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Research article

Bioconcentration factors and the risk concentrations of potentially toxic elements in garden soils

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ABSTRACT

Empirical models describe soil-plant transfers to explain the variations in the occurrence of potentially toxic elements (PTE) in soils and to estimate the Bioconcentration Factor (BCF). In this study, results were selected based on data in the literature on soils of humid tropical and temperate regions to evaluate soil-plant transfer models, to calculate the BCF and to derive risk concentrations of Cu, Cr, Pb, Ni and Zn present in the exposure pathway leading to the consumption of contaminated vegetables. The Cetesb (Environmental Agency of the State of Sao Paulo, Brazil) mathematical model was used to derive the risk posed by soil concentrations in urban and rural exposure scenarios. The results of the pseudo total contents of PTE in the soil and the contents absorbed by plants were compared and the BCFs were calculated by the use of geometric means, including a correction factor appropriate to each particular type of soil. Differences were observed between BCFs calculated for each climate region: humid tropical (HTR) and temperate (TE), which the first one presented the highest values to BCF in leaves and the lowest BCF values for root, except Ni, compared to second one. The soil concentrations with the highest risk were found in humid tropical regions as compared with those found in temperate regions, except for Ni. The obtained BCFs may contribute to any future revisions of guideline values as well as help other state environmental agencies to establish their own guideline values.

1. Introduction

Soil contamination affects many developing nations such as Brazil, where soil protection policies first appeared in 2001 with the establishment of a List of Guiding Values for Soils and Groundwaters in the State of São Paulo and the Contaminated Area Management Manual (Casarini et al., 2001; CETESB, 2005). However, federal and state laws governing protection of the soil and the management of contaminated areas were implemented only in 2009 (National Environment Council - CONAMA, 2012). According to São Paulo legislation (Law no. 13,577/2009, regulated by Decree-Law No. 59,263/2013), the soil is contaminated if it contains quantities or concentrations of matter under conditions which cause or may cause harm to the health of the human population, to the environment or to other property deserving protection (São Paulo, 2013, 2009).

The law requires that any suspected area must be investigated in order to confirm or not the existence of contamination by comparing the concentrations found in soil samples or groundwater with generic values calculated on the basis of risk, called Intervention Values or Investigative Values (VI) (CONAMA, 2012; São Paulo, 2013, 2009). Concentrations above the VI levels indicate the need for further investigation and implementation of a risk assessment program, which must be able to quantify the risks to the health of the human population, the environment or any other property deserving protection. Decisions on the intervention measures to be adopted in a contaminated area are to be made based on the risk assessment program.

Exposure of the human population to potentially toxic elements (PTE), such as lead (Pb), copper (Cu), chromium (Cr), nickel (Ni) and zinc (Zn) in agricultural soils may occur through inhalation of particles or through the consumption of soil or vegetables and

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fruits grown in contaminated soils. Mathematical models have been used to estimate exposure for the first two ways; however, the modeling required for the exposure route involved in the consumption of contaminated vegetables is more complex, since any estimate of the concentration of PTE in plants depends on those properties peculiar to any one soil and the physiological factors of plants, which add elements of uncertainty to the estimation of exposure doses (Hough et al., 2004).

The bioconcentration factor (BCF) is the ratio of the concentration of PTEs in the edible parts of plants and the total concentration in soils (Eq. (1)). This index is used in risk assessment models for estimating the concentration of chemical elements in plants, and is subsequently used to quantify the risk of the exposure route associated with the consumption of contaminated vegetables (Melo et al., 2011). However, the BCF is not a constant value, as it may vary for even the same element in soils with different chemical properties (Swartjes et al., 2007).

Melo et al. (2011) gathered results from several studies related to Cadmium (Cd) in both temperate and moist tropical regions and found that the BCF recorded for this element was higher than the measurement recorded in the first region's readings; the difference is being attributed to climatic conditions and soil characteristics. Melo et al. (2011) highlighted the importance of understanding the influence of different soil and climatic regions on plant uptake of PTEs in order to obtain BCFs representative of soils in tropical regions.

This study aimed to select the BCF results from Cu, Cr, Ni, Pb and Zn obtained from experiments carried out in temperate and moist humid tropical regions, in order to evaluate a soil-plant relationship model designed to calculate the BCF and derive risk-level concentrations of PTEs for tropical soils.

2. Materials and methods

2.1. Selection of results from bibliographical references

A database was compiled from the literature in order to derive the soil-plant relationship for lead (Pb), copper (Cu), chromium (Cr), nickel (Ni) and zinc (Zn).

The procedure is similar to this, which is being followed for cadmium (Melo et al., 2011). Selected articles provided results of total and pseudo total concentrations of Cr, Cu, Ni, Pb and Zn in soil and the concentration of PTE absorbed by plants (leaf and root crops) collected from the same location. In addition pH, clay content of the surface layer (0–20 cm) and total organic carbon (C-org) which was estimated, in a number of cases, by dividing the soil organic matter (SOM) content by a factor of 1.724 (Howard, 1965).

The results of PTE concentration in plants (on a fresh weight basis) were obtained by using conversion factors available for the water content in plants as prescribed by Swartjes et al. (2007) and USEPA (1996). Field experiment results were obtained from agricultural areas near potentially polluted areas, such as industrial units, mines, roads, or areas that suffered some application of agro-industrial waste. Results of experiments carried out under controlled conditions in a greenhouse were also used. On the other hand, results obtained from soil which had been artificially contaminated by the addition of salts (spike) were discarded.

The articles selected were grouped by region: (i) temperate (above the Tropic of Cancer, including warm temperate climate (C) and Snow Climates (D)) and (ii) humid tropical (Equatorial Climates (A)) according to the Köppen-Geiger climate classification (Kottek et al., 2006) and were divided into the following two categories based on the edible portion of the vegetable: (i) leafy and (ii) root (tubers, roots and bulbs).

In total 43 scientific articles were selected with results from 26 countries. However, not all the elements were found in all the articles (Table 1). To obtain the soil-plant relationship only PTE values below the Residential Investigation Values established by CONAMA in Resolution No. 420 (Brazil, 2009) were selected. They are as follows: Total Cr (300 mg kg^{-1}); Cu (400 mg kg^{-1}); Ni (100 mg kg^{-1}); Pb (300 mg kg^{-1}) and Zn (1000 mg kg^{-1}). For the study performed by Ding et al. (2013), developed in China, the results from both regions were recorded, since the soils were collected from areas located in both the northern (temperate) and the central (subtropical) regions. No work was carried out in Brazil using the specifications detailed above.

2.2. Procedure for calculating the bioconcentration factor

The Bioconcentration Factor (BCF) was calculated as follows:

$$BCF = PTE_{plant} \Big/ PTE_{soil} \quad (1)$$

The bioconcentration factor (BCF) is the ratio of concentration of PTEs in the edible parts of plants ($PTE_{vegetable}$) and total concentration in soil (PTE_{soil}) in mg kg^{-1}. Many researchers use the

Table 1
Bibliographical references separated by region and country used with to compile database composition.

Country	Element	Reference
Temperate		
Bulgaria	Cu, Pb, Zn	Angelova et al. (2010)
Canada	Cu, Pb, Zn	Murray et al. (2009)
China	Pb	Ding et al. (2013)
	Cu, Pb, Zn	Hao et al. (2009)
	Pb	Huang et al. (2012)
	Cu, Pb, Zn	Li et al. (2006)
	Cr	Liao et al. (2011)
	Cr	Xiao et al. (2013)
Denmark	Cr	Larsen et al. (1992)
Spain	Ni, Pb	Alegria et al. (1991)
	Cu	Castro et al. (2009)
	Zn	Madejón et al. (2011)
USA	Pb, Zn	Cobb and Sands (2000)
France	Cr, Cu, Ni, Zn	Baraud and Leleyter (2012)
Greece	Cu, Ni, Pb, Zn	Fytianos et al. (2001)
England	Cu, Zn	Datta and Young (2005)
	Cu	Davies (1992)
Italy	Cr, Cu, Pb, Zn	Adamo et al. (2003)
	Cu, Ni, Zn	Salvatore et al. (2009)
Kosovo	Pb, Zn	Filipović-Trajković et al. (2012)
Portugal	Cu, Zn	Gonzalez-Fernandez et al. (2011)
Rumania	Cu, Pb, Zn	Lăcătuşu and Lăcătuşu (2008)
	Cu, Zn	Senila et al. (2012)
Turkey	Cu, Zn	Keser and Buyuk (2012)
Humid Tropical		
South Africa	Cr, Cu, Ni, Pb, Zn	Pillay and Jonnalagadda (2007)
Bangladesh	Cr, Cu, Ni, Pb, Zn	Ahmad and Goni (2010)
China	Pb	Ding et al. (2013)
	Cu, Ni, Pb, Zn	Liu et al. (2012)
Ethiopia	Cr, Cu, Ni, Pb, Zn	Itanna (2004)
	Cr, Cu, Zn	Weldegebriel et al. (2012)
Gabon	Cu, Zn	Ondo et al. (2013)
India	Cu, Pb, Zn	Pandey and Pandey (2009)
	Cr	Gupta et al. (2009)
	Cr, Cu, Ni, Pb, Zn	Sahu et al. (2007)
	Cu, Pb, Zn	Singh and Kumar (2006)
Jamaica	Cr, Cu, Zn	Wright et al. (2012)
Nigeria	Zn	Abdu et al. (2011)
	Cr, Cu, Ni, Pb, Zn	Agbenin et al. (2009)
	Cu, Ni	Yusuf et al. (2003)
New Zealand	Cu, Pb	Gaw et al. (2008)
Uganda	Pb, Zn	Nabulo et al. (2006)
Vietnam	Cr, Cu, Ni, Pb, Zn	Marcussen et al. (2008)
Zimbabwe	Cr, Cu, Ni, Pb, Zn	Mapanda et al. (2007)