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Effects of topography and soil properties on soil selenium distribution and bioavailability (phosphate extraction): A case study in Yongjia County, China

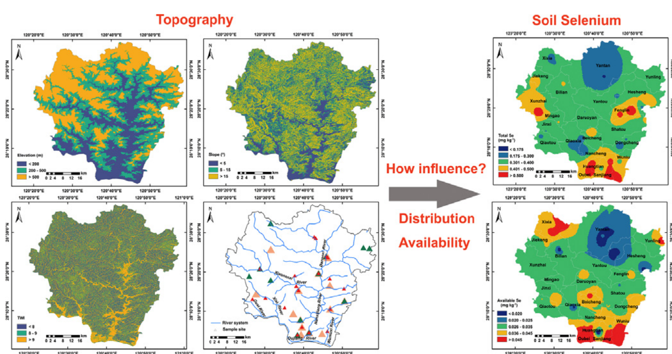
Yuefeng Xu [a,c], Yonghua Li [a,b,*], Hairong Li [a,b], Li Wang [a,b], Xiaoyong Liao [a,b,*], Jing Wang [a,c], Chang Kong [a,c]

[a] Key Laboratory of Land Surface Pattern and Simulation, Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[b] Beijing Key Laboratory of Environmental Damage Assessment and Remediation, Beijing, China
[c] University of Chinese Academy of Sciences, Beijing 100049, China

HIGHLIGHTS

- The effects of topography on soil Se distribution were first investigated.
- As elevation and slope increased, total soil Se first increased and then decreased.
- Soil phosphate extracted Se increased with increasing elevation.
- Se had a negative correlation with the coefficient of weathering and eluviation.

GRAPHICAL ABSTRACT



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ABSTRACT

Selenium (Se) is an essential trace element for humans. In order to investigate how soil Se is influenced by topography and soil properties, we selected Yongjia County, an area with mountainous topography, as a study area. This study used cultivated soil data to comprehensively analyze the effects of topography and soil properties on Se mobility and bioavailability and to identify the key factors influencing Se distribution in the environment. Factors considered in this study were elevation, slope, topographic wetness index, the coefficient of weathering and eluviation, pH, organic matter, and Fe_2O_3. The concentration of total soil Se (0.382 ± 0.123 mg kg^{-1}) was far higher than the background value of soil in China, and 98% of the soil samples were classified as having moderate Se levels (>0.175 mg kg^{-1}), indicating Yongjia County is a Se-rich region in China. Phosphate extracted Se accounted for an average of 9% of the total Se and was significantly associated with soil total Se, Fe_2O_3, pH, and the coefficient of weathering and eluviation. Fe_2O_3 primarily controlled Se adsorption, fixation, and availability in soil. Under the geo-environmental conditions in the study area, the total Se in the soil increased first and then decreased with increases in elevation, slope, and the topographic wetness index, and the phosphate extracted Se showed similar patterns except for the elevation. The findings showed that topographical attributes and soil physicochemical properties synthetically influenced the distribution and bioavailability of Se in soil.

* Corresponding authors at: Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, 11 A Datun Road, Beijing 100101, China.
E-mail addresses: yhli@igsnrr.ac.cn (Y. Li), liaoxy@igsnrr.ac.cn (X. Liao).

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1. Introduction

Selenium (Se) is an essential trace element for humans and animals. The concentration range for it to transform from an essential element to a toxic one is quite narrow (Rayman, 2000). According to the review by Kumar and Priyadarsini (2014), the role of Se in the human body has been studied intensively with regard to its antioxidant effect (Brummer et al., 2013), antithrombotic effect (Joseph, 2013), nervous system functions (Zhang et al., 2010), immune modulation (Hawkes et al., 2001), cancer prevention (Clark et al., 1996), and antimicrobial and antiulcer actions (Kumar et al., 2010). Moreover, Se has been shown to play an important role in preventing age-related diseases by improving overall health and other aspects of aging (Akbaraly et al., 2005). The production of free radicals and lipid peroxides, resulting in membrane damage, is widely recognized as the primary reason for many degenerative old-age diseases, such as Alzheimer's disease. Se is known to provide protection from cell damage and revert oxidative stress and memory impairment (Cornelli, 2010; Ishrat et al., 2009). The human body's intake of Se is mainly from soil Se, through the food chain. However, Se is not evenly distributed on the earth's crust.

Soil Se concentration usually ranges between 0.01 and 2 mg kg^{-1} with a world mean value of 0.4 mg kg^{-1} (Fordyce, 2007), although the concentration can reach up to 1200 mg kg^{-1} in some seleniferous regions (Casteel and Blodgett, 2004). Because of long-term exposure to high levels of Se, hair and nail loss and skin lesions have affected the inhabitants of Se-rich areas in China (e.g., Enshi, Hubei and Ziyang, Shanxi) (Li et al., 2011; Yang et al., 1983; Zhao et al., 1993). However, some areas are seriously deficient in Se, likely leading to white muscle disease, Keshan disease, Kaschin-Beck disease, and other Se-deficient diseases (Broadley et al., 2006). China has a low-Se stripe extending from the northeast to the southwest; therefore, approximately 72% of the national territory is Se-deficient (Tan, 1989).

In general, the total soil Se can be used to assess Se uptake and accumulation by plants. However, relatively high concentrations of total Se in soils are not always consistent with high Se concentrations in plants or plant-based foods (Yu et al., 2015). Numerous studies have demonstrated that Se uptake and accumulation by plants depends not only on the total Se content, but also the Se speciation in the soil (Cao et al., 2001; Wang and Gao, 2001). Wang et al. (2013) suggested that Se concentrations in crops could be controlled by water-soluble and exchangeable Se levels in soils, which were considered to represent soil available Se. Zhao et al. (2005) and Keskinen et al. (2009) showed that phosphate extracted Se in soils could reflect the Se available to plants. Therefore, understanding the processes governing Se concentration and speciation in soil are essential to increase Se intake by plants.

The factors that contribute to total and available Se in soil are complex. Researchers have shown that soil nutrients are affected, not only by soil internal factors (bacterial strains, competitive ions, organic matter (OM), pH, and redox conditions), but also by external factors (precipitation, temperature, land use type, and topography) (Blazina et al., 2014; Johnson et al., 2000; Jones et al., 2017; Lenz and Lens, 2009; Moore et al., 1993; Tolu et al., 2014). It has been recognized that the bioavailability of Se in soil generally decreases with decreasing pH (Wang et al., 2013). Selenite and selenate exist as free ions in the water-soluble phase or can be adsorbed by OM, oxy-hydroxides, and soil clay (Eich-Greatorex et al., 2007; Wang et al., 2013). Wang and Gao (2001) reported that the influence of soil OM on Se mobility should be emphasized in OM-rich soil, such as dark-brown earth and black soils in northeastern China. If soil OM content is very low, oxy-hydroxides are mainly responsible for the adsorption of Se, and they directly control ambient Se mobility and bioavailability (Tolu et al., 2014). Moreover, the reduction of Se is an important process in soils that can lead to immobilization of Se because Se (0) and metallic Se (-II) (e.g., FeSe) are insoluble or reduced Se can interact with OM (Fernández-Martínez and Charlet, 2009; Gustafsson and Johnsson, 1994; X.P. Li et al., 2017; Z. Li et al., 2017); this reduction can vary widely depending on the soil type and its properties.

Topography is one fundamental factor affecting soil formation, and thus soil properties. The relationship between topographical factors and soil properties has been widely studied, such as soil nitrogen (Huang et al., 2015; X.P. Li et al., 2017; Z. Li et al., 2017), soil phosphorus

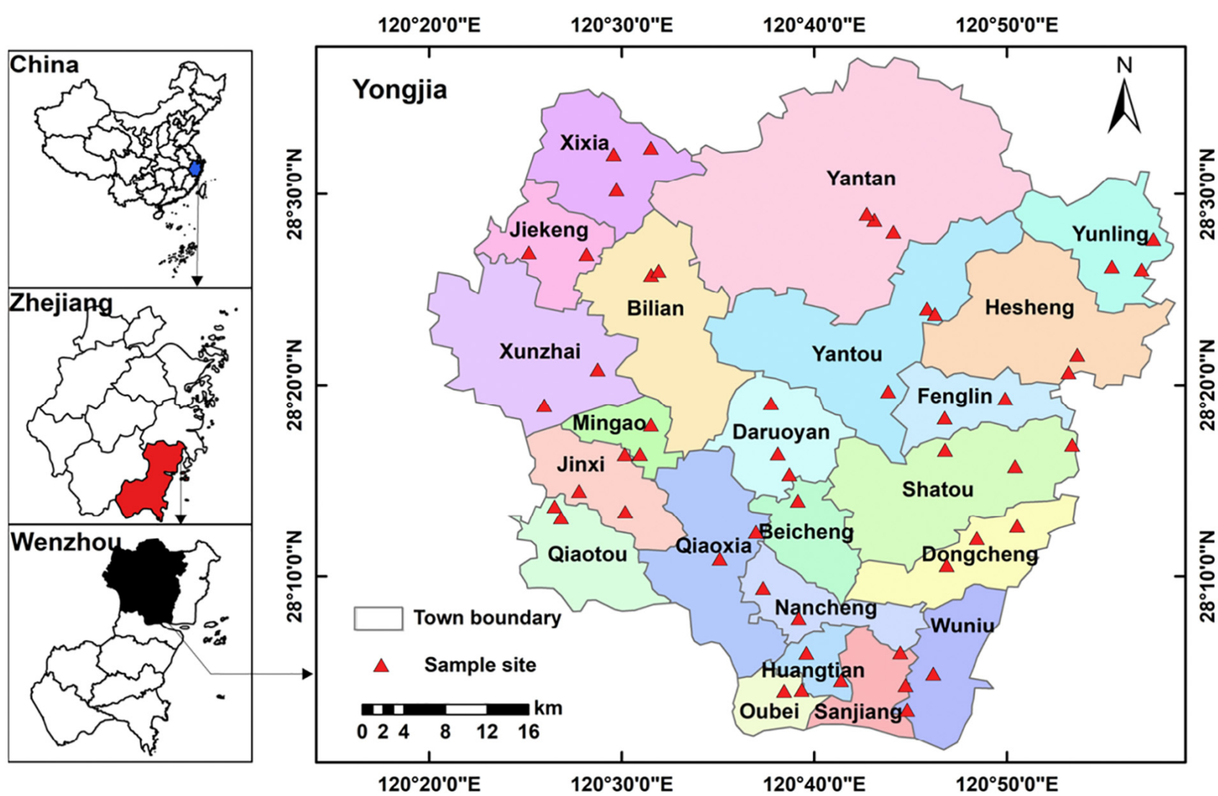

Fig. 1. Location of the study area and spatial distribution of sample sites in the study area.