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Identification of critical contaminants in wastewater effluent for managed aquifer recharge

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HIGHLIGHTS

- Multi-criteria approach was developed to select critical contaminants for MAR.
- Statistical analysis of wastewater data was used to select predominant contaminants.
- Additional representative compounds and limits were identified from published data.
- Representative emerging contaminants were also identified based on categories.
- Approach was successfully applied to a case study for indirect potable water reuse.

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ABSTRACT

Managed aquifer recharge (MAR) using highly treated effluent from municipal wastewater treatment plants has been recognized as a promising strategy for indirect potable water reuse. Treated wastewater effluent can contain a number of residual contaminants that could have adverse effects on human health, and some jurisdictions have regulations in place to govern these. For those that do not, but where reuse may be under consideration, it is of crucial importance to develop a strategy for identifying priority contaminants, which can then be used to understand the water treatment technologies that might be required. In this study, a multi-criteria approach to identify critical contaminants in wastewater effluent for MAR was developed and applied using a case study site located in southern Ontario, Canada. An important aspect of this approach was the selection of representative compounds for each group of contaminants, based on potential for occurrence in wastewater and expected health or environmental impacts. Due to a lack of MAR regulations in Canada, the study first proposed potential recharge water quality targets. Predominant contaminants, potential additional contaminants, and potential emerging contaminants, which together comprise critical contaminants for MAR with reclaimed water, were then selected based on the case study wastewater effluent monitoring data and literature data. This paper proposes an approach for critical contaminant selection, which will be helpful to guide future implementation of MAR projects using wastewater treatment plant effluents.

1. Introduction

Residential and employment growth can place pressure on groundwater-based potable water supplies and stream-based wastewater treatment systems, which are common in various parts of the world. To ensure that increased potable water demands and associated increases in wastewater discharges can be met, managed aquifer recharge (MAR) with reclaimed water has been recognized as a promising strategy for indirect potable reuse (Li et al., 2014). Many MAR projects recharge highly treated wastewater into aquifers to increase water supply, such as the Orange County groundwater replenishment system in the USA, the St-André aquifer recharge project in Belgium, and the Perth aquifer recharge project in Australia (U.S.EPA, 2012). However, wastewater treatment plant (WWTP) effluents may pose a risk to the safety of groundwater since effluent may contain residual contaminants that may have adverse effects on human health. Therefore, it is quite important to identify contaminants which require additional pre-

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treatment prior to injection/filtration.

Currently, several water reuse regulations/guidelines have included water quality objectives or requirements for MAR (e.g. Florida Reuse of Reclaimed Water and Land Application; Idaho Recycled Water Rules; Australian Guidelines for Water Recycling: Managed Aquifer Recharge; Pennsylvania Reuse of Treated Wastewater Guidance Manual; U.S.EPA, 2012 Guidelines for Water Reuse; California Groundwater Replenishment with Recycled Water) (Yuan et al., 2016). Most of these documents specify values for typical wastewater parameters such as microbial indicators, suspended solids (SS), and nutrients. To ensure the safety for potable uses, some guidelines (Florida, Idaho, California) have also included additional values for microbial, inorganic, and organic contaminants or recommend using drinking water or environmental standards to guide these values (Florida Department of Environmental Protection, 1999; Idaho Department of Environmental Quality, 2009; California Department of Public Health, 2014). These documents can serve as a reference to guide the monitoring or treatment of contaminants in wastewater effluents for MAR in regions that lack regulations in this area.

Since the number of potential regulated contaminants that require monitoring or treatment in wastewater effluents is large, studying the removal efficiency of each contaminant by different treatment alternatives will be difficult. This is also compounded by the fact that water reuse guidance documents do not include emerging contaminants, which often exist in effluents and are of potential concern. Therefore, an efficient approach is needed to select representative contaminants, based on a more frequent occurrence in WWTP effluents, more negative ecological effects on groundwater, and more severe impacts on human health. These contaminants can then be used to provide an initial assessment of which treatment technologies might be required.

Several studies have developed methods to select priority compounds for monitoring and/or treatment purposes, including priority emerging organic contaminants in surface and finished drinking waters (Kumar and Xagoraraki, 2010), emerging micropollutants for drinking water treatment studies (Jin and Peldszus, 2012), organic micropollutants in anthropogenically influenced water cycles (Jekel et al., 2015), aquatic microcontaminants in Switzerland (Götz et al., 2010), and pharmaceuticals released from WWTPs in China (Sui et al., 2012). Several screening criteria such as occurrence, biodegradability, ecological and health effects were used to select these priority chemicals. However, only Li et al. (2014) have developed a ranking system to select priority contaminants specifically for groundwater recharge, and their study only assessed organic compounds at one site in China. Other types of contaminants besides organics may also be of concern, and an approach that can be more generally used is needed.

In the present study, an approach is developed to select the critical contaminants to be monitored in wastewater effluents intended for MAR systems that will be used for potable water applications. Representative compounds were selected which have the greatest possibility to exist in municipal wastewater effluents and to cause potential adverse human and environmental health effects. Using MAR and potable water regulations/guidelines, literature data and WWTP effluent monitoring data, a list of critical contaminants was developed and applied to a case study in Canada. The approach used in this study would be useful for feasibility assessments to assess treatment requirements for future MAR projects using WWTP effluents, not only in Canada but also worldwide.

2. Approach

The development of a multi-criteria approach for selecting priority contaminants in wastewater effluent for MAR was done using several steps outlined as follows. The approach was then applied to a case study using monitoring data from a municipal WWTP in southern Ontario, Canada.

2.1. Defining recharge water quality limits

Due to the lack of water reuse regulations or guidelines for MAR in Canada, a list of required water quality parameter targets for MAR was defined. This was done by comparing three water reuse regulatory documents (Florida, Idaho, California) that include contaminant limits for MAR applications (Florida Department of Environmental Protection, 1999; Idaho Department of Environmental Quality, 2009; California Department of Public Health, 2014). Since this study assessed MAR for potable water purposes, the Guidelines for Canadian Drinking Water Quality (Health Canada, 2014) were also used as a reference. As well, this study referred to the water quality limits established in the Ontario Provincial Water Quality Objectives (Ontario Ministry of the Environment, 1994), the goal of which is to prevent pollution of natural water bodies. By including the Ontario Provincial Water Quality Objectives, this would ensure that reclaimed water recharged into aquifers will not impact the underground aquatic ecosystem. A summary of the limits for specific microbial and chemical contaminants in each of the regulatory documents is provided in Table A1 in the supplementary material. The limits for specific microbial and chemical contaminants in these five regulatory documents were compared, and target values were selected in order to establish a list of critical contaminants for MAR as described in section 2.2.

2.2. Selection of critical contaminants for MAR with reclaimed water

These were selected in three parts including the predominant contaminants, potential additional contaminants, and potential emerging contaminants. The selection criteria for each group is described as follows.

2.2.1. Predominant contaminants

This group was selected from the regulated substances that are routinely monitored in a wastewater effluent. To identify predominant contaminants, wastewater effluent monitoring data from a case study was statistically analyzed, and substances that had concentrations higher than the defined recharge water quality limits (determined in section 2.1) were identified. The municipal WWTP used in this study receives wastewater containing mainly household waste and little or no discharge from industry. The WWTP system utilizes an activated sludge biological treatment with tertiary filtration and ultraviolet (UV) disinfection. The treated effluent is discharged to a river, and therefore met the surface water quality objectives for this type of receiving environment. Effluent monitoring data from the case study WWTP over a 7 year period (2008–2014) were analyzed to determine the range and mean values. Data for some parameters contained values below the detection limit; therefore, to calculate the mean values, values below the method detection limit (non-detects) were handled by following the methods described in the U.S. EPA Guidance for Data Quality Assessment (U.S.EPA, 2000b). Using this procedure, when less than 15% of observations were below the detection limit, non-detects were replaced with half of the method detection limit. When 15%–50% of observations were non-detects, four possible methods were compared, including the Aitchison's, Cohen's, Trimmed mean, and Winsorized mean method (U.S.EPA, 2000b). An assessment of each method is described in Appendix A, and the Winsorized mean method was found to be the best approach for