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Distribution and ecological assessment of heavy metals in irrigation channel sediments in a typical rural area of south China

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ABSTRACT

Elevated levels of heavy metals in sediments of irrigation channels can pose risks for crops and livestock, as well as for human health. In this study sediment samples were collected from the irrigation channel in a typical rural area of south China, and digested, in order to analyze their contents for the presence of heavy metals Cu, Zn, Pb, Cr, Cd, and Ni, as well as the non-metal As, to assess total concentrations and pollution levels. The pollution load index and potential ecological risk index of these elements were utilized to assess contamination levels and ecotoxicity. Our results showed that the concentrations of the 7 elements were in the order of Zn > Ni > Cr > Cu > As > Pb > Cd. With the exception of Cr and Pb, concentrations of elements were higher than their background in soil, especially for Cd (1.79 mg kg^{-1}), As (99.61 mg kg^{-1}) and Ni (142.62 mg kg^{-1}), which were 18.49, 8.89 and 5.30 times their background concentrations, respectively. The whole sampled zone was characterized by medium pollution and had a very high potential ecological risk. The area of arable land presented a medium pollution risk, while areas near to the path or road showed high risk of pollution. The predominant contributors to elevated ecological risk for the whole zone were Cd and As.

1. Introduction

Many water channels were constructed in rural areas of China during the 1950s as part of a major project to increase grain production. Agricultural production increased to some extent, due not only to irrigation, but also to the use of mud from the channels as a kind of fertilizer (Li et al., 2003). In addition, the channels supplied water for the raising of fish as well as for domestic use for local residents. However, due to the lack of proper management, the water channels that once helped people to grow more grain, now pose a threat to the environment (Wenzel et al., 2003), food safety (Rajkumar et al., 2009) and human health (Cai et al., 2009) due to exposure to heavy metal and arsenic pollution.

Our study area is a typical rural area of Jianghan plain, one of China's key regions for grain production. The water channel was built in the 1950s for irrigation in order to maintain local agriculture during dry seasons. With a high population density and a dense network of water channels, Jianghan plain presents severe environmental challenges. Population expansion and industrial development since the 1950s has resulted in significant impact on the ecosystem due to anthropogenic activities such as the discharge of industrial and domestic effluents. All of the water channels are open to the air and are below ground level, and many are close to roads or paths. Run off from roads and paths flows into the channels, and in the absence of effective supervision, large quantities of rubbish are dumped by residents near or directly into the channels. Untreated waste water from fish farms, paddies and residential areas are discharged into the channel, and chemicals may be deposited. Thus heavy metals and arsenic may flow into water channels from roads (Legret and Pagotto, 1999) arable land (Huang

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et al., 2007) residential waste (Varol and Sen, 2012) and local plants (Ma et al., 2006; Huang, 2008). As a result, the channels become seriously polluted, and the heavy metals and arsenic in the water can be transferred directly to grain by irrigation and mud application, eventually affecting human and animal health by exposure via the food chains (Jia et al., 2010).

Due to its serious nature, pollution by heavy metals has raised attention all over the world (Alkan et al., 2015; Ye et al., 2014). Previous studies that have been conducted to assess the risk of heavy metals have been focused on urban areas (Chen et al., 1997; Huang et al., 2007; Wang and Zhang, 2002; Wang and Qin, 2006), mining areas (Bi et al., 2010) and some large water reservoirs (Birch et al., 2001; Yin and Lan, 1995; Song et al., 2010), but not enough attention has been paid to heavy metal and arsenic contamination in undeveloped rural areas. This is especially true in the case of water channels, the pollution of which poses a particular threat as they are closely linked to the daily lives of rural people.

Sediments act as a sink for heavy metals (Lukawska-Matuszewska et al., 2009), because heavy metals have a strong ability to bind with sediments through chemical reactions such as adsorption and complexation (Ghazban et al., 2015), and thus they encode the spatial and temporal distribution patterns of pollution processes (Zeng and Wu, 2007). Sediment is considered an important indicator for elevated water pollution (Frstner and Wittmann, 1981), therefore must also be considered when researching environmental pollution (Kishe and Machiwa, 2003).

Methods most widely used to evaluate heavy metal pollution are potential ecological risk index (ERI) (Hakanson, 1980), pollution load index (PLI) (Angulo, 1996), index of geoaccumulation (Muller, 1981), and sediment enrichment factor (Nriagu et al., 1979). PLI has been widely used to evaluate levels of heavy metal contamination of soil or river sediment, and it reflects levels as well as trends in spatial or temporal variation for each element assessed. However, the concentration of a heavy metal (as well as arsenic) might not accurately reflect its potential pollution levels because the metal may be absorbed by particulate matter, then fixed in the crystal lattice of soil minerals and thus its biotoxicity may be decreased. According to Hakanson (1980), a sedimentological risk index for toxic substances in aquatic systems requires the consideration of three factors: (1) heavy metal concentration, (2) toxic factor, and (3) sensitivity or response of the environment. By combining heavy metal contents with a potential degree of environmental risk one could reflect their pollution levels more accurately (Dou et al., 2007). By combining PLI and ERI together one can quantitatively estimate the extent of pollution from the point of view of environmental chemistry, biotoxicology, and ecology. These two indices have been widely used to evaluate pollution of river (Song et al., 2010), lake (Yin and Lan, 1995), reservoir (Luo et al., 2011) and sea (Alkan et al., 2015). Thus PLI and ERI were employed to evaluate the contamination by the elements researched in this study.

The aims of the present work were: (1) to investigate the water channel sediment contamination by arsenic and heavy metals (Cu, Zn, Pb, Cr, Cd, and Ni) at a particular rural residential area; (2) to evaluate the levels of environmental risk in local water channel sediment, in order to provide insight for management of these channels.

2. Material and methods

2.1. Study area

This study was conducted in 2013 in a rural area of Jianghan plain in south China (longitude 112°37′, latitude 30°22′, altitude 29 m). The experimental zone is a typical area of Jianghan plain, having a dense network of water channels and high population density, with severe resource and environmental challenges. The total area of this zone is 87 hectares. The research area is characterized by a humid subtropical monsoon climate, the mean annual temperature is 16 °C and the mean annual rainfall is 1250 mm. Fertile fields produce about 7.04 t ha^{-1} of grain annually, with main crops: rice, wheat, cotton and oilseed rape. Most rainfall is concentrated from April to August. Soil type is paddy soil. Crops are harvested three times per year, based on paddy rice crop rotation systems such as rice–rice–wheat, rice–wheat–vegetable, rice–oilseed rape–vegetable.

2.2. Sample collection and analysis

The sampling site was surrounded by path or road, the east side bordering on a residential area and the west on arable land. There were two fish farms on the northwest side. The sampling sites were numbered from 1 to 36. Location of sampling sites was based on the distribution of sources of pollution or on their public use (Fig. 1). Sediment samples were collected from the upper 0–20 cm of the bottom of the water channel using a plastic Grab device and stones and foreign objects were removed by hand. Five samples from within an area of 1 m^2 were pooled for each site, air dried and then lyophilized and sieved through a 2 mm nylon sieve. Sediments were then ground with a pestle and mortar until all particles passed through a 0.149 mm nylon sieve. For the analysis of total arsenic and heavy metals, each sample was accurately weighed into 0.15 g fractions and placed into Teflon digestion tubes. The samples were digested with 5 ml HNO_3 and 2 ml HF in a microwave digestion system (Milestone ETHOSONE) for 1 h (Liu et al., 2014). After digestion, the Teflon tubes were cooled to ambient temperature, and then placed on a hot plate at approximately 135 °C for 90 min to allow the evaporation of HF. After cooling, ultrapure water was added to bring the final volume of each solution to 50 ml, and these were then filtered through a 0.45 μm filter membrane and stored in PVC bottles at 4 °C prior to analysis. 7 elements (Cu, Zn, Pb, Cr, Cd, As, and Ni) were analyzed by an inductively coupled plasma–mass spectrometer (ICP–MS) (Thermo X SERIES2). Sediment pH values were measured with a pH meter in water:soil (1:5), sediment organic matter (SOM) was measured using dichromate oxidation (Nelson and Sommers, 1982).

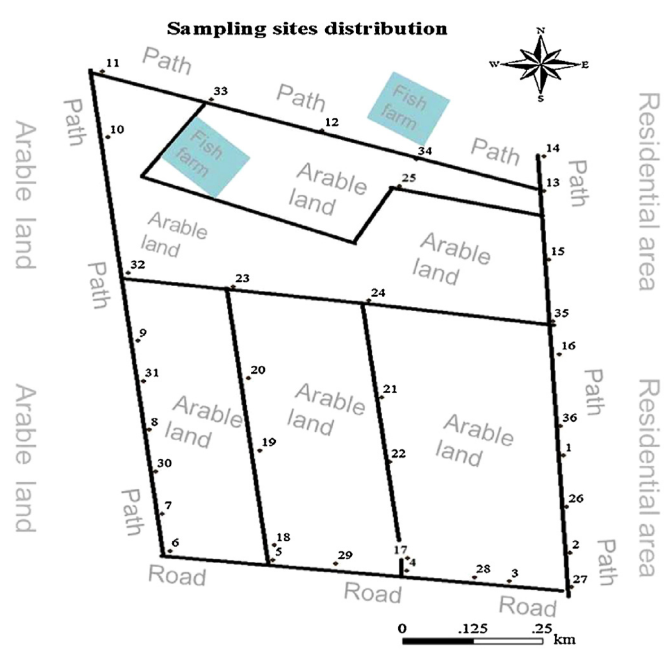

Fig. 1. Distribution of sampling sites.