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Current status and associated human health risk of vanadium in soil in China

Jie Yang [a,1], Yanguo Teng [a,1], Jin Wu [b,*], Haiyang Chen [a], Guoqiang Wang [a], Liuting Song [a], Weifeng Yue [a], Rui Zuo [a], Yuanzheng Zhai [a]

[a] *College of Water Science, Beijing Normal University, Beijing 100875, China*
[b] *College of Resources Science and Technology, Beijing Normal University, Beijing 100875, China*

HIGHLIGHTS

- Soil contamination of vanadium in China was evaluated by overlay analysis.
- The priority control area was identified.
- Comprehensive recommendations for management are proposed.

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ABSTRACT

A detailed assessment of vanadium contamination characteristics in China was conducted based on the first national soil pollution survey. The map overlay analysis was used to evaluate the contamination level of vanadium and the non-carcinogenic risk assessment model was calculated to quantify the vanadium exposure risks to human health. The results showed that, due to the drastically increased mining and smelting activities, 26.49% of soils were contaminated by vanadium scattered in southwest of China. According to Canadian soil quality guidelines, about 8.6% of the national soil pollution survey samples were polluted, and pose high non-carcinogenic risks to the public, especially to children living in the vicinity of heavily polluted mining areas. We propose the area near the boundary of Yunnan, Guizhou, Guangxi, and Sichuan provinces as priority control areas due to their higher geochemical background or higher health risks posed to the public. Finally, recommendations for management are proposed, including minimization of contaminant inputs, establishing stringent monitoring program, using phytoremediation, and strengthening the enforcement of relevant laws. Therefore, this study provides a comprehensive assessment of soil vanadium contamination in China, and the results will provide valuable information for China's soil vanadium management and risk avoidance.

1. Introduction

Vanadium is widely distributed in sedimentary and igneous rocks and minerals as a mildly incompatible, refractory, lithophilic element, which is mainly mined in South Africa, Russia and China (Huang et al., 2015). Under natural conditions, vanadium mobilization in soils is often decoupled from other metals and metalloids, and is governed by weathering and redox processes (Imtiaz et al., 2015; Shiller and Mao, 2000; Violante et al., 2010). The size and charge of V species enable it to substitute for common transition elements, e.g., Fe and Al in primary and secondary minerals. In redox conditions, vanadium can be liberated from V and U minerals (e.g., montroseite, uraninite) by weathering. In reducing conditions, the relatively immobile V (III) is dominant; the higher oxidation states are much more soluble. As a typical transition element, around 85% of the produced global vanadium is used as ferrovanadium in the steel industry, while the remainder is usually used in the chemical and aerospace industries (Moskalyk and Alfantazi, 2003). The increasing demand for vanadium can be expected to further increase the volume of this element that is cycled through terrestrial, aquatic and atmospheric systems. Hope (1997) reported that approximately 2.30 × 10^8 kg of vanadium is annually

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* Corresponding author.
E-mail address: d40614012@163.com (J. Wu).

[1] These authors contributed equally to this work and should be considered dual-first authors.

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introduced to the environment through human activities, of which 1.32 × 10^8 kg is deposited on the land and resulted in elevated soil vanadium concentration. Soil vanadium concentration in the fuel combustion venues (i.e. areas close to oil refineries, fuel powered facilities, and heavy automobile traffic) is usually much higher than natural abundance (Al-Surrayai et al., 2009; Khan et al., 2011; Teng et al., 2011a; Xiao et al., 2015). In areas with high soil vanadium concentration, assimilation of vanadium by plants is considered as the major vanadium flux from soil to biota because plants have the highest direct exposure to the soil (Tian et al., 2014).

However, vanadium becomes toxic at higher concentrations/dosages to terrestrial organism, e.g., plants, microorganisms (Olness et al., 2005; Panichev et al., 2006) and it has been recognized as a potentially dangerous pollutant to humans in the same class as mercury, lead and arsenic (Naeem et al., 2007). Canadian scientists developed guideline (130 mg kg^{-1}) about soil quality for vanadium toxicity to protect vascular plants and in-vertebrates (CCME, 2007). Although vanadium is an essential trace element for living organisms, excessive amounts in the human body can cause asthma, rhinitis, and general anemia and even increase the possibility of uremia and lung cancer occurrence (ATSDR, 2002; Crans et al., 2004; WHO, 1990, 2001). As a complex issue, soil pollution is directly related to food safety and human health. Inappropriate land use has been regarded as an important factor in recent decades (Patz et al., 2004; Pielke, 2005). Human health risks may increase as a result of the bioaccumulation of contamination through the food web, which can be initiated through land use change. Changes of land use (i.e., reclamation of mining land) can lead to crop damage, water and land degradation, changes to the function of contaminants in soil and contribute to global climate change, either directly or indirectly (Zhao et al., 2012; Pielke, 2005).

China's annual output of vanadium is more than 70,000 tons and the main vanadium resources are located in Sichuan, Anhui, Gansu and Hunan provinces (Fig. 1) although almost every province has some vanadium production. In previous studies, Teng et al. (2011a) investigated the environmental vanadium distribution in Jiangxi province and the city of Panzhihua, and its bioaccumulation in plants (Yang et al., 2015). The high contents of vanadium in farmland has attracted considerable public attention. To our knowledge, despite the elevated vanadium loading, there is little assessment of soil vanadium pollution and its associated health risk at national scale and there remains a lack of vanadium limiting values within the current soil environmental quality standard of China (GB15618-1995) (CMEP, 1995). In this study, based on the data of national soil quality and pollution survey, we determined the distribution and levels of vanadium by overlay analysis and non-carcinogenic effects by health hazard assessments in China at the national scale. It will be helpful for policy makers to set the guideline value of vanadium and formulate effective soil pollution control strategies.

2. Materials and methods

Chinese government launched the first national soil pollution survey (NSQPS) during April 2006 to December 2010 backed by a budget of about 125 million dollars. Compare with previous national scale survey, the huge amounts of NSQPS data was rarely used to study. The scope of NSQPS included the territory of the People's Republic of China (excluding the Hong Kong, Macao, and Taiwan areas), with an actual survey area of about 6.3 million km^2 and involved collecting of more than 41,000 topsoil samples (Wu, 2006; Teng et al., 2014). Detail information of dominant soil type was given in Table A1. Before field work, the sampling coding system and sampling cells were generated on 1: 250,000 digital maps within the national fundamental geographic information system, which reasonably represented the nationwide soils (Chen et al., 2015; Teng et al., 2015).

Detailed laboratory analytical procedures for the samples collected were described in Qin et al. (2008). In brief, the size of sampling grid (sampling density) varied with land use patterns, with an 8 × 8 km grid for cultivated land, 16 × 16 km grid for forest land and grassland, and 40 × 40 km grid for unutilized land. Each total sample represents composite material taken from several subsamples (0–20 cm) over a 50 × 50 m patch of land. Ten to 30 subsamples were collected at sites on rough terrain or high heterogeneity soil using the S-shaped method. Five to nine subsamples were collected at sites in cropland using the diagonal method. Five subsamples were collected at sites in flat territory and homogeneous soil using the quincunx method. Samples for element analysis and measurements of soil physicochemical properties were collected using a bamboo or stainless steel spade and stored in sealed kraft packages to avoid contamination. Preservation and transportation of the soil samples were executed according to the Technical Specification for SEPAC (2004).

2.1. Sample extraction and analysis

The soil samples were air-dried at room temperature and

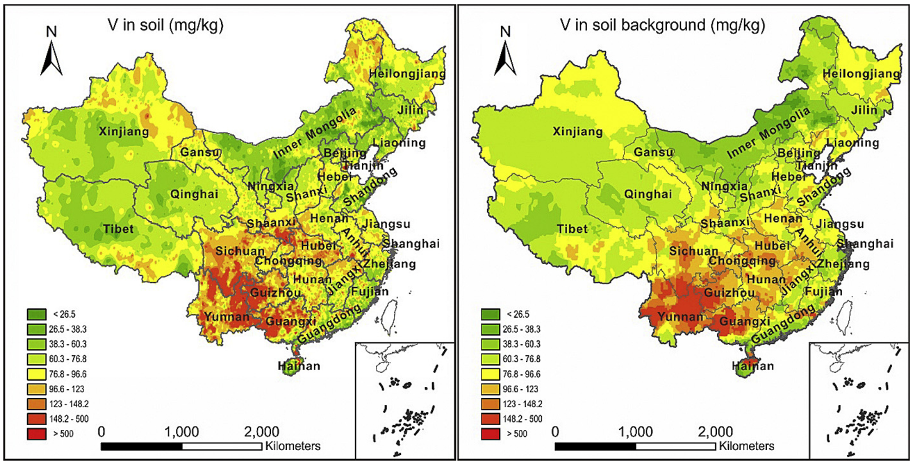

Fig. 1. Spatial distribution of V in soil V (Left) and in background soil (Right) across China. Note that the spatial distribution of vanadium in background soil was electronically obtained from CNEMC, 1994.