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Research article

Health risk characterization of maximum legal exposures for persistent organic pollutant (POP) pesticides in residential soil: An analysis

Zijian Li [a], [b], [*]

[a] Department of Civil Engineering, Case Western Reserve University, Cleveland, OH, 44106, USA
[b] Parsons Corporation, Chicago, IL, 60606, USA

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ABSTRACT

Regulations for pesticides in soil are important for controlling human health risk; humans can be exposed to pesticides by ingesting soil, inhaling soil dust, and through dermal contact. Previous studies focused on analyses of numerical standard values for pesticides and evaluated the same pesticide using different standards among different jurisdictions. To understand the health consequences associated with pesticide soil standard values, lifetime theoretical maximum contribution and risk characterization factors were used in this study to quantify the severity of damage using disability-adjusted life years (DALYs) under the maximum "legal" exposure to persistent organic pollutant (POP) pesticides that are commonly regulated by the Stockholm Convention. Results show that computed soil characterization factors for some pesticides present lognormal distributions, and some of them have DALY values higher than 1000.0 per million population (e.g., the DALY for dichlorodiphenyltrichloroethane [DDT] is 14,065 in the Netherlands, which exceeds the tolerable risk of uncertainty upper bound of 1380.0 DALYs). Health risk characterization factors computed from national jurisdictions illustrate that values can vary over eight orders of magnitude. Further, the computed characterization factors can vary over four orders of magnitude within the same national jurisdiction. These data indicate that there is little agreement regarding pesticide soil regulatory guidance values (RGVs) among worldwide national jurisdictions or even RGV standard values within the same jurisdiction. Among these POP pesticides, lindane has the lowest median (0.16 DALYs) and geometric mean (0.28 DALYs) risk characterization factors, indicating that worldwide national jurisdictions provide relatively conservative soil RGVs for lindane. In addition, we found that some European nations and members of the former Union of Soviet Socialist Republics share the same pesticide RGVs and data clusters for the computed characterization factors.

1. Introduction

Pesticides are widely applied to control pests and diseases worldwide. There are approximately 8000 species of weeds, 50,000 plant diseases, and 9000 species of insects in the world (Zhang et al., 2011). Without pesticides, significant economic losses would occur (Webster et al., 1999) and crop yields would decrease (Warren, 1998). It is estimated that approximately 13% of crop losses are attributable to weeds, 13% to plant diseases, and 14% to insects (Pimentel, 2009). The use of pesticides benefits agricultural productivity, the economy, and public health. Pesticides play a significant role in controlling vector-borne diseases (e.g. mosquito-borne), which are a main public health concern (Rose, 2001), and insecticides can prevent and control infectious diseases such as malaria and filariasis (Rivero et al., 2010). Approximately three-billion kilograms of pesticides is used in the world annually (Pan-UK, 2003), and most of them are applied in the agricultural, industrial, home and garden, and governmental sectors.

After application, pesticides can reach the surface soil, adsorb to soil particles, and be transported through the unsaturated zone (Hancock et al., 2008). Some organic pesticides resist natural degradation (i.e. biological, chemical, and photolytic) and remain in the environment; these are defined as persistent organic pollutants (POPs) (Buccini, 2003). Although some POPs, such as

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[*] Department of Civil Engineering, Case Western Reserve University, Cleveland, OH, 44106, USA.
E-mail addresses: zxl170@case.edu, zijian.li@case.edu.

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dichlorodiphenyltrichloroethane (DDT), were banned in the 1980s, they still exist in the environment and can be detected in various media (Xu et al., 2013). Once pesticides are released into the soil, they can enter the human body via soil ingestion, soil particle inhalation, and dermal contact with the soil. Many pesticides, owing to their toxicity, negatively impact the environment and human health (Alewu and Nosiri, 2011). In particular, pesticides listed by the original 2001 Stockholm Convention (Jennings and Li, 2015a), as well as those added to the Stockholm Convention list in 2009 and 2011 are of concern (Jennings and Li, 2015b).

Residential soil regulatory guidance values (RGVs) have been adopted by worldwide environmental regulatory jurisdictions to manage residential soil chemical pollutants and promulgate the maximum amount of a pesticide that can be present in the soil without triggering a regulatory response (i.e. adverse health effects) (Jennings and Li, 2014). To protect human health, residential soil RGVs should be based on exposure scenarios, human health risk models, and toxicity data. Thus, soil RGVs regulated by worldwide jurisdictions should fall within a reasonable interval, since risk characterization of humans and human toxicity data have relatively small variations. Most previous studies compared soil RGVs among different jurisdictions or used risk from uncertainty models. Pelaez et al. (2013) and Carlon (2007) analyzed and compared pesticide soil standards between jurisdictions from the United States, Europe, and Brazil. The Association of Environmental Health and Science (2003) investigated and compared the soil and groundwater cleanup standards among state regulations, and the Interstate Technology Regulatory Council (2005) discussed risk-based soil screening values of some heavy metals in 13 states within the United States. Paustenbach et al. (2006) studied and identified soil cleanup criteria for dioxins based on risk assessment. Jennings and Li (2014, 2017a,b) evaluated pesticide soil RGVs within the United States Environmental Protection Agency (USEPA) risk from uncertainty bounds. These studies have made efforts toward helping regulatory jurisdictions harmonize and rationalize soil contaminant standard values; however, they only indicate whether the standard values protect human health by comparing soil RGVs with risk from uncertainty bounds and there is little research quantifying the human health impact of pesticide soil standards. Further, current studies only compare and analyze the individual pesticide standard values of different regulatory jurisdictions for the same pesticide. For example, these studies do not compare and evaluate the performance of DDT and aldrin soil RGVs, since they have different toxicological effects. To better understand the consequences associated with pesticide soil RGVs with the purpose of preventing human health risk, we used the disability-adjusted life years (DALYs) method, which measures the burden of disease caused by pesticides, expressed as the number of years lost attributable to ill-health. We then applied this method to a health risk characterization analysis of soil RGVs by applying the lifetime theoretical maximum contribution, which was based on the maximum “legal” exposure to pesticides. Based on this approach, the health impact of pesticide soil RGVs was quantified by converting RGVs into DALYs, allowing for comparison of different pesticides. Many notable studies have evaluated the health impacts resulting from human consumption of pesticide residues based on health risk characterizations (Akoto et al., 2013; Fantke et al., 2011a,b; 2012; Lewis et al., 2016; Wang et al., 2011), but not on pesticide standard values. Therefore, the objective of this study was to evaluate pesticide soil RGVs via human health risk characterization analysis for the commonly regulated Stockholm Convention POP pesticides. The present study will help environmental regulatory jurisdictions understand pesticide soil RGVs from a health impact perspective.

2. Materials

This research focuses on soil RGVs from national jurisdictions that may have a national or global impact and could affect large populations. All soil RGVs in this study are either for residential surface soil exposures dominated by ingestion, inhalation, and dermal contact, or for the most comparable exposure classification (Jennings and Li, 2014). Table S1 in Supplementary Materials summarizes 65 worldwide national jurisdictions from 49 nations and two multinational organizations that have promulgated pesticide soil RGVs. Those jurisdictions were identified through online data sources, and the reference web links and dates are summarized in Supplementary Materials Table S2. All data used in this study are provided in Supplementary Materials Table S3. Key words from the jurisdiction titles can be used to locate jurisdictions in the case of outdated web addresses. The total number of pesticide soil RGVs and the number of RGVs for the 10 commonly regulated POP pesticides of each nation are also provided. It should be noted that some states, provinces, regions, and cities also have regulated pesticide standard values in addition to the national jurisdictions. The present study focuses on evaluating health risk characterizations for national jurisdictions and comparing them among countries worldwide. For example, many states, regional jurisdictions, territories, and sovereign Native American jurisdictions in the United States have developed their own standard values. Other nations such as Canada, New Zealand, and Australia also have regional, provincial, and/or state standard values.

POPs are organic chemicals that have the following properties once they enter the environment: they remain intact for many years, they are widely distributed in various media, they bioaccumulate through the food chain, and they are toxic to ecosystems and humans (Secretariat of the Stockholm Convention Clearing House, 2008a). In response, 12 highly toxic chemicals, or the “dirty dozen”, were initially restricted or banned under the Stockholm Convention in 2001, including nine pesticides: aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, and toxaphene (Secretariat of the Stockholm Convention Clearing House, 2008b). In addition, 16 new chemicals were restricted by the Stockholm Convention in 2009 and 2011, including 10 pesticides: a-HCH, b-HCH, g-HCH (lindane), d-HCH, chlordane, kepone, endosulfan, endosulfan I, endosulfan II, and endosulfan sulfate (Secretariat of the Stockholm Convention Clearing House, 2017). In this study, RGVs for 10 POP pesticides commonly regulated by the Stockholm Convention were selected for analysis; Table 1 summarizes some basic information about these pesticides.

3. Methods

3.1. Lifetime theoretical maximum contribution

Theoretical maximum residue contribution was applied to compute the maximum “legal” exposure to chemicals from the diet (Winter, 1992). In this study, lifetime theoretical maximum contribution (LTMC, kg) was used to assess the maximum “legal” exposure to pesticides from residential surface soil during a lifetime. Equations (1)–(3) were derived to calculate the pesticide LTMC from soil ingestion, soil dust inhalation, and soil dermal contact. The total LTMC was computed by summing up the LTMC computed from ingestion, inhalation, and dermal contact (ATSDR, 2005).

$$LTMC_{soil-ing} = \mathrm{RGV} \times CoF \times EF \times \left(IR_{chi-ing} \times ED_{chi} + IR_{adu-ing} \times ED_{adu}\right), \quad (1)$$

where $\mathrm{LTMC}_{\text{soil-ing}}$ (kg) is the LTMC computed from the lifetime soil