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Applying a statewide geospatial leaching tool for assessing soil vulnerability ratings for agrochemicals across the contiguous United States

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ABSTRACT

A large-scale leaching assessment tool not only illustrates soil (or groundwater) vulnerability in unmonitored areas, but also can identify areas of potential concern for agrochemical contamination. This study describes the methodology of how the statewide leaching tool in Hawaii modified recently for use with pesticides and volatile organic compounds can be extended to the national assessment of soil vulnerability ratings. For this study, the tool was updated by extending the soil and recharge maps to cover the lower 48 states in the United States (US). In addition, digital maps of annual pesticide use (at a national scale) as well as detailed soil properties and monthly recharge rates (at high spatial and temporal resolutions) were used to examine variations in the leaching (loads) of pesticides for the upper soil horizons. Results showed that the extended tool successfully delineated areas of high to low vulnerability to selected pesticides. The leaching potential was high for picloram, medium for simazine, and low to negligible for 2,4-D and glyphosate. The mass loadings of picloram moving below 0.5 m depth increased greatly in northwestern and central US that recorded its extensive use in agricultural crops. However, in addition to the amount of pesticide used, annual leaching load of atrazine was also affected by other factors that determined the intrinsic aquifer vulnerability such as soil and recharge properties. Spatial and temporal resolutions of digital maps had a great effect on the leaching potential of pesticides, requiring a trade-off between data availability and accuracy. Potential applications of this tool include the rapid, large-scale vulnerability assessments for emerging contaminants which are hard to quantify directly through vadose zone models due to lack of full environmental data.

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1. Introduction

Maintaining a high quality of groundwater is important for ensuring public health of the nation from its use for drinking water sources (Zogorski et al., 2006). Groundwater in the United States (US) was found to be vulnerable to a mixture of various contaminants, such as nitrate, pesticides, and volatile organic compounds (VOCs) (Nolan and Hitt, 2006; Squillace et al., 2002). Soil and groundwater contamination occurred from intensive human activities in both urban and agricultural areas, e.g., industrial discharges, landfills, hazardous waste dumps, septic tanks, and fertilizer applications (USEPA, 1997; Zogorski et al., 2006). Transport of contaminants, once introduced to the subsurface, was mainly modulated by recharge from precipitation and irrigation (Gilliom et al., 2006). Dissolved contaminants and their metabolites then reached the water table unless they were strongly bound to soils and aquifer media (Gilliom et al., 2006). Detailed information on groundwater contaminants found across the US is provided in recent national monitoring studies, for pesticides (Gilliom et al., 2006) and VOCs (Zogorski et al., 2006) with their degradates (Lawrence, 2006).

Hydrogeologic factors, such as soil permeability (as a function of soil water content), oxygen levels (or aerobic and anaerobic conditions), and flow regimes, were found to be deeply involved in the downward movement of pesticides and VOCs, along with their chemical characteristics (Hantush et al., 2002; Gilliom et al., 2006; Zogorski et al., 2006; Dusek et al., 2011). Simulating water flow and pollutant transport in the subsurface provided a structured approach to analyze the risk of contamination in response to these factors (Dusek et al., 2011; Šimůnek and van Genuchten, 2008). Various models (e.g., MACRO, PRZM3, and HYDRUS) were available that evaluated contaminant leaching in the vadose zone (Holman et al., 2004; Vanclooster et al., 2000). The performance of simulation models varied considerably depending on soil hydrology and contaminant fate and transport processes (Šimůnek, 2005). For example, the models that implemented the Richard equation were found to more accurately elucidate subsurface water flux, specifically in an upward direction, than cascading soil water balance models (Vanclooster et al., 2000). This is because cascading models do not account for the effect of soil texture on water movement precisely as well as are dedicated to a top-down (vertical) flow, as their name implies. There have been several studies that attempted to compare estimates of vertical concentration profiles among simulation models for a given scenario in a regulatory context (Dusek et al., 2011; Vanclooster et al., 2000). With increased complexity of modeled processes, a high quality monitoring data set, detailed soil profiles, and extensive computations are typically required to obtain the most accurate simulation results from any of these models (Šimůnek, 2005; Vanclooster et al., 2000). Therefore, simulation models of intermediate complexity or higher cannot be easily applied to large-scale leaching assessments (of pesticides and VOCs) that show high spatial and temporal heterogeneity in environmental conditions.

On the other hand, simple models that require a reduced number of input parameters may delineate the risk of contaminants over large areas, ensuring a rapid diagnosis of soil and groundwater vulnerability (Ki and Ray, 2015; Stenemo et al., 2007). There are some straightforward tools for assessing the leaching potential of pesticides by different input parameters and screening algorithms. Screening Concentration In GROund Water (SCI-GROW; Pereira et al., 2014), Windows Pesticide Screening Tool (WIN-PST; Brown et al., 2011), and statistical regression models of regional and national scales (Stackelberg et al., 2012) are the tools offered at the federal level from the US Environmental Protection Agency (USEPA), Department of Agriculture (USDA), and Geological Survey (USGS), respectively. Attenuation factor (AF), implemented at the State of Hawaii in the US, is a state-level tool used for pesticide evaluation procedure such as pesticide registration and certification (Ki and Ray, 2015; Stenemo et al., 2007). All these tools, except for regression models of the USGS that used additional parameters of watershed characteristics (e.g., air temperature, prevalence of artificial drainage, etc.), were similar in that they included basic information of chemical and soil properties (e.g., chemical half-life and organic matter content), which were widely available, for contaminant leaching assessment (Stackelberg et al., 2012). However, the results of pesticide leaching will not be exactly the same between the tools due to the difference in the assessment algorithms (e.g., linear *vs* non-linear regression), assumptions (e.g., the presence *vs* absence of advection-dominated flow), and data sets (e.g., sandy soils *vs* agricultural areas) used to derive them (Stackelberg et al., 2012). Although these differences are not significant in some areas, it is generally accepted that physically based screening tools which utilize basic properties that control contaminant movement tend to be more reliable and robust than subjective and empirical approaches. In addition, these empirical approaches of pesticide leaching will not show good performance in leaching assessment of new target compounds that involve the additional upward mass flux from soils such as VOCs (Hantush et al., 2002; Šimůnek et al., 2008; Vanclooster et al., 2000).

The State of Hawaii has recently advanced the physically based assessment tool extended AF (EAF) that can evaluate the leaching potential of VOCs as well as pesticides (Ki and Ray, 2015). As EAF is an extension of previous AF, they share the same information on recharge and soil characteristics, except for new chemical properties of VOCs, to assess contaminant leaching at the state level. In this study, we further expand this work to enhance soil vulnerability assessment in a large scale as this is easily done by replacing recharge and soil properties in Hawaii with those of the contiguous United States. Using this physically based approach, this study would specifically 1) identify risks of soil contamination from volatile and non-volatile chemicals at a national level, 2) estimate pollutant mass loadings in response to national patterns of each pesticide use, 3) examine variation in contaminant leaching by periodic forcing (i.e., monthly recharge and trends of annual pesticide use), and 4) ascertain current bottlenecks and future challenges of EAF in chemical leaching assessment. We hope that the proposed methodology plays an important role in addressing regional or national soil and groundwater pollution issues from various types of contaminants such as emerging contaminants that are a lack of information for detailed simulation.