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Spatial patterns and correlations of lead concentrations in soil, leaf vegetables and human hair in the Pearl River Delta region, South China

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ABSTRACT

A total of 924 soil samples, 170 leaf vegetable samples and 53 human hair samples were collected to evaluate the regional lead (Pb) concentration levels in soil, leaf vegetables and human hair across the Pearl River Delta (PRD) area. Soil Pb concentrations were greater than the risk screening value of Pb (80 mg kg^{-1}) in 3.5% of the vegetable planting area; about 8% vegetable Pb concentrations were exceeded the national standard of the maximum level of contaminants of 0.3 mg kg^{-1}. Pearson correlations indicated that there was no correlation between soil Pb and vegetable Pb in the study area. Pb concentrations of 12 hair samples were higher than the upper limit of the normal value of 10.0 mg kg^{-1}, and lower than the high-exposure risk value of 25 mg kg^{-1}. Therefore, the young residents in the PRD area had not suffered a high exposure to Pb, but still had a potential health risk. This health risk did not directly come from local leaf vegetable consumption.

1. Introduction

Lead (Pb) is one of toxic metals commonly found in soils. The natural Pb content in soils originates from parent rocks. The overall mean value of natural Pb for different soils has been calculated to be 25 mg kg^{-1} (Kabata-Pendias and Mukherjee, 2007). The major anthropogenic sources of soil Pb pollution include sewage irrigation, application of pesticides and inorganic fertilizers, some mining operations, leaded gasoline, lead-based paint and atmospheric deposition(Zhu et al., 2001; Li et al., 2006; Lee et al., 2007; Niu et al., 2013; Laidlaw et al., 2016). Pb in soils can enter into livestock and human through the food chain (Nabulo et al., 2010; Luo et al., 2012; Li et al., 2012; Chang et al., 2014). Moreover, direct ingestion or inhalation of dust or soil is an important pathway in humans (Kamenov and Gulson, 2014; Laidlaw et al., 2016). Excessive intake of Pb can pose potential adverse health effects to human especially children (Zheng et al., 2007; Norton et al., 2014; Yu et al., 2015).

The Pearl River Delta (PRD) area is the largest industrial center and fastest development area in South China. Due to rapid development of industrialization and urbanization, and lack of effective pollution control measures, the decline of the region's environmental quality has been obvious since the late 1980s. Many studies have reported that the level of Pb contamination in the PRD area was more severe than that of most other trace metals (Li et al., 2000; Zhu et al., 2001; Wong et al., 2002, 2003; Ip et al., 2005; Duzgoren-Aydin, 2007), and pointed out that the Pb concentrations in surface soils were dominantly affected by the anthropogenic activities(Wong et al., 2002; Zhang et al., 2006), which included the mining and smelter operation (e.g. the Fankou Pb ore and Shaoguan smelter, located in the north of the PRD), industrial and vehicular emissions and other sources (Li et al., 2000; Zhu et al., 2001; Wong et al., 2002, 2003; Ip et al., 2005; Zhang et al., 2006; Duzgoren-Aydin, 2007; Luo et al., 2012). The Pb contaminant from these nonpoint sources can elevate the overall background concentrations of surface soils through atmospheric deposition (Zhang et al., 2006).

Although some authors have confirmed that atmospheric deposition was the major pathway for Pb entering the soil environment (Bi et al., 2009; Luo et al., 2012), and the long-range transport of atmospheric Pb is an important external source (Hsu et al., 2006; Witt et al., 2006; Lee et al., 2007), present research around the environmental influence of Pb mainly focused on the assessment of Pb exposure near specific Pb-related locations such as Pb-acid battery factories (Luo et al., 2011) and e-waste processing sites (Chen et al., 2012). Few studies about spatial pattern of Pb in soils, vegetables, and human hair, were conducted at a large regional scale. The aims of this study were to: (1) obtain information on Pb concentrations and spatial patterns in soils and leaf vegetables across the PRD area; and (2) determine relationships between Pb concentrations in soil, leaf vegetables and human hair at

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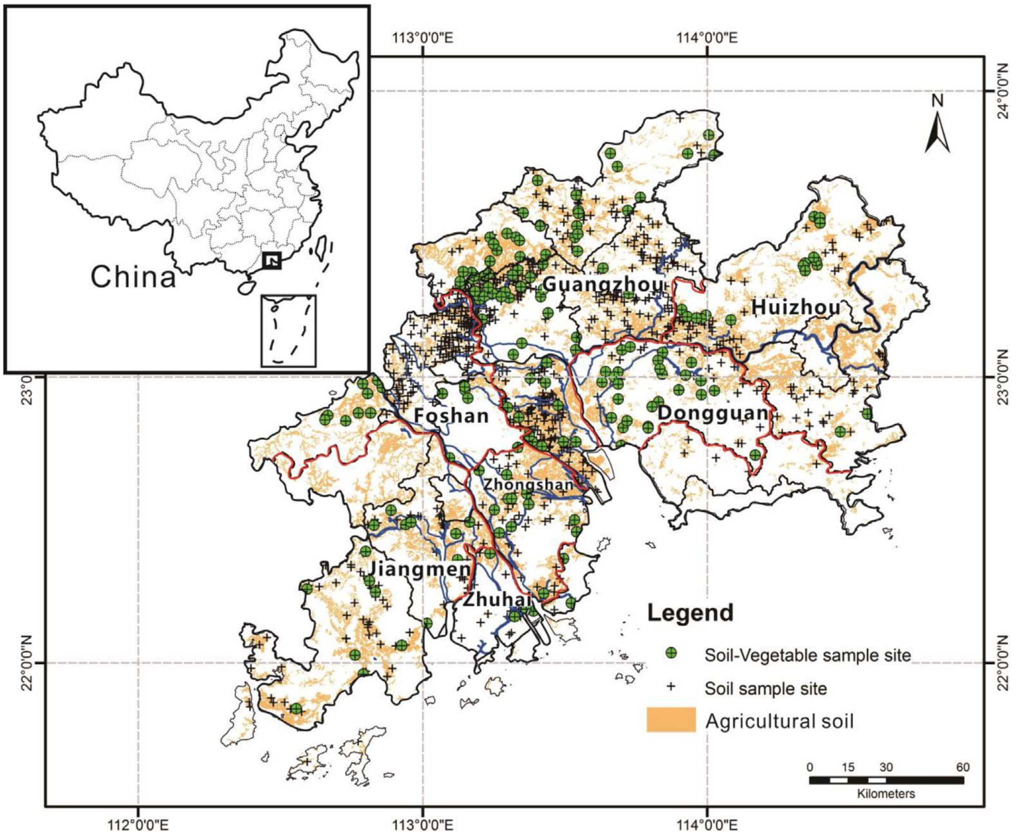

Figure 1. Locations of soil and vegetable samples in the Pearl River Delta area, Guangdong, China (The yellow areas represent the agricultural soils and the red line shows the city boundaries). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

a regional scale. The results of the present study may be used to assess the influence of soil Pb contamination on vegetable quality and human health at a large regional scale.

2. Materials and methods

2.1. Study area

The PRD area is located in the south of Guangdong Province, and covers 41,698 km^2, geographic coordinates is 21.5°–23.0°(N), 112°–115°(E).(Fig. 1). The climate in the study area is subtropical–tropical monsoon with average annual temperature of 21–22 °C and average annual rainfall of 1600–2000 mm (GSGIO, 1993). The main soil types in the PRD area are ferralsols, mostly developed on the parent material of acid igneous rocks in local hills, and paddy soils developed on the fluvial sediments (GSGIO, 1993). In the study area, 10–15 vegetable crops or three rice crops were planted annually, and a rotation of vegetable and rice was usually applied in paddy soils. In the PRD area, the vegetable planting area is about 4830 km^2. The vegetable production was 1129.2 × 10^4 tons in 2011. The leaf vegetables is the dominant consumption for local residents; their planting areas are about 33% of the total planting area (Wan, 2013). The Statistics Bureau of Guangdong Province reported that the export of fresh vegetables were up to 78.3 × 10^4 tons in 2012 (SBG, 2012).

2.2. Soil, vegetable and human hair sampling

A total of 924 soil samples were collected at 0–15-cm soil depth to investigate the spatial distribution of Pb concentrations in the study area during 2009–2010 (Fig. 1). All sample sites were located far away from obvious point source polluted areas such as industries, feedlots, and wastewater stations. Each soil sample consisted of five subsamples, and each subsample was about 1 kg.

One hundred and seventy leaf vegetable samples (corresponding with the soil sample locations) were collected on September 1st to 10th to reveal the correlation between soil Pb and vegetable Pb (Fig. 1). The vegetable species included pakchoi, Chinese flowering cabbage, leaf mustard, Romaine lettuce, Chinese lettuce, water spinach, celery, Chinese chives, spinach, amaranth, and watercress. Each vegetable sample consisted of five subsamples.

We collected 53 hair samples from local young people, 18–25 years old, of both genders (Male: 30 persons; Female: 23 persons), without dyed or treated hair. Hair samples 1–2 cm long were cut with stainless steel scissors from the nape of the neck, close to the occipital region of the scalp, and stored in plastic bags.

2.3. Analytical methods

Soil samples were air-dried at room temperature (25 °C) and ground to pass through a 150-μm nylon sieve. These samples were then digested to dryness using an acid mixture of 10 ml HF, 5 ml $HClO_4$, 2.5 ml HCl, and 2.5 ml HNO_3 (Luo et al., 2012).

The vegetable samples were thoroughly cleaned with tap water and ultrapure water to remove adhering particles, and then the edible parts were separated, weighed (fresh weight), and dried in an oven at 60 °C. The dry samples were ground to fine powder for chemical analysis. The dry samples were ashed in a muffle furnace for 16 h at 500 °C, dissolved in 0.5 M HNO_3, and diluted to 25 ml with deionized water (Luo et al., 2012).

Each hair sample was washed with a solution of 1% of Triton X-100 in ultrapure water for 5 min in an ultrasonic bath. This was repeated with a second wash with ultrapure water and no detergent. Then each hair sample was rinsed with ultrapure water and dried at 50 °C to a constant weight (GRANERO et al., 1998). Three ml of HNO_3 (Merck,