Science of the Total Environment 532 (2015) 676–687

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Assessment of wastewater treatment alternatives for small communities: An analytic network process approach

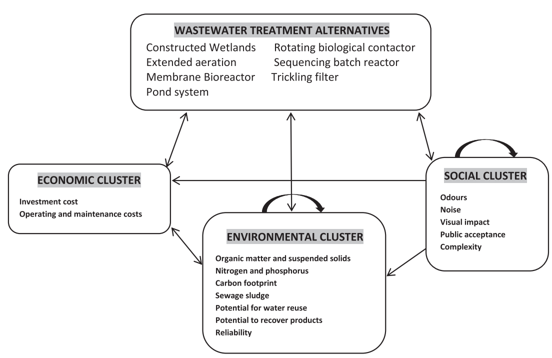
María Molinos-Senante [a,b,c,*], Trinidad Gómez [d], Rafael Caballero [d], Francesc Hernández-Sancho [e], Ramón Sala-Garrido [f]

[a] Departamento de Ingeniería Hidráulica y Ambiental, Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna 4860, Santiago, Chile
[b] Escuela de Arquitectura e Instituto de Estudios Urbanos, Pontificia Universidad Católica de Chile, El Comendador 1916, Santiago, Chile
[c] Centro de Desarrollo Urbano Sustentable CONICYT/FONDAP/15110020, Av. Vicuña Mackenna 4860, Santiago, Chile
[d] Departamento de Economía Aplicada (Matemáticas), Universidad de Málaga, Campus El Ejido, 29071, Málaga, Spain
[e] Department of Applied Economics, University of Valencia, Campus dels Tarongers, 46022 Valencia, Spain
[f] Department of Mathematics for Economics, University of Valencia, Campus dels Tarongers, 46022 Valencia, Spain

HIGHLIGHTS

- ANP is used to compare wastewater treatment alternatives for small communities.
- Experts prefer extensive technologies.
- A sensitivity analysis verified that the ranking of alternatives is very stable.
- ANP is suitable to select the most appropriate wastewater treatment alternative.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 4 March 2015
Received in revised form 15 June 2015
Accepted 15 June 2015
Available online xxxx

Editor: D. Barcelo

Keywords:
Analytic network process (ANP)
Wastewater treatment technologies
Multi-criteria decision-making
Municipal wastewater
Sustainability

ABSTRACT

The selection of the most appropriate wastewater treatment (WWT) technology is a complex problem since many alternatives are available and many criteria are involved in the decision-making process. To deal with this challenge, the analytic network process (ANP) is applied for the first time to rank a set of seven WWT technology set-ups for secondary treatment in small communities. A major advantage of ANP is that it incorporates interdependent relationships between elements. Results illustrated that extensive technologies, constructed wetlands and pond systems are the most preferred alternatives by WWT experts. The sensitivity analysis performed verified that the ranking of WWT alternatives is very stable since constructed wetlands are almost always placed in the first position. This paper showed that ANP analysis is suitable to deal with complex decision-making problems, such as the selection of the most appropriate WWT system contributing to better understand the multiple interdependences among elements involved in the assessment.

* Corresponding author at: Departamento de Ingeniería Hidráulica y Ambiental, Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna 4860, Santiago, Chile.
E-mail addresses: mmolinos@uc.cl (M. Molinos-Senante), trinidad@uma.es (T. Gómez), rafael.caballero@uma.es (R. Caballero), francesc.hernandez@uv.es (F. Hernández-Sancho), ramon.sala@uv.es (R. Sala-Garrido).

http://dx.doi.org/10.1016/j.scitotenv.2015.06.059

1. Introduction

In recent decades, both developing and developed countries have made significant efforts to improve sanitation and wastewater treatment (WWT). In spite of this, it is still a challenge worldwide regarding the implementation of appropriate WWT systems. For example, the European Directive 91/271/EEC describes the obligation of collecting and treating the wastewater generated in agglomerations larger than 2000 people equivalent (p.e.). However, it does not involve any duty to municipalities lower than said population. On the other hand, to achieve the good ecological status of bodies of water required by the European Directive 2000/60/EU (Water Framework Directive) an appropriate treatment of the wastewater is needed — including the one generated by small agglomerations (Molinos-Senante et al., 2011). Moreover, in the near future, many facilities should be updated to fulfil more stringent environmental requirements. The need of implementing WWT systems is even more evident in developing countries as it has been evidenced by UNICEF and WHO (2012), who reported that in 2010 only half of the population (56%) living in developing regions used improved sanitation facilities.

The selection of the most appropriate WWT technology is usually uncertain and complex since many alternatives are available and many criteria (such as investment costs, energy consumption, odours, etc.) are involved in the decision-making process (Molinos-Senante et al., 2014). Hence, selecting the most suitable or appropriate WWT technology is the biggest challenge faced by experts in wastewater management (Kalbar et al., 2012a). To deal with this challenge, multi-criteria decision-making (MCDM) techniques are very useful, since they use a structured and logical approach to model complex decision-making problems (Caballero et al., 2009). Therefore, several attempts have been made to address WWT technology selection problems using various MCDM methods and involving stakeholders' and/or experts' opinions (Ellis and Tang, 1991; Zeng et al., 2007; Bottero et al., 2011; Kalbar et al., 2012a, 2013; Domènech et al., 2013; Molinos-Senante et al., 2014; Ouyang et al., 2015).

Previous studies addressing the problem of wastewater treatment alternative selection following a MCDM approach have basically applied two methodologies: technique for order preference by similarity to ideal solution (TOPSIS) and analytical hierarchy process (AHP). TOPSIS was developed by Hwang and Yoon (1981), and uses a distance based approach to quantify and compare the preferences of the alternatives over the set of attributes. Kalbar et al. (2012a) used the TOPSIS method to evaluate three WWT technologies: activated sludge process (ASP); sequencing batch reactors (SBR) and membrane bioreactor (MBR) implemented in India based on seven criteria. Subsequently, using the same methodology and criteria, Kalbar et al. (2012b) extended their study (Kalbar et al., 2012a) by introducing, in the assessment, an additional WWT alternative: constructed wetlands (CW). Nevertheless, one of the well-known shortcomings of TOPSIS is that it does not provide weight elicitation or consistency checking for experts' opinions, which are essential in group decision-making (Kalbar et al., 2013).

AHP was proposed by Saaty (1977); it is a quantitative comparison method to select a preferred alternative using pairwise comparison of the alternatives based on their relative performance against each criterion. In the context of WWT alternative selection, AHP was used by Ellis and Tang (1991) and Tang and Ellis (1994) to rank eight alternatives to treat wastewater based on twenty criteria. Zeng et al. (2007) and Pophali et al. (2011) combined AHP with gray relational analysis (GRA) to select the most suitable WWT alternative. Bottero et al. (2011) applied AHP methodology to prioritize three WWT alternatives to treat the effluent from small cheese factories. Kalbar et al. (2013) evaluated three WWT technologies using AHP rather than TOPSIS methodology. Recently, Molinos-Senante et al. (2014) used AHP to assign weights to a set of indicators to incorporate the preferences of experts in the assessment of sustainability of WWT alternatives. An extension of fuzzy AHP introducing multidimensional scaling was applied by Ouyang et al. (2015) to evaluate five natural WWT systems.

AHP has been widely applied to cope with problems in which a criteria hierarchical structure can be stated and independence among criteria can be assumed and supported. However, in many real world problems, this independence cannot be verified. Rather, it may be assumed that the criteria are not all independent (Saaty, 2001). In order to overcome this shortcoming, Saaty (2001) proposed the analytic network process (ANP), which is a generalisation of the AHP. While the AHP represents a framework with unidirectional hierarchical relationships, the ANP allows for complex interrelationships among decision levels and attributes (Lee and Kim, 2000). In other words, ANP represents a decision problem as a network of elements grouped into clusters (De Felice and Petrillo, 2013). The elements of a cluster may influence some or all the elements of any other cluster, which means that a network may include interdependence of cluster and/or feedback within them (García-Melón et al., 2008; Aznar et al., 2010; Aragonés-Beltrán et al., 2010). In short, ANP allows for working with interdependent criteria and provides a more accurate approach for modelling complex environments (Liang et al., 2013; Aragonés-Beltrán et al., 2014).

Despite the fact that the criteria involved to judge a WWT technology as the most suitable are linked and have multiple interactions between them (Flores-Alsina et al., 2010), to the best of our knowledge, only Bottero et al. (2011) applied ANP method to evaluate experts' preferences towards appropriate WWT alternatives instead of AHP. Nevertheless, because their study was specifically focused on the selection of the most suitable WWT technology for cheese factories, the WWT alternatives evaluated were anaerobic digestion, phytoremediation and composting, which are uncommon technologies to treat municipal wastewater. Hence, their results and conclusions cannot be extended to urban context.

Against this background, the aim of this work was to prioritize seven WWT technology set-ups for the secondary or main treatment step by means of the application of ANP methodology. In doing so, the opinions of 29 international experts about 14 criteria were collected. Because the WWT selection problem is always situational (weight elicitation is not possible without any decision situation or scenario in mind) (Kalbar et al., 2013), our study focuses on assessing WWT alternatives capable — from a technical and land requirement point of view — to treat municipal wastewater originated in small communities (lower than 2000 p.e.). To test the stability of the ranking of WWT alternatives and to narrow the uncertainty associated with changes in expert's preferences, a sensitivity analysis was performed.

Our paper contributes to the current strand of literature by evaluating, for the first time, seven technologies to treat municipal wastewater by using ANP methodology. It should be highlighted that in spite of the significant development of empirical studies which applied ANP to support decision-making, none of them focuses on WWT alternatives. Hence, our study is a pioneering and novel approach in the framework of the selection of the most appropriate WWT since previous studies have not considered the multiple interdependences among decision levels and criteria. Moreover, our study provides insight into the preferences of WWT in the criteria considered in the decision-making process.

This study provides valuable information to support the decision-making processes that are used to select the most suitable technology to treat municipal wastewater. This aims to facilitate the selection of the most feasible technology of a wide set of possibilities.

2. Methodology

In the context of WWT technology selection, the ANP methodology is a useful tool since it allows modelling the problem as a network of criteria and alternatives (which are called elements), grouped in clusters (Saaty, 2005). All the elements in the network can be related in any possible way, considering feedback and interrelationships within