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Heavy metals in food crops, soil, and water in the Lihe River Watershed of the Taihu Region and their potential health risks when ingested

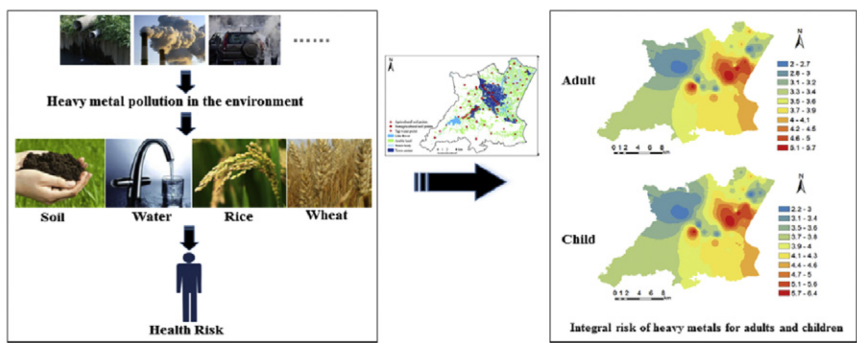
Lian Chen, Shenglu Zhou *, Yaxing Shi, Chunhui Wang, Baojie Li, Yan Li, Shaohua Wu *

School of Geographic and Oceanographic Sciences, Nanjing University, 163 Xianlin Road, Nanjing, Jiangsu 210023, PR China

HIGHLIGHTS

- Elevated concentrations of heavy metals were observed in the soil and crop locally.
- Risk assessment of heavy metal contamination was significant for local inhabitants.
- IR via ingesting rice, wheat, water and soil was high, especially for children.
- Consumption of rice and wheat was the major contribution to risk.
- The spatial distribution pattern of IR was predicted using geostatistical analysis.

GRAPHICAL ABSTRACT



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ABSTRACT

Environmental pollution by heavy metals resulting from rapid economic development is a major concern. Soil, water, wheat, and rice samples were collected from the Lihe River Watershed in the Taihu Region (east China). In this study area, many types of industrial plants, including ceramics factories, plants working with refractory materials, and chemical plants are densely distributed and cause serious heavy metal pollution. In addition, well-developed transportation and agricultural activities are also important sources of heavy metals. Thus, the concentrations of selected heavy metals including cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn) in the samples were analyzed to evaluate their potential integral risk (IR) to the health of the local population. Accordingly, the spatial distribution pattern of the IR values was determined in the study. The soil in the study area showed heavy Cd pollution, whereas the pollution by other elements was relatively slight. When the proportions of grain samples in which the concentrations exceeded the tolerance limits were examined, the grains were primarily contaminated with Pb, Ni, Cd, and Zn; and less contaminated with Cu and Cr. The drinking water of the local inhabitants was safe. The average IR value was 3.53 for adults and 3.91 for children, indicating that both adults and children may experience adverse health effects. The spatial distribution pattern of the IR values among the exposed populations in the study area showed high values in the eastern and middle parts, with maximum values >5, and low values in the western part, with minimum values <2. This is consistent with the distributions of the industries and the population. The study may provide a basis for comparison to other regions both in China and worldwide.

1. Introduction

Heavy metal environmental pollutants of all kinds have received much attention in recent years because of their persistence,

* Corresponding authors at: No.163, Xianlin Road, Qixia District, School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing, Jiangsu 210023, PR China.
E-mail addresses: zhousl@nju.edu.cn (S. Zhou), wsh@nju.edu.cn (S. Wu).

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bioaccumulation, and high toxicity (Liu et al., 2010; Liu et al., 2017; Ma et al., 2016; Singh and Kumar, 2017; Xu et al., 2016). Some heavy metals are essential for biological systems in the human body, acting as both structural and catalytic components of proteins and enzymes, but may be toxic when safe concentrations are exceeded. These include Zn, Cu, and Ni. Other metals, such as Cd, Pb, and Cr, are harmful contaminants even at low concentrations (Bermudez et al., 2011; Gall et al., 2015; Zheng et al., 2015).

Generally, the consumption of foodstuffs and water, as well as the ingestion of soil particles, from contaminated areas can contribute to human exposure to heavy metals. Studies have demonstrated that, except for occupational exposure, dietary intake through contaminated foods has become the main route of heavy metal intake by humans (Bermudez et al., 2011; Ji et al., 2013; Khan et al., 2008). However, the contamination of drinking water with heavy metals in some heavily polluted areas, such as mining areas, metal industry clusters, and so on, also significantly affects human health (Brännvall et al., 2016; Liu et al., 2010). The oral ingestion of heavy metals in soil cannot be ignored and may also pose a health risk to humans. For example, soil ingestion has been implicated in a number of case studies in which it was the main source of Pb exposure in children with elevated blood Pb levels in some areas (Hu et al., 2011; Kumar et al., 2007; Laidlaw and Filippelli, 2008).

In recent years, heavy metal pollution has become increasingly serious (Ran et al., 2016; Singh and Kumar, 2017; Yu et al., 2017). The effective assessment of the health risks to residents is imperative, so that any adverse effects can be avoided to the maximum extent. Although the health risk of heavy metals has been extensively studied (Cai et al., 2015; Chen et al., 2015; Liu et al., 2017), most researchers have only considered the potential health risks of their ingestion via a single pathway (Ahmed et al., 2015; Huang et al., 2008; Lei et al., 2015). Little attention has been paid to the potential integral health risk resulting from ingesting food or soil, and drinking water. Consuming two important cereal crops (rice and wheat), drinking water, and ingesting soil are all important routes by which heavy metals can enter the human body through the mouth. Previous studies have simply calculated the health risk values at specific sampling points, or have averaged the health risk values for different sampling points in a study area (Ahmed et al., 2015; Huang et al., 2008), but no prediction of the health risk posed in a whole study area has been made. Therefore, the IR posed by these four pathways and the proportion of the accumulative risk (AR) posed by each pathway contributing to IR in the study area were quantified. We also predicted the IR spatial distribution pattern in the whole study area using the inverse distance weighting method.

The primary objectives of this study were: (1) to assess the heavy metal pollution levels in the soil, wheat, rice, and drinking water in the Lihe River watershed; (2) to calculate the hazard quotient (HQ) for individual heavy metals, the AR for multiple heavy metals, and the IR for the local residents caused by the ingestion of rice, wheat, soil, and water; and (3) to predict the values of HQ, AR, and IR throughout the study area and analyze their spatial distribution patterns by the inverse distance weighted interpolation method. The results of our study should provide insight into the pollution levels of heavy metals and health risk assessment of human in the Lihe River watershed, and serve as a basis for comparison to other regions both in China and worldwide.

2. Materials and methods

2.1. Description of the sampling sites

The sampled zone is called the Lihe River watershed, and is located to the west of Taihu Lake. Taihu Lake is the largest lake in the China Eastern Coastal Area and the second largest freshwater lake in China. It acts as the control center of regulation and allocation of water resources, and has many functions such as flood protection, water supply, shipping, aquaculture, tourism, and climate regulation in the Taihu Basin. However, the Taihu Basin is located in the south of the Yangtze River Delta, which is one of the most developed and most vigorous regions in China. The Lihe River watershed (between 31° 09′ 00″ and 31° 20′ 31″ N, and 119° 42′ 00″ and 119° 56′ 20″ E), an area of about 260 km^2, is located in the city of Yixing, Jiangsu Province, and includes two towns: Hufu and Dingshu (Fig. 1). There is a second-order stream called the Lihe River in the study area (Fig. 1). The total length of the Lihe River is 28.8 km. It has numerous tributaries, and the main stream extends from Donggui via Dapu into Taihu Lake. To curb the Lihe River flood in 1975, a new course was excavated, and part of the runoff shifted from Lianhuadang into Taihu Lake (Li et al., 2008). The morphology of the study area is highly variable, and includes mountains, hills, and plains. The terrain is high in the southwest and low in the northeast, and the altitude ranges from 20 m to ~610 m above sea level (Li et al., 2006). The study area is in the East Asian Monsoon Climatic Zone and the average annual rainfall is 1288 mm. The precipitation in the flood season (April–October) accounts for about 75% of the annual precipitation. The average annual runoff coefficient is about 0.35. The land use pattern mainly includes woodland (accounting for 45%), arable land (41%), and construction land (11%).

This sampling area was selected because previous studies that biomonitored the soil heavy metal pollution in the river estuaries of the 24 main rivers flowing in and out Taihu Lake revealed that the Lihe River estuary was the most seriously contaminated. Moreover, the potential ecological hazard index (RI) was >220, which indicates that the pollution in this area had reached a serious level and presented a very high ecological risk (Jiao et al., 2010). However, there has been little research into the concentrations and risks to human health of heavy metals in this high-risk area. In consequence, it is necessary to investigate the levels of heavy metal pollution and the associated health risks in the area, where heavy metal pollution is one of most important issues. This is so because its agricultural and industrial production is highly developed and its population is dense.

2.2. Field sampling

The edible parts of crops and the soil in crop fields at a depth of 0–10 cm were randomly collected from 32 sampling sites throughout the study area when the crops were ready for harvest (wheat in May and rice in October) (Fig. 1). Twenty nonagricultural soils were also collected throughout the whole study area (Fig. 1). Each crop and soil sample consisted of 5–9 subsamples and weighed 500–1000 g. A total of 64 crop samples (32 wheat ears and 32 rice ears) and 84 soil samples (32 wheat soils, 32 rice soils, and 20 nonagricultural soils) were collected.

After sample collection, the crops were immediately transported to the laboratory and cleaned with deionized water. The fresh weights (FW) of all the crop samples were recorded before they were oven dried at 60 °C until they reached a constant weight, and their dry weights (DW) were recorded. The crop samples were ground to pass through a 250 μm sieve in a pre-cleaned steel grinder (Li et al., 2012). The soil samples were air dried at room temperature and ground to pass through a 2-mm nylon sieve to remove stones and plant roots. The fine crop and soil powders were then stored in polythene zip bags (Li et al., 2012).

The drinking water in the study area is tap water. An investigation made in October 2016, divided the tap water in the study area into six zones. Therefore, a tap water sample was collected from each of these zones. The six tap water samples were collected from the homes of local families. After collection, the water samples were stored in polyethylene bottles with nitric acid (0.1% *v*/v) added as a preservative (Liu et al., 2010), and were then stored at −20 °C until analysis.

2.3. Questionnaire

A standardized detailed questionnaire on the average daily intake rates of rice, wheat, and water for adults and children was developed.