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A standard-value-based comparison tool to analyze U.S. soil regulations for the top 100 concerned pollutants

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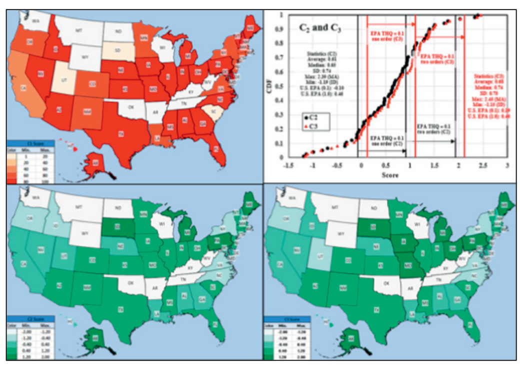
HIGHLIGHTS

- Five types of comparison scores were developed to evaluate soil regulations.
- The difference of each jurisdiction varies in order of magnitude from 0.01 to 1.93.
- Many states tend to have higher RGVs which allows more pollution to remain in soil.

GRAPHICAL ABSTRACT



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ABSTRACT

Residential surface soil contamination is often addressed by the use of regulatory guidance values (RGVs), which specify the maximum allowed concentration that can be present without prompting a regulatory action. In the U.S., there are at least 72 jurisdictions, including national, state, and regional, that have published guidance values for one or more of the one hundred most frequently regulated chemicals. A standard-value-based comparison tool in this study is developed to analyze values from 40 states and from the U.S. Environmental Protection Agency (U.S. EPA). The comparison tool can help evaluate the completeness of RGV sets, quantify the average deviation of RGVs from worldwide central tendencies, and measure the overall difference between the numbers of RGVs above and below central tendencies. The pollutants considered in this study include benzidines/aromatic amines, dioxins and polychlorinated biphenyls (PCBs), hydrocarbons, inorganic substances, nitroamines/ethers/alcohols, organophosphates and carbamates, pesticides, phenols/phenoxy acids, phthalates, and volatile organic compounds. Based on completeness and comparisons of order of magnitude variations, five types of scores are generated. The results from the completeness scores indicate that some states lack soil RGVs for the top 100 concerned pollutants. The results from the comparison scores indicate that some jurisdictions have provided the RGVs averagely deviating from worldwide central tendencies and U.S. EPA scores by over two orders of magnitude, which might be beyond the risk model variabilities and increase human health risks. Hopefully, the regulatory comparison tool developed in this study will help risk assessors and regulatory scientists to better evaluate soil standards and protect public health.

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1. Introduction

Surface soil contamination can result in human health risk. The application of industrial and agricultural chemicals generates surface soil contamination due to the fate and transport of chemicals (Fantke et al., 2011, 2012, 2017; Hemond and Fechner, 2014; Joy et al., 2013). Exposure to soil pollutants can occur via the ingestion of pollutants through contaminated soil, the inhalation of contaminated soil dust, and dermal contact with soil (Ferencz and Balog, 2010; Odukkathil and Vasudevan, 2013), which might cause adverse health effects, including carcinogenic and noncarcinogenic effects, especially for children (Zheng et al., 2010; Juhasz et al., 2011; Fantke and Juraske, 2013). Often, regulatory guidance values (RGVs) are used to limit risks by specifying the maximum amount of a pollutant that may be present in soil without prompting a regulatory response (Jury et al., 1987; Zhou, 1996; Li and Jennings, 2017; Jennings and Li, 2014; Li, 2018a, b). In the U.S., these values are also referred to as soil remediation levels, risk-based screening levels, remediation goals, target levels, or generic soil remediation standards (Potter et al., 2004). In this study, they are all referred to as RGVs. To protect the environment and public health, the U.S. Environmental Protection Agency (U.S. EPA) has developed RGVs for residential sites under its jurisdiction, and nearly all 50 U.S. states have either promulgated their own guidance values or adopted the EPA values. RGVs from 40 states that have not adopted the EPA values were selected for the study.

The development of a human health guidance value for any contaminant is complex (World Health Organization [WHO], 1994). Approximations must be made to characterize the individuals who come into contact with the pollutant (body mass, soil inhalation and ingestion rate, exposed skin surface area, etc.), the scenario by which the individual contacts the pollutant (frequency, duration of exposure), and the health impact of pollutant uptake (Kroes et al., 2004; Fantke et al., 2013). Given the number of independent jurisdictions that are making these approximations, and the inherent uncertainty in the required evaluations, variability in RGVs can be expected, but guidance values that vary by several orders of magnitude are problematic (Jennings and Li, 2015a, 2015b). Higher values can allow increased risk to human health, and lower values can lead to unnecessary remediation cost. Following are the pollutants for which there appears to be the greatest health concern. By category, the contaminants analyzed in this report include metals, cyanides, chloromethanes, chloroethanes, chloroethenes, chlorobenzenes, phenols, carcinogenic polycyclic aromatic hydrocarbons (PAHs), noncarcinogenic PAHs, historically used pesticides, currently used pesticides, and miscellaneous industrial chemicals. This study is the first to compare and evaluate soil RGVs for at least 10 different categories of soil pollutants among U.S. jurisdictions, and the objective of this study is to develop a standard-value-based comparison tool to quantify and examine the performance of U.S.-related regulatory jurisdictions. Hopefully, this study will help regulatory jurisdictions to better review and regulate soil standards to protect environmental and public health.

2. Materials and methods

2.1. Top 100 soil pollutants and RGVs

A total of 100 soil contaminants were selected for this study, which is summarized in Appendix I. These pollutants were selected because they are the most frequently regulated soil contaminants by U.S. jurisdictions in each of the major chemical classes considered, including 20 elements, seven cyanides, five halogenated methanes, seven chlorethanes and chorethenes, 12 benzenes, eight phenols, eight carcinogenic PAHs, eight noncarcinogenic PAHs, nine historically used pesticides, 12 currently used pesticides, and nine miscellaneous pollutants. Although some persistent organic pollutant (POP) pesticides were banned decades ago, massive historical use and their persistence make them ubiquitous in the environment still (Jones and De Voogt, 1999; Qu et al., 2018; Li, 2018a; Hubert et al., 2000). Due to their severe toxicity and persistence, these historically used pesticides must be regulated. The RGVs used in this study were identified by Internet searches of regulatory agency web pages or official government documents. All values are either specific to residential surface soil exposure dominated by direct soil contact (i.e., ingestion, inhalation, and/or dermal contact) or to the most comparable exposure classification.

2.2. Health risk analysis of RGVs

The U.S. EPA has provided the following equations of regional screening levels (RSLs) for computing RGVs based on residential soil (U.S. EPA, 2016), which considers three possible direct exposure routes via soil, including the ingestion of soil and dust, the inhalation of dust, and dermal contact. For noncarcinogenic models, chronic reference dose (RfD) or reference concentration (RfC) values from laboratory animal tests are used, which are usually derived from no observed adverse effect level (NOAEL) or lowest observed adverse effect level (LOAEL) values. And for carcinogenic models, cancer slope factors (CSFs) are applied instead of threshold values since carcinogens are considered to cause adverse health effects at any doses above zero.

$$SL_{res-sol-nc-ing}(\mathrm{mg/kg}) = \frac{THQ \times AT_r \times ED_c \times BW_c}{EF_r \times ED_c \times \left(\frac{1}{RfD_o}\right) \times IRS_c \times 10^{-6}} \tag{1}$$

$$SL_{res-sol-nc-inh}(\mathrm{mg/kg}) = \frac{THQ \times AT_r \times ED_c}{EF_r \times ED_c \times ET_{rs} \times \frac{1}{24} \times \frac{1}{RfC} \times \left(\frac{1}{VF_s} + \frac{1}{PEF_w}\right)} \tag{2}$$

$$SL_{res-sol-nc-der}(\mathrm{mg/kg}) = \frac{THQ \times AT_r \times LT}{\frac{CSF_o}{GIABS} \times EF_r \times DFS_{adj} \times ABS_d \times 10^{-6}} \tag{3}$$

$$SL_{res-sol-nc-tot}(\mathrm{mg/kg}) = \frac{1}{\frac{1}{SL_{res-sol-nc-ing}} + \frac{1}{SL_{res-sol-nc-inh}} + \frac{1}{SL_{res-sol-nc-der}}} \tag{4}$$

$$SL_{res-sol-ca-ing}(\mathrm{mg/kg}) = \frac{TR \times AT_r \times LT}{CSF_o \times EF_r \times IFS_{adj} \times 10^{-6}} \tag{5}$$

$$SL_{res-sol-ca-der}(\mathrm{mg/kg}) = \frac{TR \times AT_r \times LT}{\frac{CSF_o}{GIABS} \times EF_r \times DFS_{adj} \times ABS_d \times 10^{-6}} \tag{6}$$

$$SL_{res-sol-ca-inh}(\mathrm{mg/kg}) = \frac{TR \times AT_r \times LT}{IUR \times ET_r \times \left(\frac{1}{VF_s} + \frac{1}{PEF_w}\right) \times ET_{rs} \times \frac{1000}{24}} \tag{7}$$

$$SL_{res-sol-ca-tot}(\mathrm{mg/kg}) = \frac{1}{\frac{1}{SL_{res-sol-ca-ing}} + \frac{1}{SL_{res-sol-ca-der}} + \frac{1}{SL_{res-sol-ca-inh}}} \tag{8}$$

The coefficients used in these equations are defined in the following Table 1. U.S. The EPA applies health risk models to derive soil the RGVs of carcinogens and noncarcinogens, and if a group of chemicals with same mode of action can cause additive health effects, a target hazard quotient (THQ) of 0.1 is applied. Although states can derive their own standard values based on their selected human exposure variables, toxicology parameters, and uncertainty factors, an RGV higher than 10–100 times, or one to two orders of magnitude, of the U.S. EPA RGV might be considered to cause population risks, which assumes a combined uncertainty factor of 10–100 for the model and its parameters. Table 1 also summarizes the maximum and minimum values of each model variable used by state jurisdictions. ABS_d and TR values can vary by two orders of