Journal of Environmental Management 128 (2013) 844–851

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Management

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

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

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ARTICLE INFO

Article history:
Received 17 March 2013
Received in revised form
9 June 2013
Accepted 17 June 2013
Available online 18 July 2013

Keywords:
Wastewater treatment
Group decision-making
Multiple-attribute decision-making
Analytical hierarchy process
Life cycle assessment

ABSTRACT

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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0301-4797/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jenvman.2013.06.034

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).

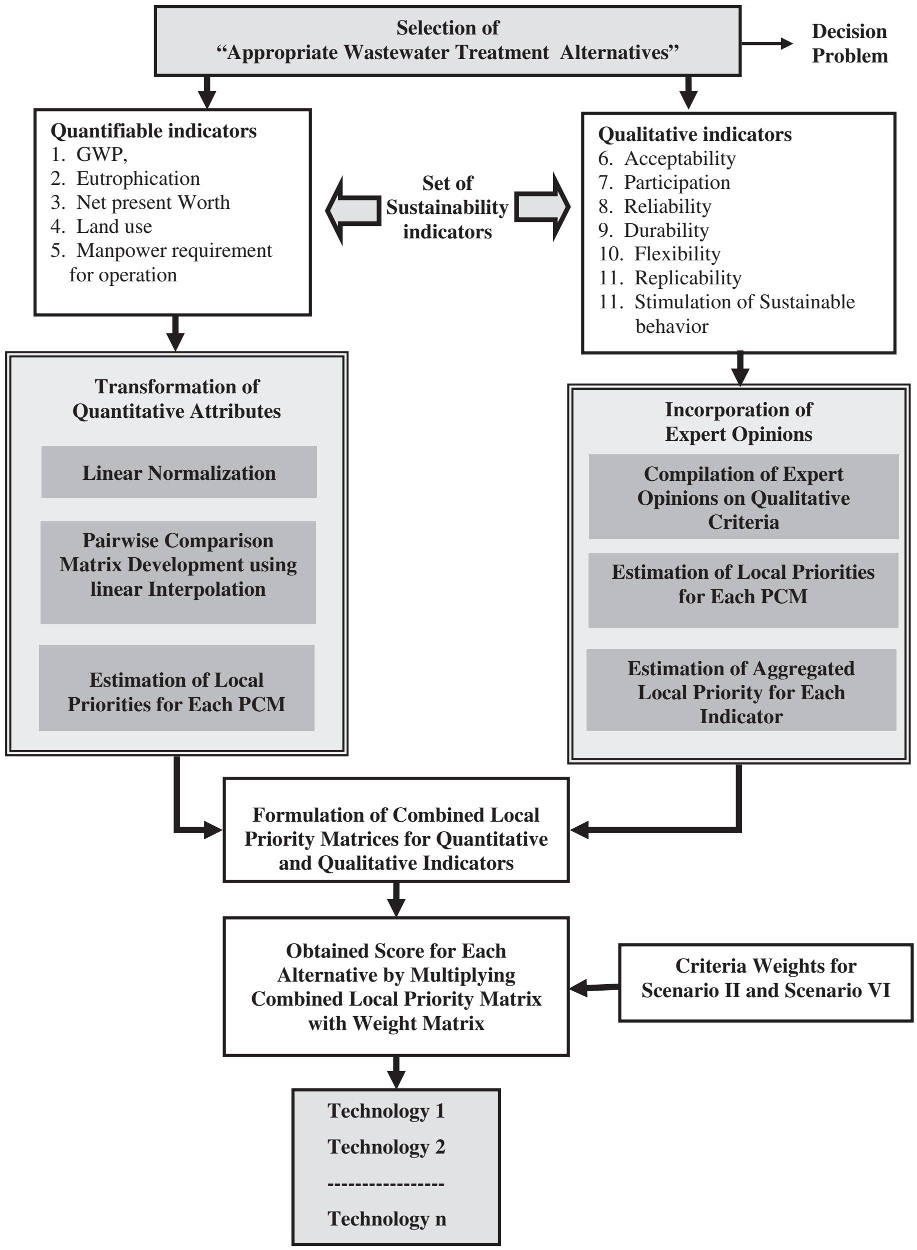
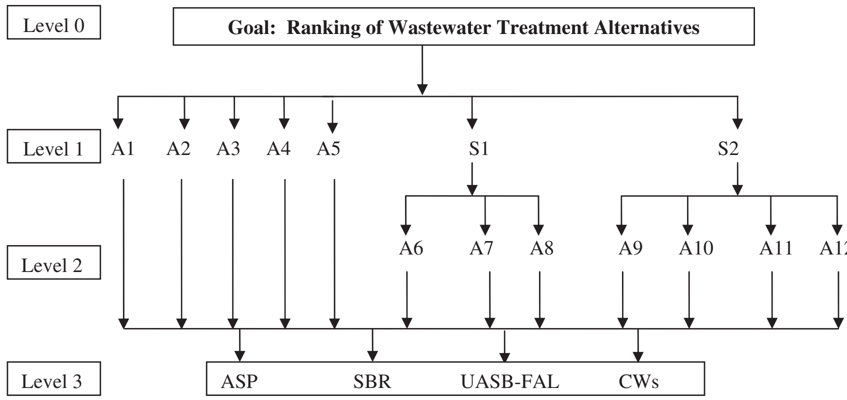


Fig. 1. Representation of the AHP approach for group decision-making.

'aggregated hierarchy'; (2) Aggregating Individual's Priorities (AIP), which synthesizes each of the individual hierarchies and aggregates the resulting priorities; and (3) aggregating the individual's derived priorities for each node in the hierarchy (Forman and Peniwati, 1998). In the present study, the AIP approach has been adopted because each of the experts is associated with different organizations and subscribes to different value systems within their own rights.

For AHP, the most recommended aggregation method is the geometric mean (GM) because it is consistent with the meaning of both judgments and priorities in AHP (Saaty, 1980; Aczel and Saaty, 1983; Forman and Peniwati, 1998; Aull-Hyde et al., 2006). Armacost et al. (1999) reported four axioms on AHP that must be satisfied to validate a conventional AHP. The four axioms are as follows: (1) the reciprocal condition: when comparing two objects, the intensity of preference of an original comparison is the reciprocal of the opposite comparison; (2) homogeneity: elements in a particular level of the hierarchy are comparable; (3) dependence: the weights of higher level elements do not depend on the lower level elements; and (4) expectations: all criteria and alternatives are represented in the hierarchy. Mathematically, it has been proven that the arithmetic mean or the geometric mean could be used to synthesize the judgments of individuals under conditions of separability, associativity, cancellativity, consensus, and homogeneity. However, when the reciprocity condition is used, the geometric mean is the only way to combine judgments (Saaty and Shang, 2007).

All of the experts have independently noted that the wastewater treatment selection problem is always situational; hence, weight elicitation is not possible without any decision situation or scenario in mind. In the present study, two decision scenarios, which are Scenarios II and VI (presented in grey shades in Table 1), are considered from six real-life decision-making scenarios that were defined in Kalbar et al. (2012b) for a demonstration of the current



Level 1 Attributes:
A1: Global warming
A2: Eutrophication
A3: Life cycle costs
A4: Land requirement
A5: Manpower requirement for operation
S1: System robustness
S2: Sustainability

Level 2 Attributes:
A6: Reliability
A7: Durability
A8: Flexibility
A9: Acceptability
A10: Participation
A11: Replicability
A12: Promotion of sustainable behavior

Fig. 2. A hierarchical decomposition of the attributes in the selection of wastewater treatment alternatives.

AHP-based group decision-making method. The details of the two decision scenarios are shown in Table 1.

2.1. Determination of pairwise comparison matrices for quantitative criteria

i) Scores for quantitative criteria (the first five criteria from Table 1) are linearly normalized considering the types of attributes (cost or benefit) using the following equations:

$$r_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \text{for benefit attributes} \quad (1)$$

$$r_{ij} = \frac{x_j^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}} \text{for cost attributes} \quad (2)$$

where x_{ij} is the score of the jth indicator for the ith alternative, and $x_j^{\min}$ and $x_j^{\max}$ are the minimum and the maximum scores, respectively, of the jth indicator. In the present problem, there are 4 alternatives and 7 criteria (with 12 indicators or attributes). The normalized scores are tabulated in Table 2.

ii) Each indicator has to be considered separately to develop the pairwise comparison matrices. The first indicator that is shown in Table 2 (shaded grey), GWP, is considered for a further illustration of the proposed methodology.

iii) For the given attribute GWP, the differences between the attribute scores of the first alternative and next alternatives are determined as shown in Table 3. The operation is based on the principle that, the stronger preference to A_i over A_j, more is the difference between $A_i - A_j$ (when non-negative), Prioritization using Saaty's scale follows the same principle. Table 3 is termed a difference matrix.

iv) Only non-negative elements of the difference matrix (as shown in Table 4) are considered.

v) Non-negative elements are linearly interpolated based on a scale of 1–9 (Saaty's scale). In this example, the zero values in Table 4 are redefined as a 1 (of least importance), and the maximum positive difference of 0.6782 is redefined as a 9 (absolute importance) on the scale. Table 5 shows the linearly interpolated elements based on the scale.

vi) The blank cells in Table 5, which are actually negative values that were obtained from the difference matrix, are replaced with reciprocal values of the respective entries of their transposed elements, and the final pairwise comparison matrix based on Saaty's scale is shown in Table 6.

vii) Similarly, pairwise comparison matrices for the remaining four quantifiable indicators are obtained. Table 7 shows the pairwise comparison matrix for all quantitative indicators.

viii) Local priorities are determined for each indicator by a normalization of the geometric mean of the PCM rows.

The qualitative criteria (last two criteria in Table 1) with seven indicators are prioritized using the inputs obtained from the experts.

Table 2
Attribute scores for quantitative criteria.

Sr. no.	Indicator	Alternative			
		ASP	SBR	UASB-FAL	CWs
1	Global warming potential (kg/p.e.-year)	0.3843	0.0000	0.6782	1.0000
2	Eutrophication potential (kg/p.e.-year)	0.4676	1.0000	0.0000	0.5481
3	Net Present Worth (Rs. Lakh/MLD)	0.7554	0.8273	1.0000	0.0000
4	Land requirement (m^2/MLD)	0.8715	1.0000	0.9055	0.0000
5	Number (for operation of medium scale plant)	0.4000	0.8000	0.0000	1.0000

Table 3
Estimation of differences between the attributes.

GWP	ASP	SBR	UASB-FAL	CWs
ASP	(0.3843–0.3843) = 0	(0.3843–0) = 0.3843	(0.3843 –0.6782) = –0.2939	(0.3843–1) = –0.6157
SBR	–0.3843	0.0000	(0–0.6782) = –0.6782	(0–1) = –1.0000
UASB-FAL	0.2939	0.6782	0.0000	(0.6782–1) = –0.3218
CWs	0.6157	1.0000	0.3218	0.0000

2.2. The aggregation of expert opinions for the qualitative criteria

A team of twelve experts from the academic, research and industrial fields was consulted for quantifying the qualitative criteria based on the seven indicators. Each of the experts was asked to fill out a thoughtfully designed questionnaire. A sample questionnaire (for reliability indicator) is shown in Appendix 1. This questionnaire was filled out for each indicator by each expert to generate PCMs for the seven indicators. Saaty's scale was implemented to collate the preferences of the experts for individual indicators. The expert opinion of each individual was tabulated as a PCM, which is shown in Appendix I. The following steps were conducted for aggregating the inputs of different experts:

i.Performing the pairwise comparisons for alternatives

The PCMs of the alternatives ($i1$, $i2$, $i3$, $i4$) for the jth attribute (where $j = 1, ..., 7$) are developed based on 12 expert opinions. If w_{i1}^{jd} and w_{i2}^{jd} represent the weights that are selected by the dth expert (where $d = 1$–12), the $a_{i1-i2}^{jd} = w_{i1}^{jd}/w_{i2}^{jd}$ represents a pairwise judgment on Saaty's scale with a value ranging from 1/9 to 9 when a scale of 1–9 is used, quantifying the importance of one alternative $i1$ over another alternative $i2$ for each individual d in the matrix A^{jd}. An element in a transpose position of the PCM (A^{jd}) such as a_{i2-i1}^{jd} will be equal to $1/a_{i1-i2}^{jd}$. In the present study, there are 12 experts, and each expert provides 7 PCMs, which results in a total of 84 PCMs.

ii.Checking the consistency of PCMs proposed by the experts

A consistency test was conducted on all 84 PCMs to test the consistency in the expert judgments. Following the logic provided by Saaty (1977), a PCM with positive entries is consistent iff $\lambda_{max} = n$, where λ_{max} is the principal eigenvalue and n is the number of alternatives that are being compared. The eigenvalue of matrix A^{jd} can be derived by solving the equation $(A^{jd} - \lambda I)x = 0$, where λ is the eigenvalue, I is an $n \times n$ identity matrix, and x is the eigenvector. The deviation from consistency is termed the Consistency Index (CI) = $[(\lambda_{max} - n)/(n - 1)]$. The ratio of the CI value to the Average Random Index (ARI) is known as the Consistency Ratio (CR), which should have a value that is less than or equal to 0.1 (Saaty, 1990) for the PCM to be "consistent". The ARIs are generated from randomly generated reciprocal matrices based on a scale of 1–9. The ARI for $n = 1$ to $n = 15$ was obtained from Saaty (1990).

Table 4
Identification of non-negative elements.

GWP	ASP	SBR	UASB-FAL	CWs
ASP	0	0.3843	–	–
SBR	–	0.00	–	–
UASB-FAL	0.2939	0.6782	0.00	–
CWs	0.6157	1.00	0.3218	0.00

Table 5
Linear interpolation for positive elements.

GWP	ASP	SBR	UASB-FAL	CWs
ASP	1.00	3.46	–	–
SBR	–	1.00	–	–
UASB-FAL	2.64	6.10	1.00	–
CWs	5.54	9.00	2.90	1.00

iii.Obtaining the decision weights or the priorities for the alternatives

The decision priorities for each PCM are obtained after the consistency check related to the eigenvector and the consistency ratios has been conducted. The priorities of individual experts (in terms of local priority) are obtained by a normalization of the geometric mean of the PCM rows. For example, the final decision priority (P_{i1}^{jd}) of the alternative $i1$ for expert d is aggregated by a normalization of the geometric mean of the rows, where

$$P_{i1}^{jd} = \left(\prod_{i=1}^{4} a_{i1-i2}^{jd}\right)^{1/4} \Big/ \sum_{i=1}^{4}\left(\prod_{i=1}^{4} a_{i1-i2}^{jd}\right)^{1/4} \quad \forall j, d \tag{3}$$

iv.Aggregation of group decisions

The local priorities to obtain the overall priority matrix are aggregated by taking the geometric mean of the local priorities of all 12 PCMs for each of the 7 attributes. For example, the aggregated priority $S_{i1}^{j}S_{i1}^{j}$ of the 12 experts for the jth attribute of alternative 1 can be expressed as:

$$S_{i1}^{j} = \left(\prod_{d=1}^{12} P_{i1}^{jd}\right)^{1/12} \quad \forall j \tag{4}$$

where $j = 1, ..., 7$, only qualitative indicators.

Similarly, other aggregated priorities for each attribute are derived and shown in Table 8.

2.3. Estimation of overall priorities

A combined priority matrix was formulated for quantitative (with 5 indicators) and qualitative criteria (with 7 indicators). The final priorities (scores) were determined by multiplying the combined priority matrix with the weight matrix (weights are given in Table 1) for two different scenarios. The scores obtained for all four alternatives for the two scenarios are shown in Table 9. Scores were also estimated for a no-scenario condition (where all attributes are equally weighted).

Table 6
A complete pairwise comparison matrix based on Saaty's scale for the GWP indicators.

GWP	ASP	SBR	UASB-FAL	CWs
ASP	1.00	3.46	0.38	0.18
SBR	0.29	1.00	0.16	0.11
UASB-FAL	2.64	6.10	1.00	0.35
CWs	5.54	9.00	2.90	1.00

Table 7
Pairwise comparison matrices for the quantitative indicators.

GWP	ASP	SBR	UASB	CWs	Local Priority
ASP	1.00	3.46	0.38	0.18	0.1164
SBR	0.29	1.00	0.16	0.11	0.0451
UASB-FAL	2.64	6.10	1.00	0.35	0.2557
CWs	5.54	9.00	2.90	1.00	0.5828
NPW	**ASP**	**SBR**	**UASB**	**CWs**	**Local Priority**
ASP	1.00	1.54	0.45	6.80	0.1757
SBR	0.65	1.00	0.64	7.45	0.6158
UASB-FAL	2.20	1.55	1.00	9.00	0.0458
CWs	0.15	0.13	0.11	1.00	0.1627
Man power req	**ASP**	**SBR**	**UASB**	**CWs**	**Local Priority**
ASP	1.00	3.60	0.28	5.40	0.1126
SBR	0.28	1.00	0.14	1.80	0.3275
UASB-FAL	3.60	7.20	1.00	9.00	0.0436
CWs	0.19	0.56	0.11	1.00	0.5163
EP	**ASP**	**SBR**	**UASB**	**CWs**	**Local Priority**
ASP	1.00	0.21	4.21	1.38	0.1757
SBR	4.79	1.00	9.00	4.07	0.6158
UASB-FAL	0.24	0.11	1.00	0.20	0.0458
CWs	0.72	0.25	4.93	1.00	0.1627
Land req.	**ASP**	**SBR**	**UASB**	**CWs**	**Local Priority**
ASP	1.00	1.16	0.31	0.13	0.4122
SBR	0.86	1.00	1.18	0.11	0.3099
UASB-FAL	3.27	0.85	1.00	0.12	0.2420
CWs	7.84	9.00	8.15	1.00	0.0359

Table 9
Scoring and ranking of each alternative when equal weights and varying weights are used during the GDM process.

Alternative ↓	Equal weights		Ranking for urban area Scenario II		Ranking for urban area Scenario VI	
	Score	Rank	Score	Rank	Score	Rank
ASP	0.1944	4	0.2205	3	0.1821	3
SBR	0.2475	2	0.3043	1	0.2344	2
UASB-FAL	0.1347	3	0.1391	4	0.1710	4
CWs	0.3767	1	0.3013	2	0.3677	1

3. Results and discussion

Twelve expert opinions (seven academic experts and five industry experts) were incorporated into the scenario-based decision-making process for the selection of wastewater treatment alternatives. Saaty's scale was used to collect the preferences for the alternatives when evaluating the qualitative criteria in the form of pairwise comparison matrices (PCMs). The consistency ratio of all PCMs (as discussed in subsection 2.2) was found to be less than 0.1, implying that there was consistency between all expert opinions. A summary of the discussions with the experts on the robustness and the sustainability of the four technologies that were considered in this paper is reported in the following two subsections. The last subsection describes the analyses of the results in the form of an overall ranking that was obtained from the developed scenario-based GDM approach.

3.1. *Robustness of the system*

The criterion 'Robustness' is explained through the three indicators reliability, durability and flexibility (Kalbar et al., 2012b). All experts unanimously agreed that mechanized treatment systems (the ASP and the SBR were considered in this study) were more reliable than the UASB-FAL and the CWs. Mechanized systems contain more sophisticated instrumentation and can therefore be controlled in a more adaptive manner, which allows them to be more compatible to effluent changes. Mechanized systems are also based on oxygen supplies, which can be precisely predetermined, and a reliable desired effluent quality can be maintained. The aggregated local priority for the reliability of the ASP was the highest (0.3393), followed by the SBR (0.3029).

The durability of the CWs was reported to be the highest in all four technologies (0.3655). The mechanized treatment systems (ASP and SBR) were found to be less durable because there was a higher chance of failure associated with the use of mechanical equipment. The UASB-FAL option was reported to be the least durable (with a local priority of 0.0867) because the structure could potentially be corroded by the development of H_2S gas.

The flexibility of the treatment system is critical because the changes in the influent hydraulic and organic loadings are unpredictable. Flexibility is one of the important indicators for analyzing the robustness of the technology. The flexibility of the ASP was the highest with a local priority of 0.4620. The experts state that the ASP is the most adaptable technology because the hydraulic and the solids retention times can be controlled independently. Other benefits of the ASP include a possible modification of the aeration system to take on a greater organic load using an aeration tank of the same volume, a modification of settling tanks, and the use of membrane separation processes, which converts the technology into a membrane bio-reactor (MBR). The second preferred technology under the consideration of flexibility is the SBR. Possible modifications to the SBR include changes in the cycle time and the aeration system.

3.2. *Sustainability*

To enable the incorporation of the 'sustainability' aspect into the decision-making process, the four indicators acceptability, public participation, replicability and stimulation of sustainable behavior (Kalbar et al., 2012b) were considered.

Table 8 shows that the experts generally preferred using CWs followed by the UASB-FAL in all four indicators that were used to quantify sustainability. The CWs are more sustainable due to the lack of energy requirement for treatment, the potential for harvesting plants, community participation for implementation and the ease of operation of the technology. The UASB-FAL is more sustainable because of the low energy consumption and the potential for recovering bio-gas from the treatment process. The ASP

Table 8
Aggregated local priorities of the experts for qualitative indicators.

Alternative ↓	Reliability	Durability	Flexibility	Acceptability	Participation	Replicability	Stimulation of sustainability
ASP	0.3393	0.2009	0.4620	0.0946	0.0832	0.0887	0.0711
SBR	0.3029	0.1674	0.2878	0.0768	0.0800	0.0717	0.0693
UASB-FAL	0.1036	0.0867	0.1088	0.1513	0.1491	0.1412	0.2428
CWs	0.0980	0.3655	0.0668	0.6291	0.6567	0.6408	0.6033

and the SBR processes were found to be less sustainable because of their higher energy consumption and their mechanized operations.

3.3. Analysis and interpretation of the overall rankings

As shown in Table 9, AHP was used in the group decision-making approach to generate distinct rankings for the two decision scenarios. The expert opinions were incorporated into the decision-making process.

The rankings generated for 'equal criteria weights' suggest that the CWs (with a score of 0.3767) were identified as the most preferred alternative followed by the SBR (with a score of 0.2475). This result can be explained because most of the experts gave a higher preference for the CWs for many of the qualitative criteria. In addition, the experts reported that the CWs has the same potential as the SBR to produce a recyclable effluent quality. The ASP process has been the most widely used technology in the 19th century; however, in this analysis, the ASP process was not preferred over the SBR. However, the implementation of advanced instrumentation and process control in the ASP process will allow it to compete with the SBR in all aspects. The UASB-FAL was found to be the least preferred option for sewage treatment, which may be attributed to the low BOD that is found in domestic wastewaters.

The 'urban decision scenario' ranking shows that the CWs and the SBR had almost equal scores (0.3013 and 0.3043). Therefore, the preference levels of these two alternatives were similar, which can be interpreted in the context of expert comments that were noted during the interviews. Most of the experts suggested that natural treatment systems should be implemented whenever land is available (in this case, the use of CWs). In the context of recent changes in the sanitation systems where experts are recommending decentralized approaches for sewage treatment, the potential of using natural treatment systems has been increased. The ASP process (with a score of 0.2205) was ranked third, followed by the UASB-FAL.

The CWs and the SBR were again found to be the most preferred for the 'rural decision scenario'. However, in this scenario, the CWs were more highly preferred (0.3677) than the SBR (0.2344). The higher preference for CWs is because CWs can easily be implemented in rural areas where land availability is not a major constraint. The SBR ranked second for its potential to produce a good effluent quality. The ASP and the UASB-FAL were ranked third and fourth with approximately equal scores of 0.1821 and 0.1710, respectively.

4. Conclusions

The selection of wastewater treatment technologies is a common decision-making problem that is encountered in the field of environmental management. The use of the MADM process shows 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 (GDM) framework. A scenario-based MADM approach developed by Kalbar et al. (2012b) addressed the first challenge by incorporating the primary information that was available to the stakeholders or decision-makers (DM) through an articulation of real-life decision-making scenarios. The concept of work scenarios and the MADM methodology developed in Kalbar et al. (2012b) are basic prerequisite for the present study.

The present study is focused on developing a rational methodology for the inclusion of expert opinions in the scenario-based decision-making approach. Also, various past studies were limited to handle only qualitative indicators in GDM but this is a first attempt to incorporate both quantitative and qualitative indicators in GDM. AHP was applied to reconcile multiple qualitative attributes, where expert judgments were quantified using PCMs based on Saaty's scale. A new approach to generate PCMs for quantitative criteria is proposed.

Two scenarios from the study conducted by Kalbar et al. (2012a, b) were selected for the demonstration of the developed approach. The rankings generated for two decision scenarios capturing the priorities of urban and rural areas suggested that natural treatment systems (in this case, CWs) were the most preferred option in India, based on the expert opinions. However, it was also determined that advanced technologies such as SBR could be preferred in urbanized areas, where land availability is a constraint. The developed framework for group decision-making under multiple scenarios, along with the incorporation of expert opinions is most desired for selecting technologies in the context of advanced technological growth. There is substantial experience available in wastewater treatment in India, which makes it essential to incorporate their opinions into the decision-making process.

In India there is a huge gap between wastewater generated and available wastewater treatment capacity. However there is need of enormous efforts and huge financial support by the Government of India to fill this gap through the implementation of appropriate wastewater treatment technologies. In this context the developed framework will be useful for urban planners and policy makers for selecting most appropriate technologies for wastewater treatment in India.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvman.2013.06.034.

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