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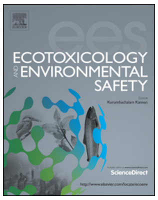

Impacts of human activities and sampling strategies on soil heavy metal distribution in a rapidly developing region of China

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ABSTRACT

The impacts of industrial and agricultural activities on soil Cd, Hg, Pb, and Cu in Zhangjiagang City, a rapidly developing region in China, were evaluated using two sampling strategies. The soil Cu, Cd, and Pb concentrations near industrial locations were greater than those measured away from industrial locations. The converse was true for Hg. The top enrichment factor (TEF) values, calculated as the ratio of metal concentrations between the topsoil and subsoil, were greater near industrial location than away from industrial locations and were further related to the industry type. Thus, the TEF is an effective index to distinguish sources of toxic elements not only between anthropogenic and geogenic but also among different industry types. Target soil sampling near industrial locations resulted in a greater estimation in high levels of soil heavy metals. This study revealed that the soil heavy metal contamination was primarily limited to local areas near industrial locations, despite rapid development over the last 20 years. The prevention and remediation of the soil heavy metal pollution should focus on these high-risk areas in the future.

1. Introduction

With the rapid global economic development, soils in certain regions of the world are being contaminated by heavy metals in excessive amounts. This contamination can cause adverse effects on soil biota and bioaccumulation in plants and may lead to food chain transfer to humans (McLaughlin et al., 1999). The cause of heavy metal accumulation in soils can be either natural or anthropogenic (Krzysztof et al., 2004), including industries (Jan et al., 2010; Chabukdhara and Nema, 2013), agriculture (Gimeno-García et al., 1996; Maas et al., 2010), and urbanization (Chen, 2007). Delineation of heavy metal accumulation into different sources of origin in soils is difficult in cases where multiple sources are involved (Borůvka et al., 2005). The methods commonly used for distinguishing between anthropogenic and geogenic sources of the elements include element speciation (Kaasalainen and Yli-Halla, 2003; Kumar et al., 2013), profile distribution (Sterckeman et al., 2000; Cai et al., 2012), and spatial distribution (Facchinelli et al., 2001). Among the above methods, profile distribution is an effective method to distinguish anthropogenic and geogenic sources of toxic elements (Blaser et al., 2000; Sterckeman et al., 2000), and spatial distribution was also demonstrated by Facchinelli et al. (2001) and Karim et al. (in press).

The land adjacent to industrial sites is vulnerable to heavy metal contamination if used for discharge of poorly treated liquid effluents and disposal of solid waste as well as deposition of exhaust gas from the industries (Fakayode and Onianwa, 2002). Heavy metal accumulation in agricultural soil can also occur via the continuous use of animal manure, fertilizers and pesticides containing trace amounts of heavy metals and using sewage sludge containing metals in excess of recommended critical limits (Alva and Graham, 1991; Gimeno-García et al., 1996; Huang et al., 2006; Wang, et al., 2013). Studies have demonstrated greater concentrations of heavy metals in soils near industrial locations and mines compared with those in soils in non-industrial locations (Krishna and Govil, 2004). It is necessary to identify the association of toxic elements related to the different sources concerned above, and profile and spatial distribution may be effective measures.

In recent years, the heavy metal contamination of agricultural soils has received increased attention in China (Chen, 2007; Huang et al., 2007; Wei and Yang, 2010). However, site selection for soil sampling for heavy metal investigation has often been based on conventional methods, i.e., soil type, relief, and regional factors such as soil utilization and management (Wang et al., 2003) or based on grid networks (An et al., 2004; Huang et al., 2007).

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The above results obtained from somewhat random samplings can be subject to criticism because of their less consideration of local factors such as industrial point-sources or limited sampling points. Some published reports that have indicated excessive heavy metal concentrations in soils may mislead the public or generate public panic (Geo-science Division, 2003). Consequently, it is necessary to conduct further investigations to evaluate the effects of sampling strategy on spatial distribution of heavy metals in soils in selected areas.

Since the 1980s, Zhangjiagang City in the Yangtze River Delta (YRD) of China has sustained rapid economic development. As a result, there has been an expansion of industries along with an increase in animal-based agriculture and large changes in soil management practices. However, the effects of local industry and agriculture on the distribution of heavy metals in soils are unclear because many small-scale factories and agricultural operations are intermixed with farmlands in this area. Consequently, soil pollutants may dramatically change even across very short distances because of the scattered industrial location and agriculture, resulting in complex variability

Thus, a special investigation with a dense sampling strategy was performed in Zhangjiagang City with the objectives of (i) investigating the impact of various industrial and agricultural activities on Cd, Hg, Pb, and Cu accumulation in soils through profile and spatial distribution analysis of the heavy metals and (ii) evaluating the impact of sampling strategies on soil heavy metal distribution. We suggest that the results could be referenced by researchers who are conducting environmental surveys and assessments.

2. Materials and methods

2.1. The study area

Zhangjiagang City is situated on a flat alluvial plain in the YRD, China (Fig. 1). It is characterized as a sub-tropical monsoon climate with four distinct seasons. There is plenty of rainfall with an annual rainfall of 1039.3 mm and a mean annual temperature of 15.2 °C. This region has a population of 860,200 and extends over 799 km^2 terrestrial area, including 404.97 km^2 (40,497 ha) of arable land.

The major soil sub-orders in this region are Aquic Cambosols and Stagnic Anthrosols (SCOSS, 1984; Gong et al., 2003). The soils along the Yangtze River in the north part of the city are slightly alkaline Aquic Cambosols (pH: 7.98 ± 0.24) (Shao et al., 2006), most of which belong to the Anthrostagnic-Dark subgroup, whereas the other soils belong to the Typic-Dark subgroup (Fig. 1). These soils were derived from alluvial parent materials with medium-light loamy texture (SCOSS, 1984). The Stagnic Anthrosols are mainly distributed in flat fields in the southern part of the city (Fig. 1). Most of the soils in this sub-order were identified as the Typic-Fe-accumuli subgroup, while others in less area as Albi-Fe-leachi and Fe-leachi-Gleyi subgroups (Fig. 1). These soils were derived from fairly clayey, neutral and slightly acidic lagoon-phase alluvial materials (pH: 6.33 ± 0.78) (Shao et al., 2006).

Prior to 1980, the prevailing cropping system in the Aquic Cambosols was cotton in summer followed by winter wheat. However, since the 1980s, the summer crop has predominantly been rice. In the Stagnic Anthrosols, the rice–wheat rotation has dominantly been the typical cropping system.

Since the 1980s, Zhangjiagang City has become one of the most rapidly developing areas in the YRD. Approximately 60 percent of the city's total GDP is derived from industries, which include chemical, metallurgical, electroplating, printing and dyeing, paper-making, and animal feeding.

2.2. Sampling

Two sampling methods were adapted in this study to evaluate the effects of sampling method on the concentrations of heavy metals in soils

1. Conventional sampling: Soils were sampled at 386 sites throughout the city in terms of major considerations on the distribution of sampling sites among various areas and soil types, as well as land-use types. Only topsoil (a 0–15 cm plough layer according to the soil description of SCOSS, 1984) was sampled at 6–8 points in each site of approximately 0.17 ha. These samples per site were pooled, thoroughly mixed, and divided into parts of 1–2 kg each. Only one of the parts was packed with a bag and brought back to laboratory for analysis. Subsoil (20–40 cm) sampling was taken only in 27 sites as a measure of background metal concentration.
2. Sampling near industrial locations: One hundred sixty-one industrial locations out of approximately 500 locations with pollutant-discharging designated by the city environmental authority were selected at random for sampling. They were grouped into the following seven groups: chemical, electronic, metallurgical, electroplating, paper-making, textile printing and dyeing, and animal feeding. Sampling sites were mainly decided by the types of waste-discharging industries. Soil samples were taken at 0–15 cm and 20–40 cm in 6–8 points in an area of approximately 0.08 ha with each sampling location spaced 50–100 m downstream from the waste water-discharging outlet. One to two kilograms of the mixed soil per sampling site was taken to the laboratory for analysis. For evaluation of atmospheric deposition of heavy metals from industrial emissions, soil samples were taken from the topsoil and subsoil layer from locations at 50–100 m spacing in the windward or counter-windward direction from the point of discharge. The sampling sites were registered using a global position system (GPS, Garmin eTrex Legend). The land-use history, vegetation, soil type, and present and potential pollutant sources were described for the sampling location.

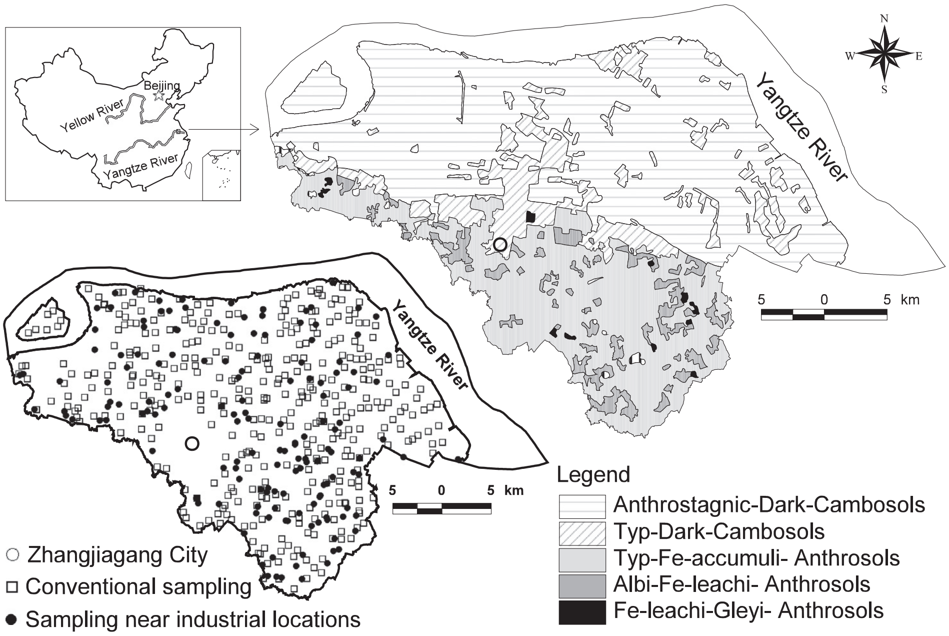

Fig. 1. Soil distribution in Zhangjiagang City.