Chemosphere 184 (2017) 1388–1395

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Multiple factors impact the contents of heavy metals in vegetables in high natural background area of China

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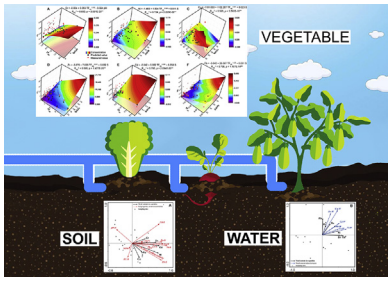
HIGHLIGHTS

- An adjusted transfer factor is adopted to characterize the vegetable species.
- Plant species, total soil metal content and soil pH are the three major factors.
- Bivariate curve equations well predict the metal contents in edible vegetables.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 29 March 2017
Received in revised form
5 June 2017
Accepted 16 June 2017
Available online 18 June 2017

Handling Editor: Petra Petra Krystek

Keywords:
Vegetable
Heavy metal
Adjusted transfer factor
RDA
Multiple regression

ABSTRACT

A field survey was conducted to investigate the concentrations of chromium (Cr), nickel (Ni), copper (Cu), zinc (Zn), cadmium (Cd) and lead (Pb) in vegetables, corresponding cultivated soils and irrigation waters from 36 open sites in high natural background area of Wuzhou, South China. Redundancy analysis, Spearman's rho correlation analysis and multiple regression analysis were adopted to evaluate the contributions of impacting factors on metal contents in the edible parts of vegetables. This study concluded that leafy and root vegetables had relatively higher metal concentrations and adjusted transfer factor values compared to fruiting vegetables according to nonparametric tests. Plant species, total soil metal content and soil pH value were affirmed as three critical factors with the highest contribution rate among all the influencing factors. The bivariate curve equation models for heavy metals in the edible vegetable tissues were well fitted to predict the metal concentrations in vegetables. The results from this case study also suggested that it could be one of efficient strategies for clean agricultural production and food safety in high natural background area to breed vegetable varieties with low heavy metal accumulation and to enlarge planting scale of these varieties.

1. Introduction

Heavy metals are harmful to organisms owing to their bioaccumulation and hazard persistence in the environment (Lenntech, 2016). These metals have detrimental effects on agricultural production, decreasing both yield and quality of vegetables

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http://dx.doi.org/10.1016/j.chemosphere.2017.06.072
0045-6535/

when their concentrations reach toxic levels (White and Pongrac, 2017). The metals accumulated and translocated by vegetables are largely dependent on environmental factors, plant genotypes and anthropogenic activities (Mclaughlin et al., 1999; Qadir et al., 2014). A multitude of studies show that planting condition and agronomic management affect the levels of heavy metals in vegetables. Significant differences have been revealed in trace metal concentrations of vegetables controlling by local traffic and planting style, that crops in urban settings have higher levels of pollutants than those in rural areas (Saeumel et al., 2012). Metal concentrations in plants grown in wastewater-irrigated soils are significantly higher than those in the reference soils (Cao et al., 2016; Khan et al., 2008). Under a particular circumstance, the distributions of heavy metals in vegetables are limited by different plant categories and species. Leafy vegetables tend to accumulate more heavy metals than rootstalk and fruiting vegetables (Yang et al., 2014). They also have higher transportation rates of metals than other vegetable types (Xu et al., 2015), with the order being leafy > rootstalk > fruiting vegetables (Hu et al., 2017).

The transfer factor, considered as the properties of the metal itself, the soil nature and the plant genotype (Sun et al., 2013), is analyzed to characterize the potential capability of metal transmission from soil to plant (Cui et al., 2004; Yang et al., 2014). It is commonly regarded as a constant for a given plant species and a certain metal, so that geometric means are calculated as a characteristic index of a kind of plant (Wang et al., 2006). However, the value of transfer factor, derived from the total soil metal content, is imprecise because of the indeterminate concentration of bioavailable metal which can be absorbed by plant from soil. Hence, the adjusted transfer factor based on the concentration of available soil metal should be established to represent the translocate capability of metal for a particular vegetable variety.

To predict metal concentrations in different edible vegetables, stepwise multiple linear regression analysis was formulated by a host of factors, including soil pH, organic matter and soil metal contents (Hough et al., 2003; Xu et al., 2015). Furthermore, other soil properties, such as electrical conductivity and cation exchange capacity, are suggested to be taken into consideration (Zeng et al., 2011). However, the plant species and the irrigation water should also be included in the scope of factors impacting the metal levels in vegetables. More importantly, a new multivariate curve model should be formed owing to the nonlinear relationship between the factors and the vegetable metal contents.

Guangxi Autonomous Region, one of the five autonomous regions in China, is adjacent to Guangdong Province in the east. This area is renowned for its abundant mineral resources, and is known as one of the ten key nonferrous metal producing units in China. Here, the reserves of 64 kinds of metals rank among the top ten in China, 12 kinds of which rank first in the country (Guangxi Government Portal, 2016). A high background of heavy metals (Cr 82.1 mg kg^{-1}, Ni 26.6 mg kg^{-1}, Zn 75.6 mg kg^{-1}, Cu 27.8 mg kg^{-1}, Cd 0.267 mg kg^{-1}, Pb 24.0 mg kg^{-1}) (CNEMC, 1990) in soil has been created because of the natural geological environment and the special Karst condition (Li et al., 2007a). Wuzhou is situated within the region, and is an important vegetable base in Guangxi. The vegetable planting area and the total yield were more than 790 km^2 and 2 billion tons in this city in 2015, respectively; 60% of these vegetables were exported to the Pearl River Delta, Hong Kong, Macao and other surrounding areas (WBS, 2016). A food survey for Wuzhou in 2010 found that the lead contents in 1 of 14 leafy vegetables and 2 of 11 rootstalk vegetables had exceeded the national standard (0.3 mg L^{-1}) (Chen et al., 2011). Local residents face a high risk of heavy metals when consuming vegetables (Zhong et al., 2017). Therefore, it is essential to study the influencing factors on heavy metals in local vegetables to mitigate the pollution risk in agricultural products.

The objectives of this study are (1) to investigate the influencing factors on the concentrations of six heavy metals in vegetables and (2) to establish the appropriate equation model for heavy metal contents in the edible parts of vegetables by multiple factors.

2. Materials and methods

2.1. Study area

The study area is in Wuzhou, a city of roughly 3.4 million people and approximately 12 588 km^2 in area. This city lies in the region of 22°37′N–24°18′N 110°18′E–111°40′E, with a subtropical humid monsoon climate. There is a moderate fluctuation in temperature from 11.9 °C in winter to 28.9 °C in summer, and average annual precipitation is 1503.6 mm (Wuzhou Government Portal, 2013). The main soil types here are lateritic red soil, purplish soil and paddy soil (Gong et al., 2003).

2.2. Samples collection and preparation

Corresponding vegetable, soil and irrigation water samples were collected from 36 open sites in the area avoiding pollution sources in October 2015, as shown in Fig. 1, depending on the field survey characteristics such as vegetable species, regional differences, soil types and irrigation water types. Sampling points 6–13, 25 and 26 in the vicinity of the city proper were defined as the urban periphery, while other points were considered as the rural area.

The edible parts of vegetables were blended from five random subsamples in each plot, rinsed by deionized water, blotted to

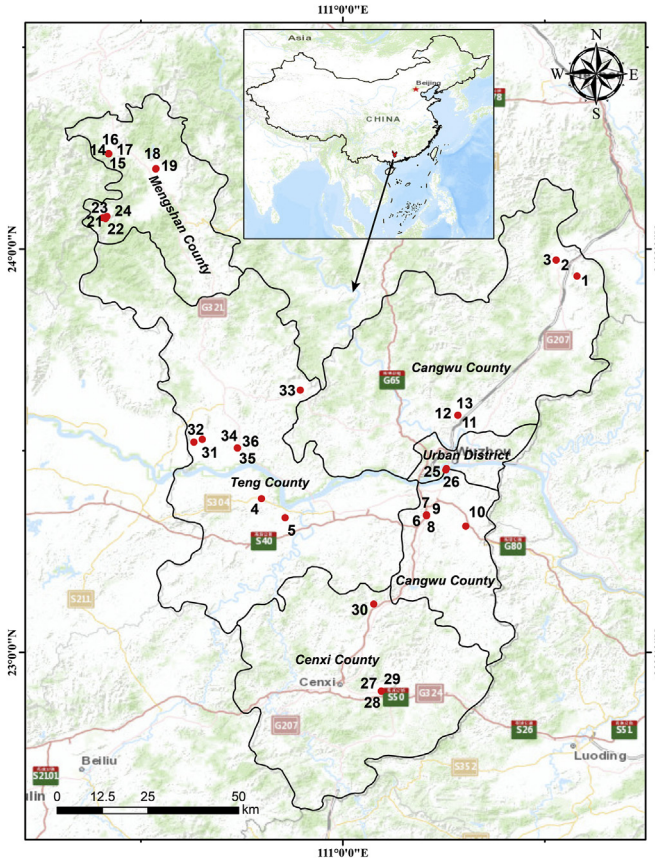

Fig. 1. Map of sampling points collected from Wuzhou, south China.