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Investigating the role for adaptation of the microbial community to transform trace organic chemicals during managed aquifer recharge

Mazahirali Alidina [a,1], *Dong Li* [a,b,1], *Jörg E. Drewes* [a,b,c,*,1]

[a] Water Desalination and Reuse Center (WDRC), King Abdullah University of Science and Technology, Thuwal, Saudi Arabia

[b] NSF Engineering Research Center ReNUWIt, Civil and Environmental Engineering, Colorado School of Mines, Golden, CO, USA

[c] Chair of Urban Water Systems Engineering, Technische Universität München, Garching, Germany

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ABSTRACT

This study was undertaken to investigate whether adaptation by pre-exposure to trace organic chemicals (TOrCs) was necessary for microbial transformation during managed aquifer recharge (MAR). Two pairs of laboratory-scale soil columns, each receiving a different primary substrate, were utilized to simulate the dominant bulk organic carbon present in MAR systems receiving wastewater effluent of varying quality and having undergone different degrees of pre-treatment, as well as organic carbon prevalent at different stages of subsurface travel. Each pair of columns consisted of duplicate set-ups receiving the same feed solution with only one pre-exposed to a suite of eight TOrCs for approximately ten months. Following the pre-exposure period, a spiking experiment was conducted in which the non-exposed columns also received the same suite of TOrCs. TOrC attenuation was quantified for the pre- and non-exposed columns of each pair during the spiking experiment. The microbial community structure and function of these systems were characterized by pyrosequencing of 16S rRNA gene and metagenomics, respectively. Biotransformation rather than sorption was identified as the dominant removal mechanism for almost all the TOrCs (except triclocarban). Similar removal efficiencies were observed between pre-exposed and non-exposed columns for most TOrCs. No obvious differences in microbial community structure were revealed between pre- and non-exposed columns. Using metagenomics, biotransformation capacity potentials of the microbial community present were also similar between pre- and non-exposed columns of each pair. Overall, the pre-exposure of MAR systems to TOrCs at ng/L levels did not affect their attenuation and had no obvious influence on the resulting microbial community structure and function. Thus, other factors such as bioavailability of the primary substrate

* *Corresponding author*. Chair of Urban Water Systems Engineering, Technische Universität München, Am Coulombwall 8, 85748 Garching, Germany.
E-mail addresses: jdrewes@tum.de, jdrewes@mines.edu (J.E. Drewes).

[1] All authors contributed equally to this work.

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play a greater role regarding biotransformation of TOrCs. These results indicate that MAR systems adapted to a primary substrate are capable of degrading TOrC without necessarily being pre-exposed to them, making MAR a robust treatment barrier for biodegradable TOrCs.

1. Introduction

Emerging trace organic chemicals (TOrCs) including household chemicals, pharmaceuticals and personal care products, hormones, industrial chemicals, pesticides, as well as disinfection by-products have been observed in the aquatic environment raising concerns due to potential adverse effects on ecological and human health (Schwarzenbach et al., 2006). TOrCs often enter the environment via wastewater discharge. Since some TOrCs are persistent during conventional biological wastewater treatment processes, they are detected in surface water, groundwater, and drinking water (Barnes et al., 2008; Benotti et al., 2009). Although advanced oxidation processes and use of activated carbon during water treatment can remove many of these chemicals efficiently, managed aquifer recharge (MAR) is an appealing choice considering the much lower energy requirement of MAR as a natural water treatment process (Ray et al., 2008).

Aquifers used as a drinking water source can be recharged using MAR by infiltrating unconventional water sources such as storm water, impaired surface water and reclaimed water. During infiltration, these systems are capable of removing organic and inorganic compounds, nutrients, pathogens, and many TOrCs. However, performance of MAR systems can vary with some TOrCs, such as carbamazepine, dilantin, primidone, sulfamethoxazole and chlorinated flame retardants being persistent to biotransformation, while others like diclofenac, gemfibrozil, ibuprofen, trimethoprim and N-nitrosodimethylamine (NDMA) exhibiting site-specific removal efficiencies (Amy and Drewes, 2007). Thus, in order to enhance the removal of TOrCs in MAR systems, it is necessary to investigate which factors affect their removal.

Among the factors which have been suggested as being important for attenuation of TOrCs is the adaptation of the microbial community (Drewes et al., 2006a). A previous study reported that after some months of operation TOrC attenuation increased – suggesting a lag or adaptation phase (Baumgarten et al., 2011). In another study where subsequent spiking studies were undertaken, higher removal of some TOrCs was also reported, with the authors suggesting that the microbial community adapted to metabolizing TOrCs (Rauch-Williams et al., 2010). The necessity of pre-exposure as suggested by these studies, however, implies that MAR systems receiving new TOrCs would require some period of adaptation to acquire the ability to biotransform them, raising concerns about performance of these systems with regards to the wide range of new chemicals introduced annually.

Better removal after pre-exposure to TOrCs implies a metabolic mechanism where microbial degraders benefit directly by obtaining energy from TOrCs as a secondary substrate. In such a situation the microbial community would adapt to the presence of TOrCs and produce the appropriate enzymes for their attenuation. We hypothesize, however, that since TOrCs typically occur in MAR systems at trace (ng/L) levels (Barnes et al., 2008; Rauch-Williams et al., 2010), in the presence of much higher (mg/L) levels of dissolved organic carbon (DOC), co-metabolism rather than secondary substrate utilization is the major mechanism of biotransformation and adaptation to TOrCs is **not** required in order to degrade them.

Co-metabolism is a process whereby some organic compounds (such as TOrCs) can be metabolized by microorganisms in the presence of a primary substrate which serves as the main energy source, and mainly caused by the enzyme or cofactor produced during microbial utilization of degradable substrates (Spain and Van Veld, 1983). Co-metabolism has been suggested to be an important biodegradation mechanism for organic pollutants, particularly synthetic organic compounds, by numerous studies using both pure bacterial cultures as well as consortia (Ryoo et al., 2000; Sharp et al., 2007; Benner et al., 2013). With co-metabolism, presence or absence of the TOrCs has no effect on their degradation since the enzymes or co-factors responsible are expressed due to the microbial degradation of the primary substrate rather than due to the presence of the TOrCs themselves.

The research hypothesis was investigated using two pairs of laboratory-scale soil column set-ups fed with synthetic wastewater effluent containing different primary substrates to simulate different stages of the infiltration process during MAR. Each pair of columns consisted of a duplicate set-up comprising the same feed solution. The only difference between duplicate set-ups was that only one was pre-exposed to a group of eight TOrCs for a period of ten months, while the second set-up received no TOrCs during this period. Following the pre-exposure period, a spiking experiment in the non-exposed columns allowed a comparison of TOrC removal between corresponding pre- and non-exposed columns. In addition, a comparison of the microbial community structure and function by pyrosequencing of the 16S rRNA gene and metagenomics was conducted. Results of this study will provide an assessment whether pre-exposure to TOrCs is necessary for their biotransformation and elucidate the dominant biodegradation mechanism of TOrCs in MAR systems.

2. Materials and methods

2.1. Soil column setup

Two pairs of column set-ups (each pair consisting of one pre-exposed and one non-exposed set-up) were established. Each individual set-up consisted of four glass columns (Spectrum