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Pollution, ecological-health risks, and sources of heavy metals in soil of the northeastern Qinghai-Tibet Plateau

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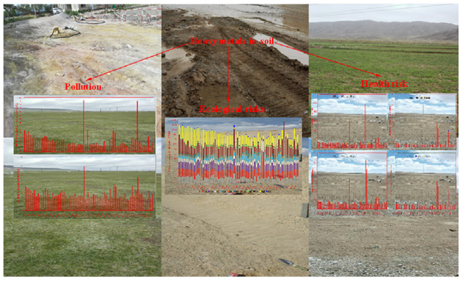
HIGHLIGHTS

- Serious soil heavy metal pollution occurred in the study area.
- The study area showed high ecological risks posed by soil heavy metals.
- Cancer risks of heavy metals were high, especially for children.
- Non-cancer risks of heavy metals for children were high.
- Industrial activities might be the main source for heavy metals in soil.

GRAPHICAL ABSTRACT



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ABSTRACT

The Qinghai-Tibet Plateau, especially the northeastern region, is not a pure land any more due to recently increasing anthropogenic activities. This study collected soil samples from 70 sites of the northeastern Qinghai-Tibet Plateau to evaluate pollution, ecological-health risks, and possible pollution sources of heavy metals. The concentrations of heavy metals in soil were relatively high. Values of geo-accumulation index exhibited that Hg pollution was the most serious meanwhile Hg possessed the strongest enrichment feature based on enrichment factor values. The modified degrees of contamination showed that about 54.3% and 17.1% of sampling sites were at moderate and high contamination degree while pollution load indexes illustrated that 72.9% and 27.1% of sampling sites possessed moderate and high contamination level, respectively. Ecological risk indexes of heavy metals in soil ranged from 234.6 to 3759.0, suggesting that most of sites were under considerable/very high risks. Cancer risks for adults and children were determined as high and high-very high levels while non-cancer risks for children were high although those for adults were low. Industrial source contributed to the main fraction of ecological and health risks. Summarily speaking, heavy metals in soil of the study area has caused significantly serious pollution and exerted high potential ecological and health risks, especially for children who are more susceptible to hurt from pollutants. Therefore, more efficient and strict pollution control and management in study area should be put out as soon as possible.

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1. Introduction

Soil, an important sink of nutrients and pollutants, plays critical function in social-ecological stability and safety. However, soil pollution has become an important obstacle for regional development and human health in recent decades (Jiang et al., 2017; Liang et al., 2017; Padoan et al., 2017; Pan et al., 2016; Peng et al., 2017; Sakai et al., 2017). Heavy metals, defined as metals or metalloids with a specific density larger than 5 g/cm^3 (Järup, 2003; Oves et al., 2012), have become an important kind of pollutants in soil all over the world (Kowalska et al., 2016; Rachwał et al., 2017; Tepanosyan et al., 2017a; Tian et al., 2016; Wu et al., 2016a).

Originated from natural and anthropogenic sources, heavy metals possess acute and chronic toxicity, environmental persistence, and bioaccumulation to exert potential risks to the ecosystem and human health (Burges et al., 2015; Jiang et al., 2017; Salmanighabeshi et al., 2015; Zhu et al., 2017). Therefore, more research starts focusing on the ecological and health risks of heavy metals besides their distribution and pollution (Jiang et al., 2017; Peng et al., 2017; Tepanosyan et al., 2017a, 2017b; Xiao et al., 2017; Zhu et al., 2017). Moreover, multiple methods such as geo-accumulation index (I_{geo}), modified degree of contamination (mC_d), enrichment factor (EF), and pollution load index (PLI) have been employed to comprehensively evaluate the heavy metal pollution in soil (Ćujić et al., 2016; Tian et al., 2017; Zhu et al., 2017). Furthermore, source apportionment of heavy metals in soil also attracts increasing attention (Jiang et al., 2017; Peng et al., 2017).

The Qinghai-Tibet Plateau, generally regarded as the pure land, has exhibited unexpected heavy metal pollution (Bing et al., 2014; Huang et al., 2008; Sheng et al., 2012; Wu et al., 2016a; Yang et al., 2007, 2011; Zhang et al., 2013). Heavy metals were frequently detected in biota of the Qinghai-Tibet Plateau with the highest Pb concentrations in fish/plant samples of 0.079/62.1 mg/kg and the maximal Hg concentration in fish samples of 2384 μg/kg, respectively (Bing et al., 2014; Yang et al., 2007, 2011). Heavy metals were also widely detected in different environmental matrices with the highest Pb/Cr concentrations in soil and water samples of 1075.69/3429.00 mg/kg and 781/2.74 μg/L, respectively (Huang et al., 2008; Sheng et al., 2012; Zhang et al., 2013). Therefore, heavy metal pollution in the Qinghai-Tibet Plateau should not be neglected. However, it is regretful that the previous studies have not illustrated the thorough information on the pollution, ecological and health risks, and source identification of heavy metals in soil of the Qinghai-Tibet Plateau, especially in the northeastern part that is the area with the most extensive anthropogenic disturbance of the whole plateau. Therefore, this study adopted different methods to assess the pollution, ecological-health risks, and source of heavy metals in soil of the northeastern Qinghai-Tibet Plateau. The objectives of this study are to provide complete and comprehensive information on heavy metals in soils of the northeastern Qinghai-Tibet Plateau and lay a basis for the soil pollution prevention and control of the high-elevation areas.

2. Materials and methods

2.1. Study area, sampling strategy, and detection methods

The study area locates in the northeastern Qinghai-Tibet Plateau. Field sampling was performed during May 31th to June 13th, 2016. Total 70 topsoil (0–20 cm) samples were collected (Fig. S1), covering the main industrial, mining, and agricultural zones and main traffic lines of the study area. The samples were *in situ* homogenized and stored in the sample bags until back to the laboratory. The soil samples were air dried at the room temperature, and then passed through 0.074 mm sieve for chemical analysis.

Soil pH was determined with the supernatants of water-soil ratio of 2.5:1 using a pH meter (Shanghai INESA Scientific Instrument Co., China). Soil total organic carbon (TOC) was measured by a multi N/C 3100 analyzer (Analytik Jena AG, Germany). Microwave-digested soil samples were analyzed by an Agilent7900 inductively coupled plasma mass spectrometry (ICP-MS, Agilent Inc, USA). Concentrations of 12 typical heavy metals including vanadium (V), chromium (Cr), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), molybdenum (Mo), cadmium (Cd), tin (Sn), antimony (Sb), mercury (Hg), and lead (Pb) were determined.

2.2. Evaluation on soil heavy metal pollution

Four methods including I_{geo}, EF, mC_d, and PLI were adopted to evaluate the soil heavy metal pollution. Proposed by Müller (1969) and defined as the following, I_{geo} generally exhibits the pollution intensity of individual heavy metal.

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

where C_x^i and C_b^i refer to the concentration of the ith heavy metal in the soil sample and its background concentration in soil that referred to MEPC (1990), respectively.

EF is mainly used to quantify anthropogenic influences on heavy metal pollution (Chester and Stoner, 1973; Clark et al., 2014; Zhu et al., 2017), defined as the following:

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

where R_{soil} and R_b represent the reference element concentration in soil sample and background soil, respectively. Elements Ti, Al, Fe, Mn, Sc or Ca can generally serve as acceptable EF reference element (Salmanighabeshi et al., 2015). This study used Ti as reference element considering that its contents in soil were relatively high and determined accurately by ICP-MS.

PLI and mC_d are comprehensive indexes to characterize the pollution degree by all target heavy metals. mC_d is defined by the following equation (Abrahim and Parker, 2008; Wu et al., 2016a).

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

where n refers to the number of pollutants.

PLI is determined as follows (Bhuiyan et al., 2010; Ćujić et al., 2016; Tian et al., 2017):

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

2.3. Ecological risks of soil heavy metals

Potential ecological risk index ($PERI$) is a factor to comprehensively assess the potential ecological risks posed by heavy metals in soil/sediment (Hakanson, 1980; Ke et al., 2017; Madiseh et al., 2009). $PERI$ is calculated using the following equation: