Ecotoxicology and Environmental Safety 166 (2018) 345–353

Contents lists available at ScienceDirect

Ecotoxicology and Environmental Safety

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

Distribution, pollution, bioaccumulation, and ecological risks of trace elements in soils of the northeastern Qinghai-Tibet Plateau

Leiming Li[a,b,c], Jun Wu[a,b,c,*], Jian Lu[c,d], Xiuyun Min[a,b,c], Juan Xu[e], Long Yang[b]

[a] Key Laboratory of Comprehensive and Highly Efficient Utilization of Salt Lake Resources, Qinghai Institute of Salt Lakes, Chinese Academy of Sciences, Xining, Qinghai 810008, China
[b] Qinghai Provincial Key Laboratory of Geology and Environment of Salt Lakes, Xining, Qinghai 810008, China
[c] University of Chinese Academy of Sciences, Beijing 100049, China
[d] Key Laboratory of Coastal Environmental Processes and Ecological Remediation, Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences, Yantai, Shandong 264003, China
[e] State Key Laboratory of Marine Geology, Tongji University, Shanghai 200092, China

ARTICLE INFO

Keywords:
Trace element
The Qinghai-Tibet Plateau
Soil pollution
Ecological risk
Bioaccumulation

ABSTRACT

Environmental quality of the northeastern Qinghai-Tibet Plateau has attracted more attention due to increasing anthropogenic disturbance. Therefore, this study investigated the distribution, pollution, ecological risks, and bioaccumulation of 12 target heavy metals and 16 rare earth elements (REEs) in soils of this area. The average concentrations of target trace elements in soils ranged from 0.16 (Hg) to 500.46 (Cr) mg/kg. Pb caused more serious pollution than the other elements based on geo-accumulation index evaluation. Hg exhibited the strongest enrichment feature with the average enrichment factor of 8.41. Compare with modified contamination degree and pollution load index, Nemerow pollution index method obtained the most serious evaluation results that 45.67% and 16.54% of sampling sites possessed high and moderate pollution. Evaluation results of potential ecological risk index showed that trace elements in soils posed very high and considerable ecological risks in 34.65% and 7.09% of sampling sites, respectively. Mining area was the region with the most serious pollution and ecological risks. Average bioaccumulation factor (*BCF*) values of target trace elements ranged from 0.05 (REEs) to 2.67 (Cr). Cr was the element that was easier to bio-accumulate in plants of the study area than the other target elements. It is in urgent need to take effective measures for controlling current pollution and potential ecological risks of trace elements in soils of the northeastern Qinghai-Tibet Plateau.

1. Introduction

Trace elements are generally non-biodegradable in natural environments with low concentrations and some of them are essential micro-nutrients (Milićević et al., 2017). Elevated concentrations of trace elements can cause serious environmental problems that not only threaten air, aquatic and soil ecosystems, but also cause food chain accumulation (Cong et al., 2010; Shao et al., 2016). Both natural and anthropogenic factors affect the distribution of trace elements and anthropogenic source is usually a main contributor (Lee et al., 2011). Trace elements including heavy metals and rare earth elements (REEs) have gained public attention in recent decades due to the relatively high concentrations detected in food, water, and soils (Li and Ji, 2017; Magesh et al., 2017; Yang et al., 2017).

Although "Heavy metals" might be a loose term to define metals and metalloids associated with possible pollution and potential toxicity (Duffus, 2002; Hodson, 2004), reports on pollution caused by "heavy metals" are continuously increasing. Moreover, heavy metal pollution has become a global problem because some metals are toxic and ready to accumulate in plants, animals, and humans (Yan et al., 2013; Wang et al., 2014a). Heavy metals are introduced to food chain to cause bioaccumulation and resultant bio-magnifications through diverse biogeochemical cycles (Yang et al., 2011; Zhang et al., 2016), causing a dangerous threat to humans because of their toxicity, persistence, nondestructible, and bioaccumulation (Abrahim and Parker, 2008; Mamat et al., 2016; Ding et al., 2017). Industrial processes, products/bi-products, mining, and discharges including untreated industrial wastes and wastewater are the sources of heavy metals (Avci and Deveci, 2013; Park and Choi, 2013).

REEs are lanthanide series which consist of a coherent group with

* Corresponding author at: Key Laboratory of Comprehensive and Highly Efficient Utilization of Salt Lake Resources, Qinghai Institute of Salt Lakes, Chinese Academy of Sciences, Xining, Qinghai 810008, China.
E-mail address: junwu@isl.ac.cn (J. Wu).

https://doi.org/10.1016/j.ecoenv.2018.09.110
Received 28 July 2018; Received in revised form 21 September 2018; Accepted 25 September 2018
0147-6513/

similar chemical properties (Henderson, 1984; Loell et al., 2011). Background levels of REEs in soils are mainly influenced by weathering, parent materials, and pedogenetic processes (Zhang et al., 2009). Some studies have indicated a gradual increase of REEs in soils caused by anthropogenic inputs such as agriculture, mining and industrial activities (Hu et al., 2006; Kumari et al., 2015). The development of high-tech industry promotes the use of REEs so as to increase the potential hazards of REEs to the ecosystems and human health (Kumari et al., 2015; Krishnakumar et al., 2016). Therefore, it is necessary to determine the concentrations of REEs in the natural environment in order to control the impacts of anthropogenic activity to the environment.

Arising from the rapid social development, pollution and risks posed by trace elements have been determined by diverse methods (Liu et al., 2017b; Ramachandra et al., 2018). Several methods such as geo-accumulation index (I_{geo}), enrichment factor (*EF*), pollution load index (*PLI*), modified degree of contamination (mC_d), and potential ecological risk index (*RI*) are widely employed to evaluate contamination and ecological risks of trace elements in soils and sediments (Wang et al., 2014b; Liu et al., 2018). Trace elements might bio-accumulate in the plants through interaction between soil-plant systems. Thus, bioaccumulation factor is also used to denote pollution (Jeelani et al., 2017; Liu et al., 2017a).

The Qinghai-Tibet Plateau is regarded as the area far from high population, urbanization, and industrialization. However, many studies have showed astonishing facts on environmental quality of this "pure land" in China (Wu et al., 2016, 2018a). Trace elements are detected in diverse matrices such as water, sediments, soils, and biota with relatively high concentrations (Luo et al., 2014; Wu et al., 2018a, 2018b; Xie et al., 2014). The northeastern Qinghai-Tibet Plateau is more populated and industrialized than the other parts. Therefore, the objective of this study is to identify the distribution, possible pollution, potential ecological risks, and bioaccumulation of trace elements in soils of the northeastern Qinghai-Tibet Plateau. The final aim of this study is to provide comprehensive and thorough insight on the trace elements in soils of the northeastern Qinghai-Tibet Plateau so as to put the basis for environmental protection of the similar high-elevation areas.

2. Materials and methods

2.1. The study area, sampling sites, and field sampling strategies

The study area is located in the northeastern Qinghai-Tibet Plateau with average elevation of 3152 m. Field sampling was carried out during June 14th to June 29th, 2017. Topsoil (0–20 cm) and plant samples were collected from 127 sampling sites (Fig. S1). The sampling sites covered 6 kinds of functional zones including background area, agricultural and pastoral area, industrial area, mining area, salt-lake area, and urban area. Soil samples were collected, stored, and prepared according to Wu et al. (2018a) for the following analysis. Plant (*Potentilla anserina* L.) sample was collected using a stainless-steel shovel to obtain the whole plant as possible and stored in a large sampling bag. Plant samples were transported back to the laboratory and stored at −80 °C.

2.2. Chemical analysis

2.2.1. Soil analysis

Soil pH and texture were measure using the same procedure and instruments of Wu et al. (2018a). X-Ray fluorescence (XRF) spectrometers Axios PW4400 (PANalytical B.V., Netherland) was used to analyze the contents of Fe in soils. Soil samples were digested using a microwave dissolution system (SINEO Microwave Chemistry Technology Co., China). The digestion procedures referred to Wu et al. (2018b). The digested soil samples were analyzed by an Agilent7900 inductively coupled plasma mass spectrometry (ICP-MS, Agilent Inc, USA) to determine the concentrations of 12 typical heavy metals including lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), zinc (Zn), molybdenum (Mo), copper (Cu), tin (Sn), mercury (Hg), cobalt (Co), antimony (Sb), and vanadium (V) as well as 16 REEs consisting of lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), Lutetium (Lu), scandium (Sc), and yttrium (Y).

2.2.2. Plant analysis

Potentilla anserina L., a common herbaceous plant grown in the Qinghai-Tibet Plateau, was selected as the target plant of this study. Plant samples (roots and aboveground parts) were thoroughly washed by running tap water to remove soil particles, then rinsed five times with ultra-pure Milli-Q water and blotted extra water with tissue paper. Next the plant samples were dried at 105 °C for 0.5 h and 75 °C for 72 h. Dry plant tissues (root and aboveground part together) were grinded to fine powder in an agate mortar, put into sample bags, and stored in a dryer at room temperature till analysis.

The plant samples were digested in a mixture solution of HNO_3, HCl and HF. Approximately 100 mg of dry plant sample was digested with 5 mL of 65% HNO_3, 3 mL of 37% HCl, and 1 mL of 65% HF (Ayrault et al., 2001; Shen et al., 2018). The other digestion procedures for plant samples were same as those for soils.

2.3. Evaluating pollution, ecological risks, and bioaccumulation of trace elements in soils

2.3.1. Pollution of trace elements in topsoils

Five methods including I_{geo}, *EF*, *PLI*, mC_d, and Nemerow pollution index (*PN*) were adopted to evaluate pollution of trace elements in topsoils of the northeastern Qinghai-Tibet Plateau. The detailed information on calculation of I_{geo}, *EF*, *PLI*, and mC_d referred to previously published articles (Wu et al., 2018a, 2018b). The background concentrations of trace elements in soils used for calculating I_{geo}, *EF*, *PLI*, mC_d, and *PN* referred to MEPC (1990). The calculations of these indices were briefly shown as the followings:

$$I_{geo} = log_2 \frac{C_m^i}{1.5 \times C_b^i}$$

$$EF = \frac{\left(\frac{C_m^i}{R_{sm}}\right)}{\left(\frac{C_b^i}{R_b}\right)}$$

$$PLI = \left(\frac{C_m^1}{C_b^1} \times \frac{C_m^2}{C_b^2} \times \ldots \times \frac{C_m^n}{C_b^n}\right)^{\frac{1}{n}}$$

$$mC_d = \frac{\sum_{i=1}^{n} \frac{C_m^i}{C_b^i}}{n}$$

where C_m^i and C_b^i are the measured concentration and background concentration of the *i*th target trace element in soils, respectively; *n* is the number of the target trace elements; R_{sm} and R_b are the measured concentration of reference element in soil sample and background concentration of reference element in soil, respectively. Elements Al, Mn, Fe, Ti, or Ca can generally serve as the reference elements for calculation of *EF* (Maanan et al., 2004). Considering Fe is an important major element in soils, this study used Fe as reference element to calculate *EF* values of trace elements in soils.

Nemerow pollution index (*PN*) is also applied to comprehensively evaluate soil/sediment quality (Chen et al., 2010; Huang et al., 2018). *PN* is calculated by the following equation: