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Prioritizing agricultural pesticides used in South Africa based on their environmental mobility and potential human health effects

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ABSTRACT

South Africa is the largest user of pesticides in sub-Saharan Africa and many studies have highlighted the occurrence of pesticides in water resources. Poor management of water treatment facilities in combination with a relatively high dependency on untreated water from boreholes and rivers creates the potential for exposure of human communities to pesticides and their associated health effects. Pesticide use, physicochemical and toxicity data was therefore used to prioritize pesticides in terms of their potential risk to human health. After eliminating pesticides used in very low quantities, four indices were used to prioritize active ingredients applied in excess of 1000 kg per annum; the quantity index (QI) which ranked pesticides in terms of the quantity of their use; the toxicity potential index (TP) which ranked pesticides according to scores derived for their potential to cause five health effects (endocrine disruption, carcinogenicity, teratogenicity, mutagenicity and neurotoxicity); hazard potential index (HP) which multiplied the TP by an exposure potential score determined by the GUS index for each pesticide (to provide an indication of environmental hazard); and weighted hazard potential (WHP), which multiplied the HP for a pesticide by the ratio of its use to the total use of all pesticides in the country. The top 25 pesticides occurring in each of these indices were identified as priority pesticides, resulting in a combined total of 69 priority pesticides. A principal component analysis identified the indices that were most important in determining why a specific pesticide was included in the final priority list. As crop specific application pesticide use data was available it was possible to identify crops to which priority pesticides were applied to. Furthermore it was possible to prioritize crops in terms of the specific pesticide applied to the crop (by expressing the WHP as a ratio of the total amount of pesticide applied to the crop to the total use of all pesticides applied in the country). This allows for an improved spatial assessment of the use of priority pesticides. The methodology applied here provides a first level of basic, important information that can be used to develop monitoring programmes, identify priority areas for management interventions and to investigate optimal mitigation strategies.

1. Introduction

Agriculture is well developed in South Africa, where a wide variety of crops are produced ranging from grains (particularly maize and wheat), to sugar cane, citrus and deciduous and sub-tropical fruit. Given the intensity of agriculture in the country, South Africa is the highest user of pesticides in sub-Saharan Africa (Dalvie et al., 2009), with over 500 active ingredients legally registered for use in the country (PAN, 2013). Runoff, leaching and spray drift result in the movement of pesticides off of intended target areas (Dalvie et al., 2003; Schulz, 2001) and as a result, a number of studies have reported the occurrence of pesticides in non-target environments, particularly in ground and surface water resources (Dabrowski et al., 2002a; London et al., 2000; Sereda and Meinhardt, 2005). The potential chronic human health effects resulting from exposure to pesticides are well known and include chronic neurotoxicity, endocrine disruption, immune impacts, genotoxicity, mutagenicity and carcinogenesis (Hallenbeck and Cunningham-Burns, 2011). In South Africa, studies have linked pesticide exposure to acute poisoning (Bennett et al., 2003), acetyl-choline esterase inhibition (Dalvie and London, 2006), possible occurrence of Guillain–Barre syndrome in a rural farming community (London et al., 2004), birth defects (Heeren et al., 2003) and endocrine disruption (Aneck-Hahn et al., 2007) in human communities. The combination of potential health risks and environmental exposure is of particular concern in a country like South Africa, where, whilst great progress has been made in improving water sanitation and supply, many poor and rural South Africans do not have access to treated, piped water and often make use of water collected directly from surface and groundwater resources (STATSSA, 2012). Furthermore, the quality of piped water is also questionable, as highlighted by the Blue Drop Report commissioned by the Department of Water Affairs (DWA, 2010) which assessed many municipalities across the country as

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falling below satisfactory standards for management of drinking water quality supplies.

Given the potential human health effects associated with exposure to agro-chemicals and their intensity of use, in combination with the questionable supply and quality of drinking water in poor communities, it is important to identify and prioritize a) those pesticides that are likely to move into water resources and pose potential risks to human health and b) areas where communities may be exposed to priority chemicals. Irrespective of the biological entity of concern (e.g. aquatic, terrestrial or human), pesticide prioritization procedures generally integrate pesticide use, physicochemical properties (or environmental fate models) and toxicity data to provide an indication of potential risk (Claeys et al., 2005; Kookana et al., 2005; Trevisan et al., 2009). The most recently published pesticide prioritization study for South Africa was conducted using sales data from 1999 (Dalvie et al., 2009). This study integrated pesticide use and toxicity data (oral LD50 for rats) to develop an acute toxicity indicator (ATI) for occupational health exposure. Other international studies used carcinogenicity as a more relevant toxicity endpoint for non-occupational exposure and also included environmental characteristics (i.e. half-life) as an additional indicator of potential environmental exposure (Gunier et al., 2001; Monge et al., 2005; Valcke et al., 2005). For all studies, pesticide sales data was used as a proxy for pesticide use. Whilst these methods provide a national overview of priority pesticides they do not provide a spatial picture of where priority pesticides are applied and which communities may be at risk of exposure. Linking pesticide use to specific crop types is a useful means to providing a more detailed first level of spatial assessment (Brown et al., 2007).

This study forms part of a larger integrated project examining the risks of current agricultural pesticide use to human and animal health (WRC, 2011). The aim of this particular study is to prioritize pesticides in South Africa based on their current use and potential to result in exposure and cause chronic health effects. Additionally, using crop specific pesticide use data, the study aims to prioritize those crops accounting for a higher proportion of priority chemical use and hazard potential. Results of this study are regarded as the first step in providing more detailed insight into the spatial distribution of priority pesticides across the country.

2. Methods

2.1. General approach

Pesticide prioritization was performed according to a modified method described in Valcke et al. (2005) and consists of two main phases. The first phase identified all active ingredients used in agricultural crop production within South Africa. These active ingredients were then prioritized based on usage and screened based on their toxicity properties, thus eliminating less important pesticides (i.e. those with low usage and/or toxicity). During the second phase of prioritization, the remaining pesticides underwent various scoring procedures for their potential to cause endocrine disruption, carcinogenic, teratogenic, mutagenic and neurotoxic effects so as to rank pesticides in terms of their relative toxicity to human health. The toxicity scores for each pesticide were then multiplied by a mobility score (determined by the Groundwater Ubiquity Score) to provide an indication of the potential environmental hazard of each pesticide. Finally, the potential hazard of the chemical was expressed as a function of its total use in relation to the total use of all active ingredients applied in the country to give a weighted hazard score.

2.2. Pesticide use data

Pesticide use data for South Africa was obtained from the Sigma™ Programme, a proprietary database maintained by the market research company GfK Kynetec (this database is now referred to as the AgroTrak™ database). The company provides quantified data on the use of agricultural active ingredients (collected from, amongst other sources, agrochemical manufacturers, distributors, trade associations and importers) on a country-by-country and crop-by-crop basis. Data purchased from GfK Kynetec was for the year 2009 and was the latest data available at the time of the study. Data provided by GfK Kynetec is also used by the U.S. Geological Survey to estimate pesticide use in the United States as part of their National Water Quality Assessment Programme (Thelin and Stone, 2013).

2.3. Screening

2.3.1. Pesticide use screening

The quantity of use of each pesticide was the first criterion used to rank and prioritize pesticides, the assumption being that humans are more likely to be exposed to pesticides that are used in higher quantities. All pesticides were ranked by volume of usage (kg). There was a large range in terms of the total amount of each active ingredient sold, ranging from 20 kg (mevinphos) to as much as 3,720,800 kg (glyphosate). For the purposes of this prioritization process, those active ingredients with less than 1000 kg sold were excluded from any further analysis as quantities below this cutoff point were subjectively considered to be low enough not to be of national importance (Valcke et al., 2005).

2.3.2. Toxicity screening

The Pesticide Properties Database (FOOTPRINT, 2006) was used to obtain information on endpoints for endocrine disruption potential, carcinogenicity, mutagenicity, teratogenicity and neurotoxicity for each of the active ingredients retained after the initial pesticide use screening procedure. All pesticides retained after the initial use screening procedure recorded positive or uncertain data for the selected toxicity endpoints and were therefore all included in subsequent prioritization procedures.

2.4. Pesticide prioritization

Pesticides retained for the second phase of prioritization were ranked or scored according to quantity of use (QI), toxicity potential (TP), environmental exposure potential (EEP) and hazard potential (HP). As pesticide sales data was available on a product by crop basis it was possible to rank pesticides at a national scale, as well as at a crop specific scale (i.e. based on the total amount of active ingredient applied to each major crop in the country).

2.4.1. Quantity index (QI)

The initial screening process retained 152 (of 203) active ingredients applied to crops at a national scale. These were all included in the latter prioritization process. These 152 pesticides (19,003,400 kg in total) accounted for 99.8% of the total quantity of pesticides sold for 2009. Fungicides, herbicides and insecticides accounted for 41%, 50% and 8% of the total use, respectively.

2.4.2. Toxicity potential (TP)

Five toxic effects were used to score each pesticide (endocrine disruption potential, carcinogenicity, mutagenicity, teratogenicity and neurotoxicity). Each toxic effect was classified into one of four different endpoint categories, namely “Yes” (there is definitive evidence that the chemical causes the toxic effect), “Possible” (there is evidence that the chemical may possibly result in the toxic effect), “No Data” (no studies have been performed to confirm whether the pesticide does or does not cause the toxic effect) and “No” (there is definitive evidence that the chemical does not cause the toxic effect). Data endpoints for each toxic effect were obtained from the Pesticide Properties Database (FOOTPRINT, 2006). The scores for each of the different categories for each toxic effect were weighted according to an adapted