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Pollution characteristics and health risk assessment of heavy metals in the vegetable bases of northwest China

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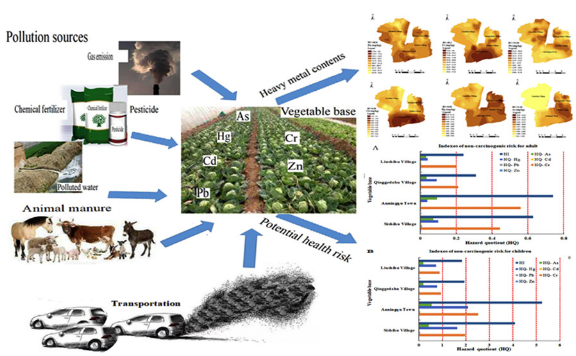
HIGHLIGHTS

- A comprehensive heavy metal pollution and health risk assessment of agricultural soil was conducted.
- Soils of the examined vegetable bases were more seriously polluted by heavy metals than was groundwater.
- Heavy metal pollution in soil leads to high health risks to the public, especially children.
- Major pollution sources affecting the vegetable bases, such as transportation, agricultural activities and stock farming.

GRAPHICAL ABSTRACT



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ABSTRACT

The objective of this study was to investigate heavy metal contamination in four major vegetable bases and determine the health risks of residents in the vicinity of the highly urbanized city Urumqi in Xinjiang, China. In this paper, we determined the contents of six heavy metals (i.e., As, Zn, Cd, Cr, Hg, and Pb) in surface soil and groundwater to evaluate the levels of heavy metal pollution and human health risks using the pollution index (PI), the Nemerow integrated pollution index (NIPI), the ecological risk factor (E^i_r), risk index (RI) and the health risk assessment model. The results showed that (1) The PI, NIPI, the ecological risk factor and risk index indicated that Cd and Hg were the primary pollutants in Sishihu village. These indices suggested moderate to slightly heavy potential ecological risks. In Anningqu town, Hg and Cd led to high levels of pollution and posed slightly heavy potential ecological risks. In Qinggedahu village, it was concluded that the metals Zn, Cr, Cd, Hg, and Pb caused moderate to heavy pollution. In Liushihu village, the pollution trends in the area were low. The results of the pollution level of the irrigation well water (i.e., groundwater) indicated that the well water was considerably safer than the soil, but Cr posed a slight pollution risk. (2) The non-carcinogenic risks for adults based on the HI values of these four vegetable bases were <1. However, when considering the non-carcinogenic risks for children, the HI values were larger than 1 in all areas, indicating the local children have a higher potential non-carcinogenic risk. In addition, CR (Carcinogenic risk) from dermal contact with the vegetables bases did not pose a high risk for residents. However, for adults, the carcinogenic risk posed by Arsenic (As) through trough inhalation was the primary pathway of exposure in three of the vegetable bases, generally in the order of Qinggedahu village

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> Sishihu village > Anningqu town. For children, the carcinogenic risks posed by As through trough inhalation and ingestion were the main exposure pathways. From the TCR results, it can be seen that in Sishihu village, Anningqu town, and Qinggedahu village, the TCR values for adults and children were >1×10^{-4} (unitless), and this degree of carcinogenic risk is unacceptable. (3) The identification of risk sources determined the main pollution sources affecting the vegetable bases were human activities and natural sources. Anthropogenic activities were most often related to traffic pollution sources and agricultural pollution sources, such as the irrational use of pesticides and fertilizers and stock farming. The results are important for designing remediation scenarios to control the spread of contamination as well as for serving as a reference point for soil environmental protection efforts in this region.

1. Introduction

With the rapid development of industrialization and urbanization in China, a series of environmental problems and health risks have progressively increased (Cai et al., 2015; Fu, 2013). Studies that have been conducted in urban environments, particularly those on urban soil contamination, indicate that heavy metal pollution in soil is one of the most controversial issues due to its harmful nature, especially when pollution levels exceed the standard amount (Kim et al., 2016; Zhuang et al., 2016; Aiman et al., 2016). Heavy metals can be spread among and accumulate in plants (i.e., crops and vegetables) and animals, and they can be absorbed by human consumers. An increasing number of reports have shown that heavy metal pollution damages the health of local inhabitants (Singh et al., 2017; Liang et al., 2017). Chronic exposure to Cd (Cadmium) can have effects, such as lung cancer, prostatic proliferative lesions, bone fractures, kidney dysfunction and hypertension (Om and Shim, 2007). High levels of Pb (Plumbum) exposure remain ubiquitous and cause numerous adverse health effects on the nervous system (Kamal et al., 2016), and Pb can cause diabetes mellitus, impair cognitive development and cause cardiac disorders (Sanchez-Soria et al., 2014). The main sources of heavy metals in the environment are geogenic and anthropogenic. Anthropogenic sources are a major cause of concern and are caused by increased levels of human activity (Uyar et al., 2007; Mansor et al., 2010; Mamat et al., 2014).

In agricultural areas, soil quality is an indicator of heavy metal contamination resulting from agricultural activities (Liu et al., 2012). The heavy metals that accumulate in soil significantly contribute to the pollution of agricultural products and indirectly become the main producer of health risks (Rajkumar et al., 2011). Thus, heavy metal contamination and their potential effects on the quality of soil that is subjected to agricultural, domestic and industrial pollution have been widely studied by many researchers (Xiao et al., 2014; Bahloul et al., 2018; Xie et al., 2016). These studies showed that the health risks associated with heavy metal contents in soils are of particular concern (Saha and Zaman, 2013; Khanna et al., 2015; Ganeshamurthy et al., 2008). Agricultural soil that is contaminated by heavy metals poses a higher risk to human beings, especially to children and adults, and these risks are even higher than the health risks posed by street dust and automobile emissions (Pourang, 2014). This is because of their low tolerance to toxins as well as the inadvertent ingestion of significant amounts of agricultural products (i.e., crops and vegetables) that were grown in polluted agricultural fields (Kachenko and Singh, 2006). Vegetables grown in contaminated soils have been identified as the cause for the heavy metal concentrations observed in the blood levels of the residents (Gisbert et al., 2006). Lăcătuşu et al. (1996) reported that soil and vegetables polluted with Pb and Cd in Copsa Mica and Baia Mare, Romania, significantly contributed to decreased human life expectancy within the affected areas, reducing the average age at death by 9–10 years. Though heavy metals are naturally found in soil, excessive concentrations are added as the result of human activities, such as agriculture, urbanization, industrialization and mining (Krishnani and Ayyappan, 2006; Hanebuth et al., 2018; Dimitrijević et al., 2016). A six-year soil pollution study in China showed that the country's soil has been widely polluted by human activities, including industrial, mining, sewage irrigation, agricultural, and farming activities (Zheng et al., 2010). Among these, agricultural sources are considered to be one of the most significant sources of heavy metal contamination (Chabukdhara and Nema, 2013) due to its direct effect on the food chain, and this pollution can lead to human health problems over time (Chabukdhara et al., 2015). From the founding of new China to 2012, the emission of major heavy metals in China increased by >30 times (Tian et al., 2015). In 2014, the national survey of soil pollution in China indicated that 16% of soil samples exceeded the standard rate. As an important resource to ensure human survival and development, farmland soil has a high rate of heavy metal pollution, it's already up to 19.4% (Li et al., 2018).

However, a very limited number of health risk assessment studies have focused on a single or a limited number of mining areas (Li et al., 2017; Zhou and Guo, 2015); actually heavy metal pollution has already began to threat the human life in the agricultural areas where are far from the mining areas, by means of overusing of agricultural pesticides and chemical fertilizer (Rai et al., 2016; Kalaivanan and Ganeshamurthy, 2016), for fully investigating and assessing the agricultural land soil heavy metal pollution level and offer some scientific evidences of environmental protection agencies the specific and targeted study has been being urgently required in some environmentally fragile lands (Tra and Egashira, 1999), such as northwest China. For make up the relative research on this field, this study purposed to assess the pollution levels and the human health risk posed by heavy metals in the vegetable base in northwest China, and the study can provide a scientific basis for the prevention and control of heavy metal pollution in agricultural lands.

2. Materials and methods

2.1. Study area

Urumqi City (86°37′33″-88°58′24″ E, 42°45′32″-44°08′00″ N) is the capital of the Xinjiang Uyghur Autonomous Region of China and is located in the northwest region of China, in the hinterland of continent (Wei et al., 2009). The study area is in the middle zone of Xinjiang, which is at the northern foot of the TianShan Mountains and the southern edge of the Jungger basin (Fig. 1). The urban area of Urumqi is surrounded by the TianShan Mountains from three directions, with peaks up to 5000 m, and there is only a mouth facing northward, where the wind can carry the soil dust into the urban area of the city (Chen and Mai-Maitiming, 2018). The climate is a temperate continental climate, and the annual sunshine hours are 2400–3000 h; additionally, the average maximum temperature is 38 °C, the average annual minimum temperature is approximately −20 °C, and the average temperature is −15 °C in winter. In summer, the average temperature is 23 °C. The average annual rainfall is 260 mm, and the spring rain accounts for approximately 40% of the annual precipitation; finally, the study area has abundant solar heat resources (Chen et al., 2005).

The area of vegetable cultivation in Urumqi City is divided into the vegetables bases of the northern and the southern suburbs. The Anningqu district (Northern suburbs) is situated on the alluvial plain