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A multi expert decision support tool for the evaluation of advanced wastewater treatment trains: A novel approach to improve urban sustainability

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ABSTRACT

Wastewater Treatment (WWT) for water reuse applications has been accepted as a strategic solution in improving water supplies across the globe; however, there are still various challenges that should be overcome. Selection of practical solutions is then required whilst considering technical, environmental, socio-cultural, and financial factors. In this study, a multi expert decision support tool that considers a variety of evaluation criteria is proposed to provide a ranking system for competing advanced WWT technologies in terms of their performance. Two scenarios of water reuse in the contexts of Brazil and Greece are defined, and evaluation is undertaken based on opinions of water reuse experts. The results prove that the tool would successfully facilitate rigorous and methodical analysis in evaluation of WWT technologies for water reuse applications with potential for use under various sets of evaluation criteria, WWT technologies and contexts.

1. Introduction

The global population has doubled to seven billion people in half a century, placing considerable pressure on water resources. It is projected that by 2025, 67% of the global population will face significant water stress and 35% will suffer high constraints in accessing fresh water (Lazarova et al., 2001). Additionally, it is predicted that in the coming decades crowded urban settlements, that will generate heavy loads of water pollutants, will form a large proportion of the habitable world with higher levels of water withdrawal both for domestic and industrial use (Rosegrant et al., 2011). One potential solution to reducing water stress would be the application of water reuse technologies. Water reuse both augments opportunities for natural water quality improvement and improves management of competitive water demands.

There have already been various configurations of Wastewater Treatment (WWT) trains (Joksimovic et al., 2006), including membrane-assisted technologies, that have been acknowledged as suitable and reliable solutions regarding the removal of emerging pollutants and have been capable of meeting different water reuse standards (Dogan

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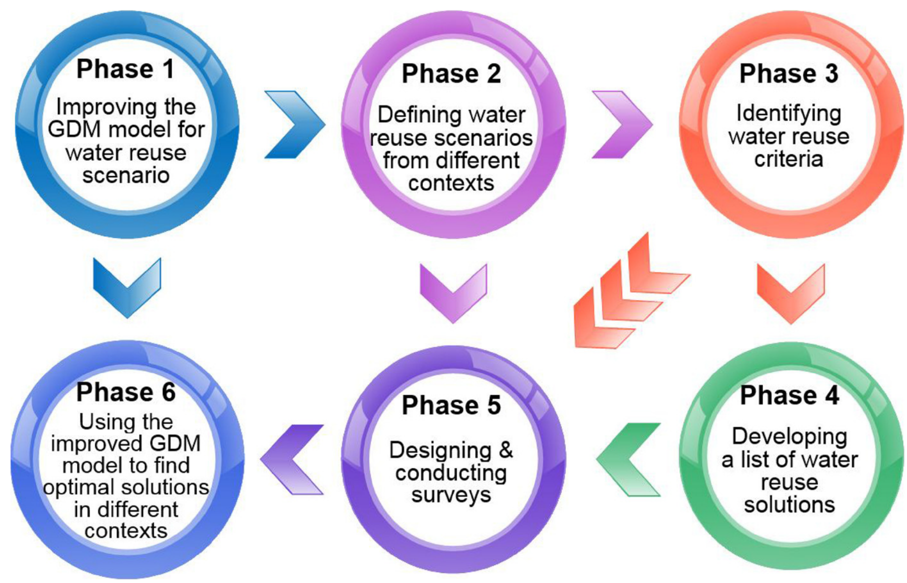

Fig. 1. The six phases towards selection of wastewater treatment technologies different water reuse scenarios.

et al., 2016). However, the complexity of the advanced unit processes, together with solution variety, requires a systematic assessment so as optimum solutions are able to be identified and selected. In fact, to find a practical solution is often rather complex, as a wide range of decision requirements and uncertain conditions should be taken into account (Dheena and Mohanraj, 2011).

Regulations have also been an important obstacle to water reuse implementation (Casani et al., 2005), as they can significantly affect the number and type of solutions and further complicate the process of decision making. This has recently received more attention from the stakeholders and a number of regional, national, and international guidelines or regulations have been established; for example, the World Health Organisation (WHO) has published a number of guidelines on water reuse (for both non-potable and potable water) and wastewater management (WHO, 2017, 2006a, 2006b). Another well-established water reuse guidelines are developed by the US Environmental Protection Agency (USEPA) (USEPA, 2012). A number of countries, such as India and China, have issued their own national water reuse standards/regulations (Eldho, 2014; Sadr et al., 2018; Yi et al., 2011; Zhu and Dou, 2018), however, in many other countries, local regulators still develop their own water reuse standards on a "case-by-case" basis (Casani et al., 2005).

Multi-Criteria Decision Analysis (MCDA) is a well-established decision support method that strives to model expert thoughts and reasoning, and illustrates modelled results by systematic procedures (Cakir and Canbolat, 2008), whilst evaluating a number of solutions based on a set of criteria (Walker et al., 2015) with respect to economic, environmental, social and technical aspects (Sadr et al., 2015). Decisions, involving various issues, in particular environmental concerns and their associated policies and regulations, oblige the participation of multiple stakeholders, as these decisions may have both local and global impacts on the environment and/or the society (Kalbar et al., 2013). To this end, the aim of any group decision activity is to identify the alternatives that are assessed by a set of individuals as the optimum ones. To achieve a more realistic approach, the experts are asked to assess not only the range of 'agree-disagree' but also they are requested to provide intermediate degrees as well, corresponding to partial agreement (Bordogna et al., 1997).

Taking into account the fuzziness in Group Decision Making (GDM) and the fact that the main contributors are experts, linguistic values can be employed, instead of numerical ones. These values are used both for assigning the weights of criteria and for evaluating each alternative against different criteria. Multi-Criteria Multi-Expert Decision Making (MCMEDM) has already been proved to be a useful tool to achieve rankings based on experts' judgement (Chen, 2001, 2000). In GDM, the approaches that are adopted for the aggregation of experts' opinions play a major role (Fan and Liu, 2010). Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Analytic Hierarchy Process (AHP) are commonly employed in the MCDA models and tools (especially for GDM) (Agrawal et al., 2016; Behzadian et al., 2012; Jaiswal and Mishra, 2017; Zyoud et al., 2016). TOPSIS is the most preferred method when decision problems involve large numbers of criteria and technologies, especially if there are bits of quantitative information in the data (Kalbar et al., 2013); whereas, the AHP is a quite powerful technique when the criteria function autonomously (Behzadian et al., 2012). Hybrid models/tools of TOPSIS and AHP have also been developed and applied to different fields (Ertuğrul, 2011; Jolai et al., 2011; Tavana and Hatami-Marbini, 2011; Yousefi and Hadi-Vencheh, 2010). To date and to the best of the authors' knowledge, only few pieces of research focused on fuzzy based TOPSIS-AHP group decision making (i.e. multi-expert decision making) in wastewater treatment and water reuse applications (Kamble et al., 2017; Karahalios, 2017; Zyoud et al., 2016).

This study builds on the work previously presented by Sadr et al., (2015), which adapted an MCMEDM (fuzzy-TOPSIS) for the selection of WWT options in different water reuse situations. In brief, Sadr et al., (2015) addressed a number of critical challenges in water reuse technology selection; namely: (1) alleviated the challenges of using linguistic variables, (2) incorporated opinions of different stakeholders in a panel of decision-making, (3) Showed how to deal with numerous water reuse aspects, criteria, and technologies, and finally, (4) systematised and classified the plethora of information about water reuse scenarios, criteria, and technologies.

In this work, we implemented an improved GDM method via integrating fuzzy TOPSIS with AHP for the selection of WWT technologies for non-potable water reuse applications in different contexts with distinct regulations and different geographical, environmental, economic and demographic conditions. The approach was tested and validated by application to two case studies: (1) in São Paulo, Brazil, and (2) in Herakleion, Greece.

2. Methodology

Based on the lessons learnt from the previous study, we aimed to