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Review

Removal of organic micropollutants in waste stabilisation ponds: A review

Yolanda Gruchlik*, Kathryn Linge, Cynthia Joll

Curtin Water Quality Research Centre (CWQRC), Curtin University, GPO Box U1987, Perth, WA 6845, Australia

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A B S T R A C T

As climate change and water scarcity continue to be of concern, reuse of treated wastewater is an important water management strategy in many parts of the world, particularly in developing countries and remote communities. Many countries, especially in remote regional areas, use waste stabilisation ponds (WSPs) to treat domestic wastewater for a variety of end uses, including using the treated wastewater for irrigation of public spaces (e.g. parks and ovals) or for crop irrigation. Thus, it is vital that the resulting effluent meets the required quality for beneficial reuse. In this paper, both the performance of WSPs in the removal of organic micropollutants, and the mechanisms of removal, are reviewed. The performance of WSPs in the removal of organic micropollutants was found to be highly variable and influenced by many factors, such as the type and configuration of the ponds, the operational parameters of the treatment plant, the wastewater quality, environmental factors (e.g. sunlight, temperature, redox conditions and pH) and the characteristics of the pollutant. The removal of organic micropollutants from WSPs has been attributed to biodegradation, photodegradation and sorption processes, the majority of which occur in the initial treatment stages (e.g. in the anaerobic or facultative ponds). Out of the many hundreds of organic micropollutants identified in wastewater, only a limited number (40) have been studied in WSPs, with the majority of these pollutants being pharmaceuticals, personal care products and endocrine disrupting compounds. Thus, future research on the fate of organic micropollutants in WSPs should encompass a broader range of micropollutants and include emerging organic pollutants, such as illicit drugs and perfluorinated compounds. Further research is also needed on the formation and toxicity of transformation products from organic micropollutants in WSPs, since the transformation products of some organic micropollutants can be more toxic than the parent compound. Combining other wastewater treatment processes with WSPs for removal of recalcitrant organic micropollutants should also be considered.

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* Corresponding author.
E-mail address: Y.Gruchlik@curtin.edu.au (Y. Gruchlik).

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1. Introduction

Waste stabilisation ponds (WSPs) are large shallow ponds that utilise physical and biological processes to remove organic materials, pollutants and pathogens present in raw wastewater. They are one of the simplest methods of wastewater treatment and are widely employed all over the world, particularly in developing countries where sufficient land is normally available and the climate is more favourable (high temperature and sunlight) for their operation (Mara, 2006, 2004; Mara and Pearson, 1998; von Sperling, 2007). In Europe, WSPs are widely used for small rural communities of up to approximately 2000 inhabitants, although larger systems are found in France (over 3000 WSPs), as well as in Spain and Portugal (Keffala et al., 2013). Approximately one third of all wastewater treatment plants (WWTPs) in the USA are WSPs, usually servicing communities of up to 5000 people. In warm climates, such as North Africa, the Middle East, Asia and South America, WSPs are commonly used to treat wastewater from large (up to one million) populations (Keffala et al., 2013). In Australia, WSPs operate for a range of population sizes, from small remote communities of 1000–2500 inhabitants (Sheludchenko et al., 2016), to larger facilities servicing populations of up to 600,000 (Busine and Oemcke, 2003).

The scarcity of reliable water sources in many parts of the world, due to population increases, deterioration in the quality of surface waters, depletion of groundwater and climate change, has resulted in the use of recycled water as an alternative water source (Chen et al., 2012b). In many communities, treated wastewater is often the only irrigation option, particularly in developing countries with heavily utilized agricultural areas. However, to date, the majority of studies of wastewater reuse have focussed on large metropolitan treatment plants employing advanced activated sludge treatment and water recycling technologies, such as reverse osmosis membranes or advanced oxidation processes (Busetti et al., 2015; Rodriguez et al., 2009; Van Buynder et al., 2009). This type of treatment is considered to be “best practice” and produces high quality recycled water (Rodriguez et al., 2009). However, in rural WSPs, treatment for water reuse is often limited to disinfection by chlorine. Unlike reverse osmosis, chlorine disinfection does not provide additional chemical removal from wastewater, and may actually react with organic micropollutants present in wastewater to produce potentially harmful disinfection by-products (Krasner et al., 2008; Liew et al., 2012).

Organic micropollutants include a wide group of anthropogenic and natural compounds, such as pharmaceuticals and personal care products (PCPPs), steroid hormones and other endocrine disrupting compounds (EDCs), surfactants, industrial chemicals and pesticides (Luo et al., 2014). While current wastewater treatment processes can reduce the concentrations of many micropollutants, they are not specifically designed to remove them. Therefore, these contaminants can still be present in the resulting wastewater effluent, which is then either discharged to the environment or used in recycling schemes. Additionally, it is possible that some organic micropollutants are transformed into other compounds during wastewater treatment. The impact of these transformation products on the environment must also be considered, as these transformation products can be more toxic than the parent compound (Garcia-Rodríguez et al., 2014). The concentrations of organic micropollutants in wastewater effluents can range from a few nanograms per litre (ng/L) to several micrograms per litre (μg/L) (Luo et al., 2014).

Many organic micropollutants have been identified in wastewater and in wastewater-impacted environments (Barnes et al., 2008; Focazio et al., 2008; Schwarzenbach et al., 2006; Ying et al., 2009), with growing concern about the health and environmental impact of these chemicals in both environmental discharge and wastewater reuse applications. However, to date, there have been relatively few studies of micropollutant removal in WSPs. Most studies and reviews of micropollutants in wastewater have focussed on mechanised wastewater treatment processes, such as activated sludge treatment or membrane bioreactors (Bonvin et al., 2016; Fernandez-Fontaina et al., 2012; Homem and Santos, 2011; Jiang et al., 2013; Kim et al., 2007; Luo et al., 2014; Ternes, 1998; Verlicchi et al., 2012), reverse osmosis (Busetti et al., 2015; Rodriguez et al., 2009; Van Buynder et al., 2009) or advanced oxidation processes (Chen et al., 2012a; Huber et al., 2005; Lee and von Gunten, 2010; Reungoat et al., 2012; Ternes et al., 2003).

Choosing low cost and low energy technologies for wastewater treatment and reuse is of great importance, particularly in developing countries and remote rural communities. While some aspects of WSP performance, such as pathogen inactivation (Bolton et al., 2010; Curtis et al., 1992; Davies-Colley et al., 2000, 1999; Hosetti and Frost, 1998; Mara, 2013; Maynard et al., 1999) and nutrient removal (Brown and Shilton, 2014; Camargo Valero et al., 2010a, 2010b; Maynard et al., 1999; Mayo and Abbas, 2014; Powell et al., 2011a, 2011b; Senzia et al., 2002; van der Linde and Mara, 2010) have been well studied, WSP performance in the removal of organic micropollutants, has not been widely investigated. Garcia-Rodríguez et al. (2014) reviewed the ability of biologically based wastewater treatment systems (i.e. constructed wetlands, WSPs, high rate algal ponds (HRAPs) and *Daphnia* and fungal reactors) to remove organic micropollutants, however, much of the review focussed on constructed wetlands, with only a few studies on WSPs. Thus this paper reviews the current state of knowledge on the application of WSPs for the removal of organic micropollutants from wastewater, including the possible removal mechanisms and the impact of design and environmental factors on the removal efficiency. Potential knowledge gaps for further research in the future are also identified. This is the first comprehensive review of the performance of WSPs for the removal of organic micropollutants.

2. An overview of WSP treatment and performance

Conventional WSPs, often referred to as lagoons, usually consist of a combination of three different types of ponds: anaerobic ponds (APs), facultative ponds (FPs) and maturation ponds (MPs) (Mara, 2006, 2004; Mara and Pearson, 1998; Polprasert and Kittipongvises, 2011; Sah et al., 2012). The main features and functions of each pond type are summarised in Table 1. The ponds