

(Im)mobilization of organic pollutants by soil constituents in the soil/ground water system – Strategies for innovative management

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1. Summary

In industrialized countries, soil and groundwater contamination by harmful substances is a contemporary problem. Therefore, minimizing health risks and impacts on the environment, caused by the contamination, is urgently needed, also for fitting the land use requirements and to ensure a permissible use for future generations.

In the last years, research was successfully performed and has increased our knowledge about the behaviour of organic chemicals in the soil and groundwater system and the factors that control their behaviour. This knowledge is of primary importance to (i) predict the fate and potential risk, (ii) ensure public safety and environmental protection, and (iii) enable rational decision-making for the development of management strategies, suitable tools and effective operations.

Here, the state of the art regarding the main mechanisms, processes and factors governing the fate and behaviour of organic contaminants in the soil-ground water system is summarized on the basis of a literature review in the frame of IOPSIM project [89], under the umbrella of the SNOWMAN ERA-NET [90].

In this area, an enormous amount of literature exists, mostly focusing on pesticides, because annually large quantities are applied in agriculture. One task within this project was dedicated to the identification and selection of substances which potentially will gain relevance in the interaction of the soil – ground/surface-water system focused on veterinary antibiotics and energetic compounds. The scope is to provide useful and precise information for end-users and support their work in the field of organic pollutants in the environment and to stimulate the development of new techniques for a sustainable management.

2. Introduction

The behaviour of organic contaminants in soils is generally governed by a variety of complex physical, chemical and biological processes. These processes directly control the transport of contaminants within the soil and their transfer from the soil to water, air or into the food chain. Both, the direction and rate of these processes depend on the chemical nature of the organic contaminant and the physi-

cal, chemical and biological properties of the soil. Persistence of contaminants in soils increases the potential for environmental consequences while their mobility in soil environments is a key factor in assessing the environmental risk. Some compounds are strongly adsorbed on the surface of soil particles and remain in the soil, in some cases being inaccessible for microbial degradation. Compounds interacting weakly or not at all with soil surfaces will be leached together with the soil solution and have the potential for contaminating surface or ground water reservoirs far from the site of contamination. Clays, oxides and organic matter are the primary constituents in soils responsible for the sorption of organic contaminants. Influences of different soil and environmental characteristics on organic contaminants behaviour in soil and groundwater are highlighted and summarized in this review. Furthermore, results of literature research on selected current and emerging organic pollutants are presented. Based on this literature research, knowledge gaps were defined as well as directions for future improvement of the risk management.

3. Influences on the fate of organic contaminants

The ability to take into account the processes that control the overall behaviour and fate of organic contaminants in soil systems will allow effective decision making through reliable evaluation of current and future risks. This will be possible by risk-based management using a source-pathway-receptor approach, taking into account site-specific conditions and potential changes of these conditions, such as changes in land use, climate or receptors. Knowledge about the main properties of the soil system that control the occurrence and extent of these processes will allow a more effective management and anticipation of the future changes of these properties, e.g. changes in geochemical conditions, which could affect these processes. The main properties that control the behaviour of organic contaminants in various soil processes are summarized them in Table 1.

Table 1 indicates that the properties of the organic contaminant are constant in their behaviour in soil systems, with respect to the sorption and degradation processes. No changes occur in their behaviour in the soil system, unless changes are made to the input side

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Table 1:

Summary of identified main properties of organic contaminants, soil and sediment and of environmental conditions with reference to the main processes that influence their behaviour in soil systems.

* Numbers ^{1,2,3} are referring to the processes determined by the main properties of organic contaminants, soil, sediment and environment.

Main properties that influence the fate		
Organic Contaminant	Soil and Sediment	Environmental conditions
<ul style="list-style-type: none"> • Electrical charge² • Hydrophobicity (Koc/w)^{1,2} • Lipophilicity³ • Molecular weight^{1,3} • Functional groups^{1,2,3} 	<ul style="list-style-type: none"> • Clay content² • Oxides content (DCB soluble Fe+Al)² • Content of organic matter OM^{1,3} • OM acid dissociation constant (pKa)² • OM composition^{1,3} • Carbonate content^{2,3} • Microbial Mass³ • Soil Structure^{1,2,3} 	<ul style="list-style-type: none"> • pH^{2,3} • Eh/redox³ • Temperature³ • EC² • Composition of soluble cations and anions²
Processes that determine fate		
Non-ionic Sorption (1)	Ionic Sorption (2)	Degradation (3)

of the system (source), such as reduced application or use of alternatives. Within the soil system the environmental conditions and those associated with the soil components themselves are variable, on shorter and longer time scales respectively.

Various environmental conditions influence organic contaminant behaviour in many ways. Three major types of changes can be identified:

a) Physical changes:

Such caused by human activities (e.g., land use change and associated soil excavation, changes in the water table) or natural phenomena (e.g., droughts or floods). Depending on the degree of physical disturbance, contaminants that were previously unavailable may become more available or have changed their transport pathways, potentially leading to increased exposure to receptors [9, 62, 64, 41, 54, 27, 39, 12].

b) Chemical Changes:

Such as changes in pH or ionic strength. This may occur as a result of natural changes (plant growth) or human activities (liming, application of fertilizers and industrial byproducts, disposal of waste materials) in the vicinity of contamination. Changes in pH can affect the speciation and consequently the availability of many metals as well as the binding capacity to soil particles for organic compounds [4, 19, 5, 74, 75, 62, 25, 66, 2, 65, 10, 67, 61, 48, 24, 44, 20, 17, 7].

c) Biological Changes:

Such as toxicity effects of the pollutant or molecule modification, solubility that suppresses the biological activity of organisms, changes in organic matter and nutrient content e.g. (N, P), redox potential, temperature, presence/absence of oxygen, and microbial composition [17, 7, 46, 47, 50, 70, 30].

4. Management Strategies for Organic Pollutants

Depending on the properties and spatial distribution of an organic contaminant in a particular management area there are 3 types of management measures possible: measures that target the source (regional scale), those that target the process (sub-regional scale), or those that target the effects (local scale) (Fig. 1).

Source measures aim to isolate or remove the source of contamination, or to reduce the risk at the source of one contaminant or of multiple contaminants, for example a change in the use of the target chemical or in-situ remediation. This prevents the contaminant to enter the soil system. These are typically measures that are taken at a *local scale*, and could be enforced through legislation. The other two types target the contaminant after they have spread in soil system beyond the scale where source measures are feasible.

Process measures are aimed at the pathway by which the contaminants are transported in the soil system, and are typically performed at a (sub)regional scale. These measures can be taken at the start of the pathway. If the contamination has not moved far yet, for instance through strong retardation which will have a strong risk reduction effect on the surface water quality at the end of the pathway. However, if the contaminant is already affecting the quality of the surface water, than measures at the beginning of the pathway, e.g. liming, will take a long time to result in quality improvements for surface and groundwater. In these cases, the fastest improvement of surface and groundwater quality will result from measures at the end of the pathway, such as vegetated buffer strips.

Effect measures are taken at the contaminant receptor and occur typically at the local scale, such as the treatment of groundwater for drinking water production.