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The influence of expert opinions on the selection of wastewater treatment alternatives: A group decision-making approach

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A B S T R A C T

The application of multiple-attribute decision-making (MADM) to real life decision problems suggests that avoiding the loss of information through scenario-based approaches and including expert opinions in the decision-making process are two major challenges that require more research efforts. Recently, a wastewater treatment technology selection effort has been made with a 'scenario-based' method of MADM. This paper focuses on a novel approach to incorporate expert opinions into the scenario-based decision-making process, as expert opinions play a major role in the selection of treatment technologies. The sets of criteria and the indicators that are used consist of both qualitative and quantitative criteria. The group decision-making (GDM) approach that is implemented for aggregating expert opinions is based on an analytical hierarchy process (AHP), which is the most widely used MADM method. The pairwise comparison matrices (PCMs) for qualitative criteria are formed based on expert opinions, whereas, a novel approach is proposed for generating PCMs for quantitative criteria. It has been determined that the experts largely prefer natural treatment systems because they are more sustainable in any scenario. However, PCMs based on expert opinions suggest that advanced technologies such as the sequencing batch reactor (SBR) can also be appropriate for a given decision scenario. The proposed GDM approach is a rationalized process that will be more appropriate in realistic scenarios where multiple stakeholders with local and regional societal priorities are involved in the selection of treatment technology.

1. Introduction

Environmental decisions require the participation of multiple stakeholders and have large-scale implications, which affect the local as well as the global environment. As reported by Kalbar et al. (2012a), technology selection in India is mainly skewed toward a certain number of criteria such as a compliance with stipulated regulatory standards and the technology cost. Many other essential criteria, such as the location, the socioeconomic conditions and the impacts on the environmental receptors (such as the air, the soil, rivers and lakes), are not accounted for when choices are made regarding the appropriate selection of technology for a given scenario. The wrong choice may lead to a long-term wastage of resources such as energy and chemicals. The misallocation of limited financial resources is also an unintended consequence of such decision-making (Kalbar et al., 2012a). Hence, it is of utmost importance to adopt a rational decision-making procedure that will select appropriate wastewater treatment technologies. Many attempts have been made to address wastewater treatment technology selection problems using various multiple-attribute decision-making (MADM) methods (Tecle et al., 1988; Ellis and Tang, 1991; Zeng et al., 2007).

The current MADM literature reviews (Kiker et al., 2005; Pirdashti et al., 2011; Huang et al., 2011; Behzadian et al., 2012; Yue, 2013) show that there are two major challenges that are currently being addressed: (1) the avoidance of information loss in decision-making through scenario-based approaches, and (2) the inclusion of expert opinions under a group decision-making framework. The first challenge has recently been addressed by Kalbar et al. (2012b) through the development of a scenario-based MADM approach. The approach developed by Kalbar et al. (2012b) incorporated primary information available to the stakeholders or decision-makers (DM), such as the location of the plant, the level of the treatment, the scope of recycling and the land availability in the region through an articulation of real-life decision-making scenarios. Scenarios are defined as a set of weights of attributes that capture the local and regional priorities of a given decision-making situation. The four most frequently used sewage treatment technologies in India namely: Activated Sludge

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Process (ASP), Sequencing Batch Reactor (SBR), Up-flow Anaerobic Sludge Blanket reactors followed by Facultative Aerobic Lagoon (UASB-FAL) and Constructed Wetlands (CWs) were ranked for six decision making scenarios.

Addressing the second challenge is more difficult as the inclusion of expert opinions will convert the problem into a more complicated scenario-based group decision-making (GDM) problem. A general framework for multi-criteria GDM methodology has been presented by Yu and Lai (2011). In GDM, the approaches that are adopted for the aggregation of expert opinions play a major role. The Technique for order performance by similarity to ideal solution (TOPSIS) and analytical hierarchy processes (AHP) are the most commonly used MADM methods for group decision-making (Ramanathan, 2001; Vaidya and Kumar, 2006; Shih et al., 2007; Aragonés-Beltrán et al., 2009; Behzadian et al., 2012). TOPSIS is the preferred method when decision problems involve large numbers of attributes and alternatives, especially when objective or quantitative data are available (Kalbar et al. 2012b). However, TOPSIS does not provide weight elicitation or consistency checking for expert opinions, which are very crucial in group decision-making.

Literature review suggests that GDM has been employed by various researchers for selection of wastewater treatment technologies. Anagnostopoulos et al. (2007) and Karimi et al. (2011) have reported a fuzzy AHP approach for selection of wastewater treatment problem. Number of criteria encompassing technical/administrative criteria, economic criteria and environmental criteria are considered for the evaluation. These studies have considered quantitative criteria, for example capital cost, land requirement etc., but have treated them as qualitative criteria by using experts' opinions thorough questionnaires. The major difficulty is found as use of numerical inputs of quantitative criteria to form scores in AHP, which is one of the reasons of not to directly use of numerical data and quantifiable indicators in decision making process. Hence, there was a need to develop a new GDM approach which will consider both quantitative and qualitative indicators.

In this study, appropriate wastewater treatment technologies have been selected using both quantitative and qualitative criteria/attributes. AHP is applied to reconcile multiple qualitative attributes, where expert judgments are quantified using pairwise comparison matrices (PCMs) [or Factor Evaluation Matrices] based on Saaty's scale. A new approach to generate PCMs based on quantitative criteria is proposed. The developed framework for group decision-making in multiple scenarios (representing local and regional societal priorities in the form of set of attribute weights) along with the incorporation of expert opinions is most desired for technology selection in the context of advanced technology growth.

The next section describes the methodology that is used for the determination of pairwise comparison matrices based on quantitative criteria, the aggregation of expert opinions based on qualitative criteria and the estimation of overall priorities. The results and discussion section reports the robustness and the sustainability of the technologies primarily obtained through consultations with experts. The analysis and the interpretation of the overall rankings that are generated by the developed GDM approach are also discussed in the same section. Finally, the conclusions section summarizes the model development, the applications and the research findings.

2. Methodology

In this study, the set of criteria and indicators used by Kalbar et al. (2012a, b), are considered as shown in Table 1. In the study conducted by Kalbar et al. (2012a, b), a comprehensive approach was followed to quantify the scores of the quantitative criteria using Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and field data (such as land and manpower requirements) obtained from actual wastewater treatment plants (WWTPs). Kalbar et al. (2012b) used five quantitative criteria derived from LCA, five indicators derived from LCC, and two qualitative sustainability criteria that possessed seven indicators to rank the four alternatives. However, as it was mentioned earlier, this study did not involve expert opinions into decision-making process.

In the present study, the scenario-based GDM process that incorporates expert opinions was developed and is depicted in Fig. 1. A hierarchical decomposition of the criteria and the indicators that were used in the study are shown in Fig. 2. The criteria "Robustness of the Technology" and "Sustainability" are qualitative. Three indicators, namely the reliability, the durability and the flexibility, are used to quantify the "Robustness of the Technology" criterion. "Sustainability" is quantified using four indicators, namely the acceptability, the participation, the replicability and the promotion of sustainable behavior. These indicators are qualitative in nature, and expert opinions are taken into consideration to quantify these indicators.

AHP has been recommended as one of the methods for group decision-making (Ramanathan and Ganesh, 1994; Honert and Lootsma, 1996; Barzilai et al., 1987). There are many approaches to aggregate the group decisions, and the most commonly used approaches are the following: (1) Aggregating the Individual Judgments (AIJ) for each set of pairwise comparisons into an

Table 1
Criteria with respective indicators and scores used for the selection of appropriate wastewater treatment technologies.

Sr. no.	Criteria	Indicator	Criteria weights for urban area Scenario II	Criteria weights for rural area Scenario VI	ASP	SBR	UASB-FAL	CWs
1	Global warming[a]	Global warming potential (kg/p.e.-year)	20 (cost)	20 (cost)	18.20	31.97	7.67	−3.86
2	Eutrophication[a]	Eutrophication potential (kg/p.e.-year)	80 (cost)	80 (cost)	3.76	1.38	5.85	3.40
3	Life Cycle Costs[b]	Net Present Worth (Rs. Lakh/MLD)	20 (cost)	90 (cost)	137	127	103	242
4	Land requirement[b]	Land requirement (m^2/MLD)	80 (cost)	80 (benefit)	1400	353	1123	8500
5	Manpower requirement for operation[b]	Number (for operation of medium scale plant)	10 (cost)	80 (benefit)	10	6	14	4
		Reliability	40 (benefit)	40 (benefit)	Qualitative			
6	Robustness of the System	Durability	40 (benefit)	40 (benefit)	Qualitative			
		Flexibility	40 (benefit)	40 (benefit)	Qualitative			
		Acceptability	10 (benefit)	80 (benefit)	Qualitative			
7	Sustainability	Participation	10 (benefit)	80 (benefit)	Qualitative			
		Replicability	20 (benefit)	80 (benefit)	Qualitative			
		Promotion of sustainable behavior	10 (benefit)	80 (benefit)	Qualitative			

[a] Kalbar et al. (2012a).
[b] Kalbar et al. (2012b).