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Geochemical baseline establishment and ecological risk evaluation of heavy metals in greenhouse soils from Dongtai, China

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ABSTRACT

Currently, heavy metal (HM) contamination in greenhouse soils is a significant concern due to the rapid expansion of greenhouse agriculture. However, it is difficult to accurately assess HM pollution in greenhouse soils in China due to the lack of local geochemical baseline concentrations (GBCs) or corresponding background values. In the present study, the GBCs of HMs in Dongtai, a representative greenhouse area of China, were established from subsoils using cumulative frequency distribution (CFD) curves. The pollution levels of HMs and potential ecological risks were investigated using different quantitative indices, such as geo-accumulation index (I_{geo}), pollution index (PI), pollution load index (PLI) and ecological risk index (RI), based on these regional GBCs. The total concentrations of six metals (Cd, Cr, Cu, Ni, Pb and Zn) in surface soils were determined and shown to be lower than the concentrations reported in other greenhouse regions of China. The GBCs of Cd, Cr, Cu, Ni, Pb and Zn were 0.059–0.092, 39.20–54.50, 12.52–15.57, 20.63–23.26, 13.43–16.62 and 43.02–52.65 mg kg^{-1}, respectively. Based on this baseline criterion, Cd, Pb and Zn accumulated in the surface soils because they were present at concentrations higher than their baseline values. The soils were moderately polluted by Cd according to the I_{geo} values, and the PI results indicated that moderate Cd contamination was present in this area. The large variation of I_{geo} value of Cd revealed that Cd in this area was likely influenced by agricultural activities. The PLI showed that most of the study area was moderately polluted. However, an analysis of the RI showed that the investigated HMs had low ecological risks. Correlation analysis and principle component analysis suggested that the Cd, Pb and Zn in the greenhouse soils mainly originated from anthropogenic sources (agricultural activities, atmospheric deposition etc.), while Cr, Cu, and Ni originated from natural sources. The findings of this study illustrated the necessity of GBC establishment at the local scale to facilitate more accurate HM evaluation of greenhouse soils. It is advisable to pay more attention to Cd, which could cause environmental problems in the greenhouse system.

1. Introduction

Increasing demands for food have resulted in more intensive use of existing croplands (de Vries et al., 2013; Tilman et al., 2011), which has promoted the continuous accumulation of heavy metals (HMs) in soils due to the intensive application of agrochemicals, fertilizers and manures (Bai et al., 2015; Rodríguez Martín et al., 2013). Soil pollution in intensive agricultural areas may pose an even greater risk to human health because it can result in greater human exposure to soil and agricultural products than heavily polluted areas (e.g., mining sites and industrial area) (Sultan and Shazili, 2009). Hence, HM contamination of agricultural soils is an environmental issue of major concern due to its potentially negative impacts on the agro-ecosystem.

Greenhouse agriculture, which is a type of intensive agriculture, has expanded rapidly in recent years in China (Bai et al., 2010; Kong et al., 2014; Yang et al., 2013), due to the surging demand for vegetables with an increasing population (van Grinsven et al., 2015). By the end of 2014, greenhouse agriculture occupied an area of more than 4.1 million hectares in China. To achieve high yields and profits, greenhouse agriculture involves a high multi-cropping index (Bai et al., 2015; Chen et al., 2014), high chemical inputs (e.g., fertilizers and pesticides) (Chen et al., 2014; Sungur et al., 2016), and huge amounts of irrigation (Kong et al., 2014). All of these practices could contribute to HM enrichment in greenhouse soils (Bai et al.,

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2015; Gil et al., 2004; Rodríguez Martín et al., 2013). Thus, there are urgent needs for accurate evaluation of HM contamination to greenhouse soil.

Geochemical baseline concentrations (GBCs) are defined as the natural levels of HMs in soils that have not been influenced by human activities (Bech et al., 2005; Galán et al., 2008). Due to diverse geological properties and dominant soil forming factors (Galán et al., 2008), GBCs can vary widely across regions (Jiang et al., 2013; Micó et al., 2007; Song et al., 2014; Tack et al., 1997). However, because background values (BVs) are lacking for most studied areas, series of data (e.g., the average concentrations in the continental crust or in shale, preindustrial concentrations, etc.) have commonly been used as reference data when determining the HM contamination statuses of soils (Horckmans et al., 2005; Li et al., 2015b; Reimann et al., 2005). As a result, some widely used quantitative indices (Jiang et al., 2013), such as the geo-accumulation index (I_{geo}), pollution index (PI), pollution load index (PLI) and ecological risk index (RI), could contain bias when used to assess HM pollution, and an evaluation error might occur when applying GBCs at a large scale in a specific area (Horckmans et al., 2005; Wang et al., 2011). Hence, the establishment of GBCs at local scales is a priority in agricultural soils to better evaluate HM pollution (Albanese et al., 2007; Baize and Sterckeman, 2001; Galán et al., 2008; Ramos-Miras et al., 2014). The local HM baselines in greenhouse soils in Spain were established by Sierra et al. (2007) and Ramos-Miras et al. (2011). In China, although considerable research of greenhouse soils has been conducted, mainly focused on the assessment of HM contamination (Bai et al., 2015; Kong et al., 2014; Yang et al., 2015), the establishment of local GBC is seriously lacking. Consequently, the objectives of the present work are to i) determine the GBCs of HMs in a specific greenhouse system; ii) evaluate the pollution statuses and potential ecological risks of HMs using the I_{geo}, PI, PLI and RI; and iii) identify possible sources of HMs.

2. Materials and methods

2.1. Study area and sample collection

The study area is located in Dongtai, Jiangsu Province, China, and is adjacent to the coastline of the China Yellow Sea (Fig. 1). This is an area of the transition from a subtropical to warm temperate zone with a monsoon climate and has a mean annual precipitation of 1061 mm and a mean annual temperature of 15 °C. The soils in the study area are mainly Halosols (Gong et al., 2003), which developed from the marine deposits. Although the soils present low fertility, agriculture in this area is based on greenhouse vegetable production, which is one form of intensive agriculture. Different from perennial greenhouses in the northern China (Bai et al., 2015; Kong et al., 2014), seasonal greenhouses in this region are only covered by plastic during winter (from October to the following April). Moreover, vegetables are grown in rotation, i.e., vegetable–vegetable and then wheat–rice/maize rotations. Alternatively, vegetable–corn/bean rotation is also used. A rotation system of alternating intensive (greenhouse) and conventional farming is practiced by individual families. For example, conventional farming (wheat–rice/maize rotation during a year) would be practiced after 5 years of vegetable–vegetable rotation. The main vegetables include cauliflower (*Brassica oleracea* L. var. *botrytis* L.), cabbage (*Brassica oleracea* L. var. *capitata* L.), carrot (*Daucus carota* L. var. *sativa Hoffm.*), radish (*Raphanus sativus* L.), turnip (*Brassica juncea* L. *Czern. et Coss.*), lettuce (*Lactuca saliva*), broccoli (*Brassica oleracea* L. var. *italica Planch.*), pepper (*Capsicum annuum* L.) and watermelon (*Citrullus lanatus Thunb. Matsum. et Nakai*).

According to our investigation, chicken manure, compound fertilizer and urea are the three main fertilizers used for vegetable cultivation in this area. Chicken manure is applied as a basal fertilizer, with a yearly application rate of approximately 22.5–46.95 t ha^{-1} for vegetables. Large amounts of compound fertilizer (581.25–727.5 kg ha^{-1}) and urea (300–767.25 kg ha^{-1}) are applied each year as basal and topdressing fertilizers. Additionally, chemical fertilizers are over-applied to maize by local farmers, while little or no manure addition. The study area is watered infrequently due to high ground water levels. Pesticides are widely used in greenhouse agriculture to control insects and diseases in vegetables and other crops. The frequency of pesticide use is high, i.e., once a month for the prevention of disease and insects, and once a week when insects and diseases occur.

A total of 108 surface soil (0–20 cm) and 31 subsoil (40–60 cm) samples were collected from the greenhouse area using a stainless-steel auger in the spring of 2015 (Fig. 1). The sampling sites were chosen with the aim of representing the entire region, but were not regular due to the location of villages and the lack of permission from some local farmers. The sampling density was approximately 1 sample per 1.7 km^2. Composite samples of 5 random subsamples were obtained within approximately 100 m^2 of each sampling site. Two uncultivated soils (0–20 cm) were taken from the low beaches of the Yellow Sea, which were approximately 8 km away from our study area. These soils were selected as an experimental control because they were minimally affected by human cultivations and had the same parent material with the greenhouse soils. The sample locations were recorded using a hand-held global positioning system (GPS). All samples (approximately 1.0 kg for each) were air-dried at ambient temperature, mixed thoroughly, passed through 2 mm nylon sieves (portions of soil samples were passed

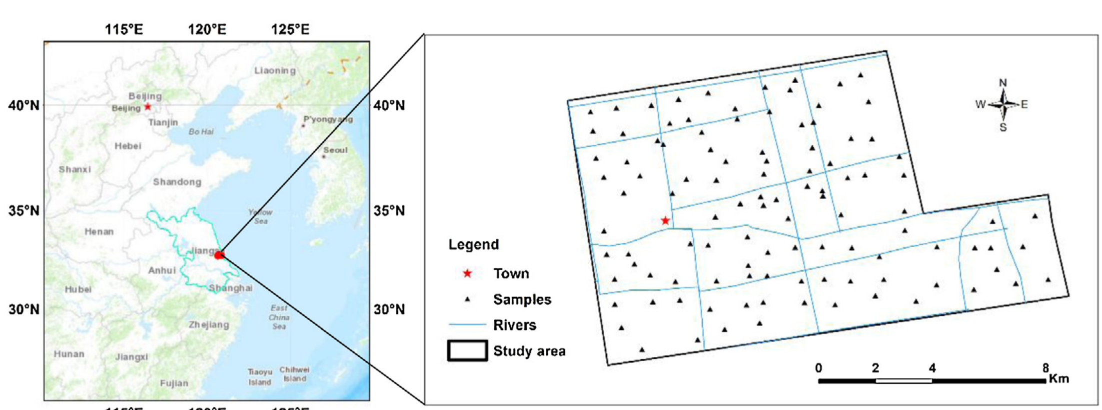

Fig. 1. Location of study area and samples across study area.