soils, especially for Cd and Hg, which are 2.00 and 1.27 times the guide values, respectively. Multivariate and geostatistical analyses suggested that soil Cr, Ni, and Zn had a lithogenic origin. Whereas, soil contamination of Cd and As was mainly related to industrial and agronomic practices, and the main sources of Hg were coal burning exhausts, industrial fumes, domestic waste, and vehicle exhausts. The origin identification of As and heavy metals in agricultural soils is a basis for undertaking appropriate action to reduce their inputs.

1. Introduction

Soil is one of the most important environmental components because it is not only a geochemical sink for contaminants, but also acts as a natural buffer by controlling the transport of chemical elements and substances to the atmosphere, hydrosphere and biosphere (Gallego et al., 2002; Huang et al., 2007). Soil pollution has become an important environmental issue in China owing to rapid urbanization and industrialization, and increasing reliance on agrochemicals in the last several decades (Hu et al., 2013; Sun et al., 2010). In all kinds of soil pollutions, heavy metal contaminations are an important environmental problem because of their non-biodegradable nature and long biological half-live for excretion from the human body (Abollino et al., 2002; Man et al., 2010).

The natural concentrations of heavy metals in agricultural soils depend primarily on the geological parent material composition (Lu et al., 2012; Micó et al., 2006). However, normal agricultural practices can generally cause enrichment of heavy metals (Cai et al., 2010; Nicholson et al., 2003). In agricultural ecosystems, where related agricultural practices are intensive, heavy metals can also reach the soil due to the application of commercial fertilizers, sewage sludge and pesticides, which usually may contain a wide variety of heavy metals as impurities (Chen et al., 2008; Luo et al., 2009). In addition, some areas can suffer increased levels due to the impact of atmospheric deposition caused by their proximity to industrial plants (Cui et al., 2004; Wong et al., 2003) or the combustion of fossil fuels (Huo et al., 2010). The human input of several heavy metals to agricultural soils has exceeded natural input due to pedogenic processes in some local areas, even on a regional scale (Rodríguez et al., 2008; Romic and Romic, 2003).

The Pearl River Delta (PRD) is one of the most advanced regions in China with a high population density, where heavy metal pollution is one of the most important environmental issues (Hu et al., 2013; Wong et al., 2002). Heavy metal pollution has been reported for Dongguan, Huizhou and Guangzhou in this region (Cai et al., 2010, 2012; Duzgoren-Aydin et al., 2006). However, research on this topic is lacking in the Shunde region, one of the most rapidly developing areas in the PRD.

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In the last three decades, the Shunde region has undergone a rapid transition from a traditionally agricultural-based economy to an increasingly industrial- and technological-based economy (Li et al., 2008). The establishment of industrial operations and subsequent expansion of the population have considerably increased industrial and municipal wastewater discharge and other pollutant emissions in the region (Hu et al., 2013). Coupled with the lack of pollution controls, human activities associated with these developments have caused significant impacts on the local environment. An increase in contaminant emissions may pose substantial implications on the local agriculture, as heavy metals may enter and accumulate in agricultural soils through irrigation and atmospheric deposition, which could enhance the risk of metal contamination through the food chains in the region (Cai et al., 2010; Wong et al., 2002). However, little literature exists about the pollution level and source of arsenic (As), cobalt (Co), cadmium (Cd), chromium (Cr), mercury (Hg) and nickel (Ni) in agricultural soils of the area. Therefore, the aims of the study were: (1) to investigate the contents of As, Cr, Co, Cd, Hg and Ni in the agricultural soils of the Shunde region, a typical area in the PRD; and (2) to analyze their possible sources and spatial distributions in soils.

2. Materials and methods

2.1. Characteristics of study area

The study area is the central and west area of the Shunde city, with an area of about 540 km^2 and situates in the center PRD (Fig. 1). The area has a subtropical climate with an average annual temperature 21.9 °C, and an average precipitation of 1649 mm (SBS, 2012). Eighty three percent of rainfall is in the rainy season from April to September. Wind comes from the north in dry winter and from the south or southeast in rainy summer. The soil parent materials in the investigated area are mainly river alluvial deposits from the West River and North River (Li et al., 2008). These river alluvial deposits are transported mainly sediment generated by the weathering of limestone, granite, quartz sandstone, shale and sandstone, and mainly consist of sand, clay and sandy clay. The soil types in the study area are mainly paddy soil, stacked soil and lateritic red soil according to the classification and codes for Chinese soil (National standard, GB/T 17296-2009) recommended by the General Administration of Quality Supervision, Inspection and Quarantine of the P.R.C. (AQSIQ, 2009).

2.2. Sampling and analytical methods

An elaborate investigation of soil was performed in December 2007. A total of 238 topsoil samples (0–20 cm depth) were collected from agricultural fields in the study area (Fig. 1). Soil samples were collected using a wood spade by means of a completely randomized design, on the basis of the sizes of agricultural area, industrial distribution, waste discharging, irrigative water and the prevailing wind direction to assess the human activity on soil quality, and each main soil sample, consisted of 10–15 sub-samples, were randomly taken from the surroundings of each site, pooled and homogenized to form a representative sample and at least 200 m away from industry, traffic and residential areas (Huo et al., 2010). The coordinates of sampling locations were recorded with a GPS (model e Trex Vista H, UniStrong Co.). All collected samples were kept in sealed kraft packages respectively to avoid contamination and transported to the laboratory immediately.

All soil samples were air-dried at room temperature (20–23 °C), removed stones and other debris, then passed through 2 mm polyethylene sieve. Portions of all samples (about 50 g) were ground in an agate grinder and sieved through a 0.149 mm mesh (Lu et al., 2012; Micó et al., 2006). The prepared soil samples were then stored in polyethylene bottles for analysis. These samples were analyzed for pH, organic matter (OM), SiO_2, Al_2O_3, Fe_2O_3, total phosphorus (P), As, Cr, Co, Cd, Hg and Ni. Soil pH was measured in a 1:2.5 soil:water suspension and organic matter concentration was determined by the Walkley–Black method (Cai et al., 2012). The amounts of total SiO_2, Al_2O_3 and Fe_2O_3 were investigated by powder X-ray fluorescence spectrometry (XRF). Before the concentrations of As, heavy metals and total P were measured,

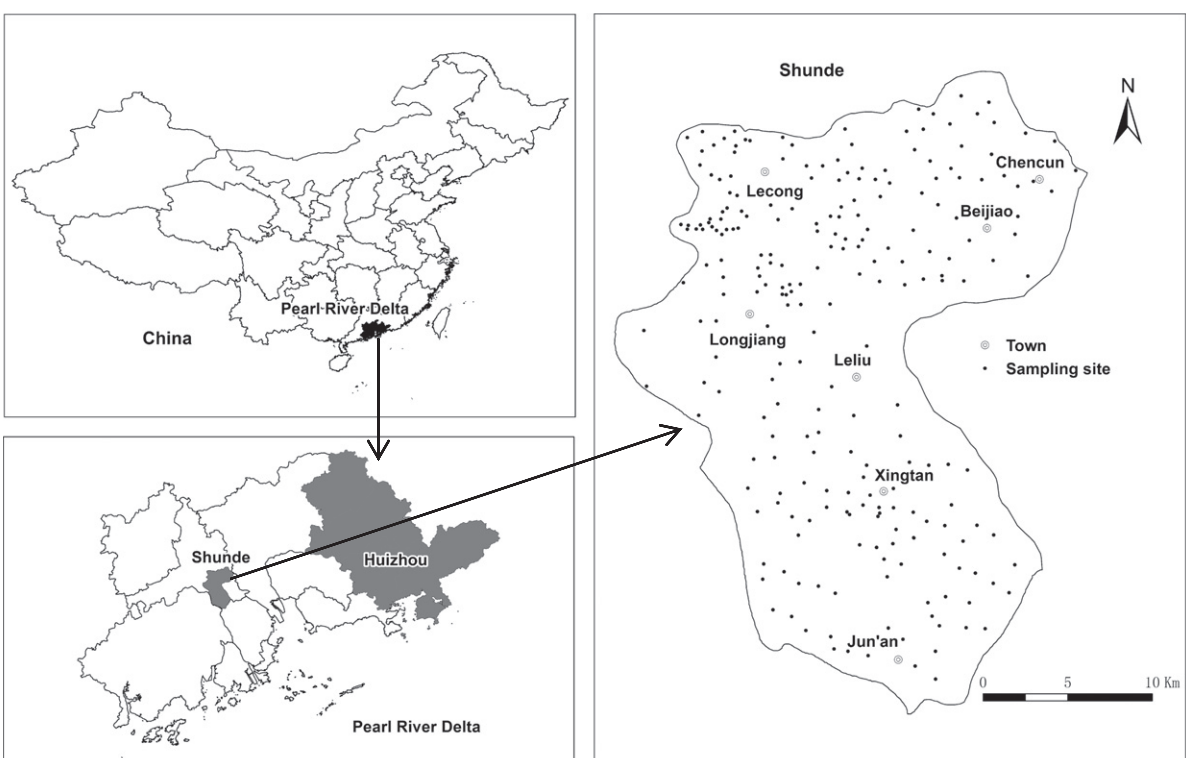

Fig. 1. The location of study area and distribution of sampling points.