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Research article

Global variations in pesticide regulations and health risk assessment of maximum concentration levels in drinking water

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

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

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1. Introduction

Pesticides are used to control and kill pests on croplands worldwide. They are also used in numerous homes and gardens, and have commercial and industrial applications. Society benefits from pesticides because they improve agricultural productivity and help fight disease. However, their application can damage the ecosystem as they penetrate the soil, groundwater, surface water, atmosphere, and biomass. Human health is also affected following inhalation, ingestion, and dermal contact with contaminated air, soil, food, and water.

Worldwide, regulatory jurisdictions are acting to protect people from the health risks of pesticide-contaminated water. In addition to regulating which pesticides can be used and how these pesticides may be applied, many jurisdictions have established maximum concentration levels (MCLs) that specify the maximum allowable concentration of pesticides in drinking water. These MCLs are often calculated based on health risk exposure scenarios and pesticide toxicology data. However, analysis demonstrates that MCLs often vary by 5–7 orders of magnitude. This indicates that worldwide regulatory jurisdictions do not agree on how the health risks of pesticide-contaminated water should be quantified. This also indicates that extremely high MCLs are unlikely to adequately protect human health.

Several previous studies have examined variability in MCLs of drinking water by comparing values from selected regulatory jurisdictions. For example, in an evaluation of the Ontario Canada drinking water standards, Gammie (2001) examined the differences between Canadian national, the World Health Organization (WHO), US, Australian, United Kingdom, and Ontario MCLs. They analyzed values for several pesticides, but did not conduct quantitative comparison. Radcliff (2003) tabulated MCLs of the US, Australia, Canada, United Kingdom, European Union (EU), and WHO for numerous contaminants including 15 of the 25 pesticides considered in this study, but conducted minimal analysis of the tabulated data. The David Suzuki Foundation (2006) compared the MCLs of the WHO, EU, Australia, US, and Canada and discussed the nature of the differences observed. The contaminants considered included 12 of the 25 pesticides considered here. Mamba et al. (2008) compared the MCLs of the WHO, EU, and the Netherlands to those of South Africa, but did not include information for individual pesticides. Macler (2009) compared US Environmental Protection Agency (USEPA) MCLs to those of California, Arizona, and Hawaii to create an extensive list of pollutants, including 17 of the 25 pesticides considered here.

More recently, the California Department of Public Health (2013) compared its current MCLs to those of the USEPA. Bamidele (2015) examined the differences between the MCLs of the WHO, EU, US, Canada, and the Nigerian national standards for two pesticides (metolachlor and 2,4-dichlorophenol, an intermediate of 2,4-D), for which Nigeria does not have an MCL. Lenntech (2016) compared the 1993 WHO and 1998 EU drinking water standards, but did not include information for individual pesticides. The Minnesota Department of Health (2016) compared the comprehensive list of state MCLs of pollutants to the USEPA MCLs and MCLGs (MCL goals), but no other jurisdictions were considered.

The most comprehensive previous study on this subject appears to be that of Drury (2013), who compiled an extensive body of worldwide MCL data for the WHO. Data for 14 of the 25 pesticides considered here were acquired from similar sources and using similar methods as those used in this study from approximately 100 nations worldwide. The results included the number of MCLs identified for each pesticide, their maximum, medium, and minimum values, and degree to which these values agreed with the WHO MCLs. However, these numbers showed poor agreement with the values presented here because Drury (2013) only included data

* Corresponding author. Department of Civil Engineering, Case Western Reserve University, Cleveland, OH 44106, USA.
E-mail address: zxl170@case.edu (Z. Li).

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for US national MCLs and omitted data from more than 50 other US national, state, and territory jurisdictions with promulgated MCLs. Drury (2013) also omitted several regional international jurisdictions and may have not accounted for the number of nations that have adopted EU standards.

Although numerous studies have focused on comparing MCLs, the full span of values applied to the pesticides considered here, distribution of MCLs within these value spans, or relationship of the values to human health risk model results are unclear. Thus, the objective of this study was to use health risk models to evaluate worldwide pesticide drinking water MCLs to control human health risk.

2. Materials and methods

2.1. Worldwide pesticide drinking water MCLs

The most commonly regulated pesticides were defined as those for which more than 100 MCLs have been promulgated. The nature of this class of water pollutants makes them considerably complex. Pesticides are typically chemically complex compounds. They can be identified by their chemical nomenclature such as that of the International Union of Pure and Applied Chemistry, but many regulatory jurisdictions identify these compounds by one of their more common trade names. Pesticides are usually named by their chemical names, active ingredient names (i.e. names used to substitute for chemical names) and product names (names for products formulated from active ingredients, sometimes several, and adjuvants). This may function well in a single jurisdiction, but makes it difficult to compare MCLs from many jurisdictions because identical pesticides are marketed under different names in different regions of the world, and trade names are more difficult to translate from multiple languages because they do not necessarily correspond to common words. Thus, it would be helpful to add CAS No. for ingredients (USEPA, 2017).

The pesticide MCLs used in this study were obtained from an internet search of official national regulatory agency web pages or online resources of intergovernmental organizations such as the CARICOM Regional Organization for Standards and Quality, East Africa Community, EU, Gulf Standardization Organization, Gulf Cooperative Council, Pacific Community, and WHO. The sources of MCLs from all jurisdictions considered here are shown in Supplemental list S1 and list S2. References for each are provided in Supplemental list S3. Worldwide pesticide drinking water MCL values are provided in Appendix I. Readers are cautioned that web pages are often updated and rearranged. The web Uniform Resource Locators (URLs) cited may not remain active. When URLs become inactive, the desired information can typically be located by word searches of the official websites.

2.2. Analysis of global MCLs

The numbers of total, US-related, and non-US-related MCLs are characterized by N, N_{us}, and N_w, respectively. The arithmetic mean (μ), median, geometric mean (μ_G), log10 mean (μ_L), and log10 standard deviation (σ_L) were also computed from each MCL set. Empirical cumulative distributions were generated from MCL sets as follows:

$$P(MCL_r \le MCL_i) \approx \frac{n_i}{N}; \quad \forall i = 1, \ldots, N \tag{1}$$

where MCL_r is a random value for a pesticide MCL, MCL_i is the known value for the same pesticide, and n_i is the integer rank of MCL_i in the set of N known values.

The cumulative distribution was also used to identify non-random MCL values. A data cluster was defined as an MCL interval (MCL_i - MCL_{i+M}) containing M values unlikely to have occurred randomly. A binomial probability function was used to estimate the probability (P_c) of a randomly occurring cluster as follows:

$$P_c[M\ MCL(MCL_i, MCL_{i+M})] = \left[\frac{N!}{M!(N-M)!}\right][F(MCL_{i+M}) - F(MCL_i)]^M\{1 - [F(MCL_{i+M}) - F(MCL_i)]\}^{N-M} \tag{2}$$

where the probabilities $F(MCL_i)$ and $F(MCL_{i+M})$ were computed from the lognormal cumulative distribution calibrated with the MCL set statistics. A probability of less than 0.001 (i.e. probability of occurrence of less than 1 in 1000) was considered to indicate that the cluster did not occur randomly.

2.3. Human health risk model uncertainty bounds for drinking water

Regulatory jurisdictions often apply health risk models to determine the magnitude of their MCLs. These models require two types of coefficients. The first type is based on details of the exposed individual such as their weight and amount of water they consume on an average day. These values are independent of the type of pesticide considered. Although there are commonly used values for these coefficients, it is not unusual for jurisdictions to make adjustments to accommodate for local conditions. The second type of coefficient defines the degree to which a specific pesticide is toxic or carcinogenic to a human. These values are rarely developed by individual regulatory jurisdictions. Most often, they are extracted from the body of research on pesticide toxicity.

Pesticide toxicity is generally quantified using animal exposure tests to quantify health impacts based on long-term ingestion. The no observable effect level (NOEL) or lowest observed effect level (LOEL) is often used to quantify the maximum amount of pesticides that can be ingested without adverse health effects.

$$AD = \frac{NOEL(LOEL)}{SF} \tag{3}$$

Here, AD is the animal dose (mg/kg-day) at which an effect is observed, to which as safety factor (SF) is often applied to account for different degrees of sensitivity between test animals or uncertainty introduced by the number and type of species tested. MCLs are then derived based on an exposure scenario and the AD as follows:

$$MCL = \frac{(AD)(HW)(PF)}{(V)(SF)} \tag{4}$$

Here, HW is the human weight (kg), V is water intake rate (l/day), and PF is a proportion factor that quantifies the portion of total pesticide exposure allocated to the drinking water ingestion