Status, next steps and documentation of groundwater ecotoxicity characterization

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Authors:	Emmanuel Maillard, Peter Fantke
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Abstract

Addressing ecotoxicological impacts on groundwater organisms (stygobiota) requires the incorporation of a separate groundwater compartment, in addition to exposure and effect data for these organisms. Approaches for addressing groundwater organisms in a multimedia modeling context are available from risk assessment, relying on a specific set of assumptions that will need to be tailored toward applicability for LCA. Several studies indicate that groundwater organisms have longer life cycles due to lower metabolic rates, greater fat storage, and adaptation to low-energy environments, and show different sensitivities to chemical exposure than phylogenetically related surface-water species, although similar sensitivities have also been indicated. However, the availability of experimental data for toxicity to groundwater organisms is extremely limited, making it difficult to introduce a separate impact pathway at this point. Therefore, the benefit of representing toxicity to organisms in groundwater in LCA is currently considered a low priority, based on the findings from a consensus-building effort under the auspices of the Life Cycle Initiative (Fantke et al. 2018).

1. Introduction

The purpose of this document is to briefly present the state of the art in assessing the ecotoxicological impacts of chemicals on groundwater organisms in the context of life cycle assessment. The aim is to provide details on how groundwater organisms are considered in risk assessment regulations, and then summarizes the work done on their consideration in life cycle assessment.

2. LCA ecotoxicity indicator for groundwater organisms

A short presentation of groundwater organisms

A short litterature review carried out in the context of the OLCA-Pest project allows understanding that the number of hypogean (or stygobiotic) species is not exceedingly high, even in the richest groundwater regions. In average, the number of stygobiont species hardly reaches 7.5% of the total registered aquatic fauna in Europe (Sket 1999). In his paper, Sket proposes to consider three reasons for this comparative poverty of hypogean fauna:

- the limited accessibility of habitats

Animals can penetrate cave waters only through ponors or resurgences and interstitial waters through a sieve of unconsolidated sediment. Thus, the extent of the contact zones and therefore of the possible ecotonal regions between epigean and hypogean habitats is much smaller than between epigean habitats. (Sket 1999)

- the relative homogeneity (i.e. the small number of different habitats and potential niches)

The hypogean realm has several important characteristics: while most characters of the hypogean habitats can be found in different combinations also in some epigean habitats, the whole realm lacks any green plants and thus all those numerous habitats or feeding or housing niches dependent on them; Moreover, temperature fluctuations underground are null or very low around the value of the local yearly mean temperature, whereas in surface habitats, temperatures fluctuate daily and yearly with different amplitudes and with different averages; the situation is similar in the evaluation regime: only one regime – permanent darkness – is possible underground.

- the energetic poverty and inhospitality of hypogean habitats.

The low food resources and their low diversity is a direct consequence of the absence of green plants. It mainly means the absence at least of fresh plant tissues and their easily degradable ingredients, as well as the gradual reduction of resources towards deeper underground zones.

Although surface water dominant taxa, including insects and vertebrates, are also represented in groundwater, hypogean fauna overwhelmingly comprise crustaceans belonging to several taxonomic groups. In Europe, it appears that stygobiotic species account for approximately 40% of the total crustacean fauna (Danielopol et al. 2000). Crustacean copepod is by far the most abundant and species-rich taxon in groundwater. It is therefore relevant to think of the consideration of the ecotoxicological impacts of pesticides on these organisms.

Risk assessment scheme of pesticides for groundwater organisms

Fate modelling: processes

Let us present some general introduction of the environmental risk assessment of pesticides on groundwater organisms. The main processes that allow pesticides to reach groundwater are linked to leaching. More specifically, mixed leaching mechanisms ("chromatographic and preferential flow) have been reported to be involved in the contamination of adjacent aquifers with different water residence times.

- Preferential flow is characterized by fast flow through "preferential pathways" that bypass other parts of the chemical flows because of the macropore characteristics. A great number of studies have pointed out that non-uniform water flow and solute transport in structured soils are significantly affected by fast flow through "preferential pathways" that bypass other parts of the medium because of macropore characteristics.

- Chromatographic leaching is leaching at the molecular level, linked to physico-chemical mechanisms.

Pesticides degradation and sorption are considered the most important chemical processes affecting the fate of pesticides (Arias-Estévez et al. 2008; Van der Werf 1996). Pesticide adsorption results from different chemical and physical bonds between pesticide and soil particles. It decreases the pesticide concentration in the solute phase, and therefore, the toxicity and leaching risk are decreased. However, the adsorbed pesticides may desorb back into solution. Degradation means the transformation of a pesticide into another chemical compound or compounds, and is mainly a microbiological process for most compounds. Strongly absorbed pesticides are not available for microbes and form boundary bound residues.

The simplest way to handle sorption is to divide the pesticide mass into adsorbed and solute phases according to a linear partitioning coefficient (K_d). For the relevant herbicides, the main processes in transformation path are microbiological. In addition, hydrolysis and photochemical reactions may be important. The dominant process varies with a given chemical, available microbes and environmental conditions.

The extent of leaching is highly dependent on

- soil properties
- pesticides physico-chemical properties
- formulation types
- distribution of rainfall events or irrigation strategy
- hydrogeological processes

Pesticides properties such as water solubility, octanol-water partition coefficient, dissociation (pKa) and Henry's law constant are determining factors of their leaching potential. However, in the case of preferential flow, pesticides can be rapidly transferred to groundwater irrespective of their physico-chemical properties. Furthermore, biodegradation, soil porosity, hydrogeology, apparent age of groundwater (water residence time) and aquifer characteristics affect the extent of groundwater contamination.

Fate modelling: models

A wide number of models of environmental risk assessment of pesticides for groundwater have been developed as potentially effective and inexpensive tools to assess numerous options and to identify the best cropping systems. In Europe, four models are mainly used (Dubus et al. 2003): PRZM, PELMO, PEARL and MACRO, but a lot of other models exist in the literature. Each of these models have their own specificities and comparison studies have demonstrated that large differences between the models can sometimes be obtained. Moreover, the prediction of pesticides leaching by process-based models is fraught with considerable uncertainties.

These models, developed in the context of environmental risk assessment, are not consistent with LCA boundary conditions listed in (Fantke et al. 2018) : emission data availability and resolution is purposefully very different for Life Cycle Assessment and hence will not be suitable for being used in the listed model.

Ecotoxicity data for groundwater organisms

At the moment, toxicity data for groundwater organisms are currently very scarce.

(Verweij et al. 2015) found acute toxicity data for 18 compounds in total of a wide range of chemical structure and function. This list is composed of 6 pesticides: 3,4-dichlorophenol, aldicarb, chlorpyrifos, pentachlorophenol, permethrin, thiram. In the PPDB database, the analysis of ecotoxicological data on a sample of 40 active substances characterized in the OLCA-Pest project did not reveal data on groundwater organisms.

For the substances for which data are available, the tests showed that sensitivity of groundwater organisms is more or less similar to that of surface water organisms, and that if surface water standards would be applied to groundwater, groundwater organisms are protected from acute effects. The difficulty of rearing and handling hypogean copepods in a laboratory is the reason why so few ecotoxicological studies have been performed to date. Moreover, several authors (Hoose 2007) (Humphreys 2007) cautioned against the temptation of inferring the sensitivity of obligate groundwater species to toxicants from the sensitivity values of their surface-water relatives. Main concerns arise from the differences in physiological traits that groundwater organisms have evolved to cope with different environmental conditions in groundwater ecosystems, striving to reduce energy expenditure in an energy-limited environment.

They also have greater fat storage and are low energy adapted. Such physiological traits can lead to different sensitivities to toxicants. True groundwater species have longer life cycles compared to epigean relatives, therefore facing a high risk of multiple exposure along their life span. Hence, (Humphreys 2007) cautioned against the uncritical acceptance of groundwater risk assessment based on the sensitivity of epigean taxa with no close phylogenetic relationships with stygobiotic counterparts. In the face of this state of affairs, ecotoxicological tests on stygobiotic taxa are an obligate step toward a more appropriate assessment of groundwater quality and groundwater ecosystem protection.

Groundwater ecotoxicity indicator in Life Cycle Assessment

A bibliographical research allows confirming that there is currently no models available for addressing the ecotoxicological impacts on groundwater organisms. Further developments shall be provided in order to integrate the groundwater ecotoxicity impacts in life cycle assessment.

A groundwater indicator needs to be in line with the general toxicity/ecotoxicity framework in Life Cycle Impact Assessment as shown in Figures 4 and 5 of Fantke (2019).

To date, as the availability of experimental toxicity data is extremely limited, ecotoxicological effects on groundwater ecosystems are currently not recommended to be included in Life Cycle Impact Assessment, and this problematic is considered as low priority.

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