Journal of Integrative Agriculture 2018, 17(4): 765–774

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REVIEW

Overview on current criteria for heavy metals and its hint for the revision of soil environmental quality standards in China

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Abstract

Following rapid social and economic development over the past several decades, soil pollution by heavy metals (HMs) has been both serious and widespread in China. The Soil Environmental Quality Standards (SEQSs) in China (GB 15618-1995) have been introduced to encourage and enforce sustainable soil HM management. However, in recent years, HM contents in soils have frequently been found to exceed their associated standard values, while the crops growing on them might still meet regulatory standards, and *vice versa*. There is thus growing awareness that GB 15618-1995 does not effectively regulate current soil HM pollution, as it has encountered bottlenecks, and disappointing outcomes caused by poor execution along with deficiencies and gaps in the policies. However, due to the deficiency of scientific research about relationships between soil HM concentrations and their ecological or human health effects, the development of SEQSs in China is still greatly restricted. This paper discusses international SEQSs of HMs as well their development in China over time, then examines current Chinese SEQSs to demonstrate their potential regulatory deficiencies by referring to international SEQSs. The corresponding legislative policies are described, and scientific information or responses are outlined for maintaining soil environmental quality. China's experience has shown that policy and science can be linked to work in tandem to better understand and manage soil quality issues.

Keywords: soil, heavy metals, regulatory standards, soil science, policy

1. Introduction

Soil depletion and degradation have been increasingly recognized as important environmental issues in China (Wei and Yang 2010). Heavy metal (HM) pollution in soils has become serious with rapid industrialization and urbanization over the last two decades (Teng *et al.* 2014; Li *et al.* 2015). The Ministry of Land Resources (MLR 2007) in China reported that more than 10% of cultivated land was heavily polluted by HMs from various emission sources, such as oil extraction and refining, mining and

Received 26 July, 2017 Accepted 8 December, 2017
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doi: 10.1016/S2095-3119(17)61892-6

metallic smelting, waste rock stockpiles, industrial wastes or sewage irrigation (Li *et al*. 2015). Similarly, Song *et al.* (2013) collected data from 138 regions based on published documents and reviewed soil HM pollution of cultivated land in China and found that the probability of HM pollution in soils was about 16.67%, implying that 1/6 of cultivated land in China may suffer from HM pollution. HM-polluted soils occupy a comparatively large area of China, and the risks they created for humans, animals, plants, and groundwaters have become increasingly serious. Therefore, it is important to develop criteria and standards that can be used to assess the degree of risk from contaminated soils or to establish guidelines for their remediation.

Soil Environmental Quality Standards (SEQSs) are an important instrument for implementing soil protection policies. They can be applied as a decision-support tool in risk assessment of polluted soils and their impacts on human health, water resources, and other environmental areas (Atanassov 2008; ME 2011; Jarva 2016). In 1995, China enacted SEQSs (GB 15618-1995) specifying the maximum allowable concentrations of ten pollutants (eight heavy metals) based on protection targets and soil properties, as well as the corresponding monitoring methods. This standard has been considered as the most important legal basis and criteria for soil quality protection and pollution prevention in China since it has been issued (Teng *et al.* 2014). However, with rapid industrialization and urbanization, Chinese SEQSs (GB 15618-1995) are outdated: they do not reflect the serious level of soil pollution and serve little useful purpose in assessing the performance of contemporary soil restoration processes. In recent years, review and research articles have provided assessment of Chinese SEQSs (1995) (He *et al.* 2004; Zhou and Qin 2005; Zhang *et al.* 2014). Such studies help to further raise public awareness of soil HM contamination and to facilitate policies for revision of SEQSs. However, in China, there remains a lack of systematic development and scientific discussion about SEQSs, meaning that rules, regulations, guidelines, and implementation protocols are often fragmented and chaotic.

This paper provides an overview of China's national SEQSs of HMs and local specific regulations or guidelines, and also covers the development of scientific and legislative frameworks employed in China to assess HM pollution. First, the progress of international SEQSs for HMs is reviewed. Then the scientific and legislative development of SEQSs for HMs in China over time is characterized. We follow this with an examination of the existing SEQSs to demonstrate potential regulatory deficiencies. The analysis in this paper indicates that a closer relationship between legislative policies and scientific information is needed for efficient control of the risks and hazards of HMs in soil.

2. International SEQSs of HMs

It is commonly acknowledged that reliable information on geochemical background concentrations, specifically SEQSs from different countries is essential in soil contamination or remediation studies (EA 2004; Carlon 2007). SEQSs are thus necessary for implementing policies related to soil protection. SEQSs can be applied as a decision-support tool in risk assessment of polluted soils and their impact on human health, water resources and other environmental aspects (Atanassov 2008; ME 2011). SEQSs have been broadly adopted in many countries to regulate the management of contaminated land, and they usually come in the form of concentration thresholds (mg kg^{-1} soil dry weight) of contaminants in soils, above which certain actions are recommended or enforced.

(1) Generally, the legislative framework of each country considers the following questions when their SEQSs or guidelines are developed (Provoost *et al.* 2006):

(2) When SEQSs are exceeded, what actions are taken (further investigation or remediation)?

(3) What is a generic step-wise approach for developing SEQSs?

(4) Do SEQSs differ based on the type of land use?

(5) Which receptors are considered: human health, the ecosystem (ecology), groundwater and/or surface water?

2.1. Types of SEQSs

There are different names for SEQSs around the world. In Denmark, China, and Sweden they are called "soil quality criteria/standards" (Carlon 2007; Zhou *et al.* 2007); in the USA they are "soil screening levels" (US EPA 1997); in the Netherlands they are "target values" (ME 2011); in the UK they are "soil guideline values" (EA 2009); in Australia they are "investigation levels" (NEPC 2011); and in Germany they are "trigger values/levels" (Carlon 2007). Though different names are used among countries, the countries have similar meanings for various risk levels and corresponding applications, which are demonstrated and displayed in Fig. 1.

2.2. Derivation of SEQSs

The derivation of SEQSs differs among countries. Generally, ecotoxicological and geochemical methods are widely adopted (Wu *et al.* 1991; Zhou 1996; Zhou and Zhu 1997). For example, certain methods based on the species sensitivity distribution (SSD) or the assessment factor (AF) have been applied in derivation of quality criteria since the 1980s (US EPA 1985), and are becoming useful tools to deal