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Distribution and migration of heavy metals in soil and crops affected by acid mine drainage: Public health implications in Guangdong Province, China

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ABSTRACT

Acid mine drainages (AMD) contain high concentrations of heavy metals, and their discharges into streams and rivers constitute serious environmental problems. This article examines the effects of AMD on soil, plant and human health at Dabaoshan mine in Guangdong Province, China. Although the large scale mining was stopped in 2011, the heavy metal pollution in soil continues to endanger crops and human health in that region. The objectives of this study were to elucidate distribution and migration of Cd, Cu, Zn, As and Pb and associated health implications to local inhabitants. We collected and analyzed 74 crop samples including 28 sugarcane, 30 vegetables, 16 paddy rice and the corresponding soil samples, used correlation and linear relationship for transformation process analysis, and applied carcinogenic and non-carcinogenic risk for hazard evaluation. Results showed that the local soils were heavily polluted with Cd, Cu and As (especially for Cd) and the mean I_{geo} value was as high as 3.77. Cadmium, Cu, and Zn in rice and vegetables were comparable with those found four years ago, while As and Pb in edible parts were 2 to 5 times lower than before. The root uptake of Cd and Zn contributed mainly to their high concentrations in crops due to high exchangeable fraction of soil, while leafy vegetables accumulated elevated As and Pb contents mainly due to the atmospheric deposition. Metal concentrations in sugarcane roots were higher than those in rice and vegetable roots. The risk assessment for crops consumption showed that the hazard quotients values were of 21 to 25 times higher than the threshold level for vegetables and rice, indicating a potential non-carcinogenic risk to the consumers. The estimated mean total cancer risk value of 0.0516 more than 100 times exceeded the USEPA accepted risk level of 1×10^{-4}, indicating unsuitability of the soil for cultivating the food crops. Therefore, the local agricultural and the land-use policies need to be reevaluated.

1. Introduction

Mining activity and processing of metal ores are the double-edged sword for the society, on the one hand, gaining economic benefits of production, but, on the other hand, bringing seriously contamination to the environment. The environmental concern in mining areas is primarily related to physical disturbance of the surrounding landscape, spilled mine tailings, emitted dust and acid mine drainage (AMD), exposing surrounding environment to toxic heavy metals (Johnson and Hallberg, 2005). Toxic metal contamination of agricultural soil and crops, results in phytotoxicity, entering the food chain through the food crop uptake (Pruvot et al., 2006), posing a potential health risk to the local inhabitants in the mine-affected areas.

Notorious mine-affected areas in China, including villages around Dabaoshan mine (Shaoguan City, Guangdong Province), are known to have high cancer rates, even the Shangba village is known as a world-wide cancer village. Mining activities at Dabaoshan have generated large quantities of untreated mine wastes since the beginning of mining in 1970s (Chen et al., 2007). These wastes and AMD have spread down-slope to the Hengshi River mainly used for irrigation of agricultural fields. Previous investigations showed that 83 villages situated at the pollution area, together with 68500 m^2 paddy fields, and 2200 m^2 ponds around

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the mine (Li et al., 2009). The pollution has not only led to severe contamination of soils, sediments, and food crops, but has also resulted in health problems of people. According to the investigation, in villages downstream from the Dabaoshan mine area, found that more than 420 people died of cancers between 1987 and 2014 (Fig. S1), and esophageal, liver and gastric cancer are the most common cancers. In addition, the cancer deaths in 2014 were compared with 2013 and were lower than previous years, but the rate was still high, suggesting that the health risk in this area will continue for a long time.

The heavy metal pollution in the area received extensive attention since 2005, especially after the Cd pollution occurred in the Beijiang River in December 2005. Most of the studies have focused on the environmental impact of AMD, such as water chemistry and toxicity to aquatic life (Lin et al., 2007), heavy metal migration in the water and sediments (Ma et al., 2011), and mineral characteristics of the water affected by AMD (Zhao et al., 2012). Specifically, Zhou et al. (2007) found high level of Cd, Cu, Zn, and Pb in the soil in the mine's vicinity, and Zhao et al. (2012) evaluated the health risk of heavy metals in different land uses near the mine, Cd and As were found to exhibit more toxicity effect to the human health. Zhuang et al. (2009a) measured the heavy metal concentrations in food crops in 2009, and estimated the potential health risks of the consumption of polluted food crops by using calculated target hazard quotient. The results revealed that a great health risk appears to the local inhabitants by consuming rice and vegetables. However, the migration of heavy metal from soil to crop, and the factors affecting migration remains unclear. Moreover, sugarcane is another major crop in the area, the heavy metal pollution and migration behavior has not been concerned before.

The environmental problems of mining have been of increasing concern of various stakeholders (e.g. local and downstream inhabitants). As a result, in early 2011, the Dabaoshan mine was forced by the local authority and the government of Guangdong Province to stop the large-scale mining activities with regard to the environmental and economic aspects. However, the environmental pollution left by the decades of mining activity may last for very long time. Also, a few mining units are still operating for the sake of the economic income. Additionally, the leaking mud-retaining impoundment (MRI) built for preventing landslides has become a stationary pollution source of the Heangshi River (Fig. 1), with a long-lasting perspective until the MRI's impermeability is completely restored. This all makes the pollution situation unclear. It makes, therefore, meaningful to study the distribution of heavy metals in rice, vegetables and the soils to clear the results of the stopped large scale mining. The analysis of the heavy metal pollution in sugarcane is also an important task since it is widely cultivated for raw consumption and extracting sugars.

Therefore, the objectives of the study include investigations of the heavy metals (Cd, Zn, Cu, As and Pb) spreading in three kinds of crops (paddy rice, vegetables and sugarcane) and the soil samples after the large-scale mining was stopped. The risk of the long-term exposure of local inhabitants to the heavy metal pollution through the food crops consumption had been assessed. A correlation analysis between the soil properties and the content of metals in the edible part of crops was undertaken to identify the metal transfer rates and the relevant factors. To the best of the authors' knowledge, this is the first study focusing on metals migration from soil to crops and risk assessment of heavy metals in sugarcane in this mine-affected land area.

2. Materials and methods

2.1. Study area and sampling sites

The Dabaoshan Mine (24°31′02″N, 113°43′26″E) is a well-known poly-metallic sulfide meso-hypothermal deposit, located at the boundary between Qujiang and Wengyuan counties of Guangdong Province in South China (Fig. 1) (Zhuang et al., 2009a; Li et al., 2009). Due to the intense mining activities, especially the illegal mining in recent decades, large amounts of mining wastes have been left on the land surface. These wastes subjected to a

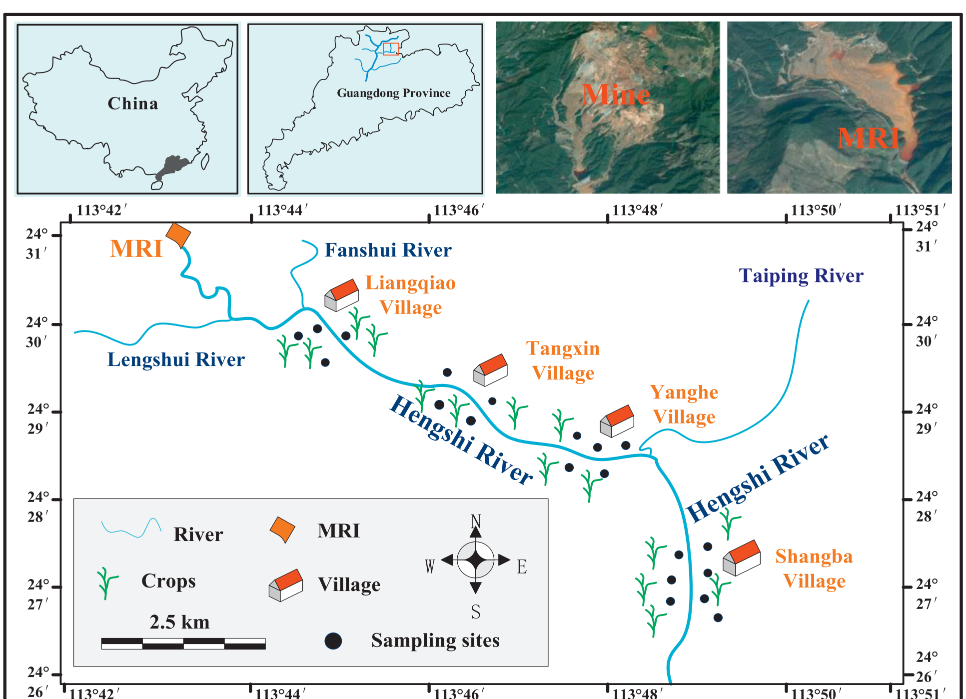

Fig. 1. Location and sampling sites in the four villages of Xinjiang Town along the Hengshi River in vicinity of the Dabaoshan mine area in Guangdong Province, China. The four sampled villages include: Liangqiao (LQ), Tangxin (TX), Yanghe (YH) and Shangba (SB).