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Life cycle-based decision support tool for selection of wastewater treatment alternatives

Pradip P. Kalbar [a], Subhankar Karmakar [a, b, c, *], Shyam R. Asolekar [a]

[a] Centre for Environmental Science and Engineering, Indian Institute of Technology Bombay, Powai, Mumbai 400 076, India
[b] Interdisciplinary Programme in Climate Studies, Indian Institute of Technology Bombay (IITB-CECS), Mumbai 400 076, India
[c] Centre for Urban Science and Engineering, Indian Institute of Technology Bombay, Powai, Mumbai 400 076, India

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ABSTRACT

We report the development and application of a user-friendly, scenario-based decision support tool (TechSelect 1.0). The objective of the study focuses on implementation of the 'scenario-based' multiple attributes decision-making (MADM) approach recently proposed by Kalbar et al. (2012a). The tool incorporates multiple scenarios to deal with complex decision-making situations typically encountered in urban, suburban and rural areas. The scenario-based decision-making implemented through the tool reduces complexity in the selection of the appropriate wastewater treatment technology. It also uses a life cycle sustainability assessment framework for assessing technologies from environmental (life cycle assessment), economic (life cycle costing) and social (various sustainability indicators) perspectives. In addition, a user-friendly computational platform has been provided for the convenience of end users and stakeholders. The tool has been tested and validated on two real-life case studies pertaining to the problem of decision-making under complex situations. The results clearly explain the technology selection process and justify the simplicity of the tool in both the case studies. The proposed tool will broaden the application of scenario-based decision-making approaches in wastewater management.

1. Introduction

Decision-making problems in the field of environmental science are multidimensional in nature and require the participation of multiple stakeholders. In most of the cases, the decision-maker cannot take rational decisions considering the difficulty in collating and analyzing all the relevant data. Results of past research demonstrate the necessity of Decision Support Tools (DSTs) for various environmental decision-making problems (Brunner and Starkl, 2004; Mysiak et al., 2005; Matthies et al., 2007; Bani et al., 2009, Hamouda et al., 2009; Garrido-Baserba et al., 2014).

Most of the DSTs developed in the past are based on multiple criteria decision-making frameworks (Wierzbicki et al., 2000; Figueira et al., 2005). In the past few decades, several authors have developed and applied DSTs to wastewater management problems. The following subsection provides a comprehensive review on the past efforts for the development and implementation of DSTs for selecting wastewater treatment technologies.

1.1. Decision support tools (DSTs) for selection of sustainable wastewater treatment technology: a brief review

Balkema et al. (2001) developed a methodology of comparing wastewater systems for assessing sustainability. Three steps (viz. goal and scope definition, inventory and optimization) analogous to the Life Cycle Assessment (LCA) approach were articulated for sustainability assessment of Wastewater Treatment Plants (WWTPs). Integer programming (having the objective function as a weighted sum of the sustainability indicators) was used to select wastewater treatment options. The DST was developed using the MATLAB Simulink toolbox. The study concluded that it was not possible to find an alternative that optimized all sustainability criteria simultaneously; hence, a non-inferior solution (Podinovskii and Nogin, 1982) had to be adopted.

Poch et al. (2004) reported the experience of designing and building two real Environmental Decision Support Systems

* Corresponding author. Centre for Environmental Science and Engineering, Indian Institute of Technology Bombay, Powai, Mumbai 400 076, India.
E-mail addresses: subhankar.karmakar@gmail.com, skarmakar@iitb.ac.in (S. Karmakar).

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Abbreviations

ASP	activated sludge process
CWs	constructed wetlands
DST	decision support tool
DM	decision maker
LCA	life cycle assessment
MADM	multiple attribute decision-making
MBR	membrane bioreactors
MLD	million liters per day
SBR	sequential batch reactor
TOPSIS	the technique for order preference by similarity to ideal solutions
UASB-FAL	up-flow anaerobic sludge blanket reactor followed by facultative aerobic lagoon
ULBs	urban local bodies
WWTPs	wastewater treatment plants

(EDSSs): one for WWTP supervision, and the other for wastewater treatment technology selection in small communities. Both the EDSSs were based on a rule-based system (RBS), which was, in turn, based on decision trees. Although the developed EDSSs provided an easy-to-use platform, they failed to offer robust algorithms for decision-making. Moreover, decision trees suffer from a few distinct disadvantages themselves. For instance, they are unable to consider multiple criteria simultaneously and have an appreciable probability of giving greater weight to attributes at the higher level. Further, decision trees have proved to be efficient for a problem having highly relevant attributes, and their performance deteriorates for attributes having complex interactions (Maimon and Rokach, 2005).

Malmqvist and Palmquist (2005) developed a decision support basis for hazardous flow assessment in wastewater treatment systems. Two systems were studied: a combined wastewater system and a separate system (which separates gray and blackwater at the source, i.e., in a house). Five sustainability criteria were established during the assessment, *viz.*, health and hygiene, environment, economy, socio-cultural and technology. For the five criteria, a total of 15 indicators were selected. The assessment shows that the combined system caused a higher substance flow to the receiving water body than the separate system.

Manic et al. (2006) developed a DST for sewerage management. The developed tool simulated the behavior of both the wastewater treatment plant and the sewer network system. This tool interfaced two commercial simulators: Inforworks-CS™ (sewer network modeling) from Wallingford Software Ltd., and WEST® (WWTP modeling) from Hemmis.

Water-Energy Sustainability Tool (WEST) was developed by Stokes and Horvath (2006). WEST is based on hybrid LCA approach where elements of process-based and economic input-output-based LCA are combined. The tool compares three water supply alternatives: importing, recycling, and desalination. WEST is an MS-Excel-based DST that takes into account the material provision, construction, operation, and maintenance phases of the life-cycle for a water supply system.

Hidalgo et al. (2007) developed a multi-criteria DST to aid policy-makers in selecting the most efficient solutions for reusing treated effluent for agricultural purposes. The developed tool had separate sections for existing WWTP data, WWTP design assistance, statistics, and databases. There were five subsections: (i) legislation, (ii) crop tolerance, (iii) soil tolerance, (iv) treatment options and (v) user management, in the "Databases" section. The tool prioritizes (based on ranks) the alternative scenarios, and the alternative with lower cost but meeting the water quality objective was recommended.

Makropoulos et al. (2008) developed a DST (termed an Urban Water Optioneering Tool (UWOT)) for evaluating various water-saving strategies and technologies. The selected options were targeted to achieve integrated sustainable water management for new developments. UWOT was developed to take care of wastewater systems and to consider temporal resolution of wastewater flows. A Genetic Algorithm (GA) was used for optimization in UWOT. The tool evaluates technologies based on the commonly used sustainability criteria for assessing the sustainability of water and wastewater treatment systems. UWOT couples the Simulink tool of MATLAB and Microsoft Excel (*via* Excel's Visual Basic for Applications (VBA) programming environment) and facilitates computationally efficient and user-friendly DST.

Garrido-Baserba et al. (2010) developed a complex Decision Support System (DSS) based on knowledge base for WWTP alternative selection. The DSS was based on a hierarchical decision-making process incorporating about 88 parameters (covering technical, economic, environmental and social aspects) from which a set of criteria can be formulated by user. Chamberlain et al. (2012) developed a comprehensive three-stage DSS for design and evaluation of sustainable wastewater solutions based on environmental, economic and social criteria. The complex nature of DSS and intensive data requirement limits the application of these tools to developing countries such as India, where data availability and ease of use are the main concerns.

A comprehensive review of DSTs suggests that it is essential to incorporate sustainability criteria in the decision-making process of water and wastewater treatment technology selection. Palme et al. (2005), Palme and Tillman (2008), Muga and Mihelcic (2008), Singhirunnusorn and Stenstrom (2009) and Kalbar et al. (2012a, 2013a) emphasized the need to incorporate sustainability criteria in the multiple criteria decision-making process while selecting wastewater treatment technology. The following section describes the need for scenario-based decision support tools, especially for wastewater treatment technology selection in India.

1.2. Need for a scenario-based decision support tool

Kalbar et al. (2012a) reported that one of the biggest challenges decision makers (DMs) encounter is variation in the quality and scale of the information. In most cases, while addressing the problem of wastewater treatment technology selection, first-level or primary information is available to DMs, such as the land availability in the region and end-use of the treated water. In addition, second-level or secondary information such as the number of available alternatives is highly pertinent for decision-making. The third level of information is related to the alternative scores for criteria or indicators. Weights of the criteria or indicators are referred to as the fourth level of information. Kalbar et al. (2012a) identified and classified the aforementioned information accessible to the DMs and concluded that transforming this information within a mathematical framework should be the objective of an efficient Multiple Attribute Decision-Making (MADM) algorithm. Conventional MADM methods efficiently incorporate second, third and fourth levels of information. However, due to a lack of clarity of the decision-making problem to the DMs, the first level of information is usually neglected. Kalbar et al. (2012a) developed a scenario-based decision-making approach to include the primary information into MADM methods. Scenarios (basically sets of weights of attributes) were articulated to account for local and regional priorities of a given complex decision-making situation.

In the context of the need for DST for real-life applications, it is acknowledged that the selection of wastewater treatment technologies has been the most challenging task faced by national, regional and local policy-makers and governing institutions (Kalbar et al., 2012b). It is now recognized that "sustainable development" can only be achieved through implementation of the technological options that balance the technological possibilities with the priorities of the community (*i.e.*, stakeholder satisfaction: Asolekar et al., 2014). Clearly, the planning and implementation agencies for development across the world are looking for a suitable framework capable of guiding and supporting their decision-making processes. There is a greater need for devising such tools in the context of the sustainable development of communities in India, which are further challenged by the complexities associated with poverty, a large population, increasing demand for water-infrastructure and rising costs.

There has been a demand expressed by small and medium rural and urban communities for treatment of their sewage, as the rivers and lakes in India are progressively becoming contaminated due to disposal of partially treated wastewater. Policy-makers and elected representatives, particularly in the less developed countries, require rationalization of their decisions, so that investments in the wastewater treatment sector can justifiably be supportive of sustainable development of the community.

Thus, there is an urgent need for a DST for wastewater treatment technology selection in developing countries. This type of tool is essential, especially in India, due to the large gap between domestic wastewater generation and existing treatment capacities. A mere 11,777 Millon Liters per Day (MLD) of the 35,254 MLD of domestic wastewater generated in urban cities receive biological treatment (CPCB, 2009). In order to fill this gap, the Government of India will have to make tremendous effort and investments.

This has stimulated a need for DSTs that will capture all of the priorities of multiple stakeholders in the decision-making problem, and help the policy-makers and elected representatives to rationalize their decisions. The scenario-based decision-making approach developed by Kalbar et al. (2012a) is well suited to handling such problems. Hence, the objective of this study is the implementation of the scenario-based decision-making approach in the form of a user-friendly DST.

1.3. Organization of the paper

The following section describes the methodology followed to develop the scenario-based DST and also reports the algorithm used for ranking and architecture of the tool. Section 3, Results and Section 4, Discussion, reports on the testing and validation of TechSelect 1.0 in two real-life case studies. Finally, conclusions are given in the end.

2. Methodology

A DST was developed for the selection of an appropriate wastewater treatment alternative. For the wastewater treatment alternative selection problem, the end users of the developed DST are primarily the officials from Urban Local Bodies (ULBs) and planning authorities. The ease of understanding the MADM method and its ease of use with a simple software platform are two important criteria for them (Beynon et al., 2002; Hajkowicz and Higgins, 2008). Nonetheless, it is already recognized that there is no need for a highly sophisticated, computationally rigorous MADM method; efforts need to be focused on defining and designing the decision-making problem more clearly (Janssen, 2001; Hajkowicz and Higgins, 2008; Kalbar et al., 2015). The following sub-sections describe the criteria, indicators, and methods used in ranking the alternatives and architecture of the proposed DST. The developed DST has been named 'TechSelect 1.0' and will be referred to by this name henceforth.

2.1. Ranking of alternatives in TechSelect 1.0

TechSelect 1.0 is based on the MADM approach. MADM addresses discrete decision problems where available alternatives are ranked based on the chosen method. Many MADM methods are available to solve different decision-making problems (Hwang and Yoon, 1981; Yoon and Hwang, 1995; Figueira et al., 2005). Each of the MADM methods uses a unique attribute information processing approach and mathematical principle to rank the alternative. Hence, it is essential to apply a class of multiple MADM methods and then to choose the most suitable for a given decision-making problem. Kalbar et al. (2015) applied five MADM methods for wastewater treatment technology selection and showed that Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) is the best suited MADM method for selecting wastewater treatment technology. TOPSIS uses an easy-to-understand algorithm and logic that mimics human thinking. In the context of the wastewater treatment alternative selection problem, the technology with the least cost and fewest adverse impacts on the environment must be selected. Hence, the best suited method, TOPSIS, was used in TechSelect 1.0 for wastewater treatment technology selection.

The methodology used for ranking in TechSelect 1.0 is depicted in Fig. 1. The first step is to choose the set of criteria and indicators that will rationally prioritize alternatives. Once this set is in place, some preliminary operations such as data transformation (i.e. handling negative values) and normalization (i.e. vector normalization) are performed. The user must choose the scenario under which the decision is to be taken. As emphasized in Kalbar et al. (2012a), it is vital to select the scenario prior to undertaking decision-making for wastewater treatment technology selection. The user can choose various scenarios available in TechSelect 1.0. For instance, if the case study is that of urban areas, where recycling of water is preferred, the user can choose scenario I (see Fig. 2).

2.2. Algorithm used for ranking alternatives in TechSelect 1.0

The algorithm implemented in TechSelect 1.0 is briefly described below. The detailed description of the algorithm along with various scenarios and type of attributes can be found in Kalbar et al. (2012a). A finite number of alternatives $A_i = (A_1, A_2, \ldots \ldots, A_m)$, based on a set of attributes/criteria/indicators, $X_j = (X_1, X_2, \ldots \ldots, X_n)$ is ranked using TOPSIS.

2.2.1. Formulation of decision matrix

The decision matrix is formulated based on information available from decision-makers. The matrix consists of qualitative and quantitative indicators and is represented as below.

$$
\text{Alternatives/Options}\quad
\begin{array}{c}
 \\ \\ A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_m
\end{array}
\begin{array}{ccccccc}
\multicolumn{7}{l}{\text{Criteria/Attributes}} \\
X_1 & X_2 & X_3 & \cdots & X_j & \cdots & X_n \\
x_1(a_1) & x_2(a_1) & x_3(a_1) & \cdots & x_j(a_1) & \cdots & x_n(a_1) \\
x_1(a_2) & x_2(a_2) & x_3(a_2) & \cdots & x_j(a_2) & \cdots & x_n(a_2) \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
x_1(a_i) & x_2(a_i) & x_3(a_i) & \cdots & x_j(a_i) & \cdots & x_n(a_m) \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
x_1(a_m) & x_2(a_m) & x_3(a_m) & \cdots & x_j(a_m) & \cdots & x_n(a_m)
\end{array}
\qquad [1]
$$

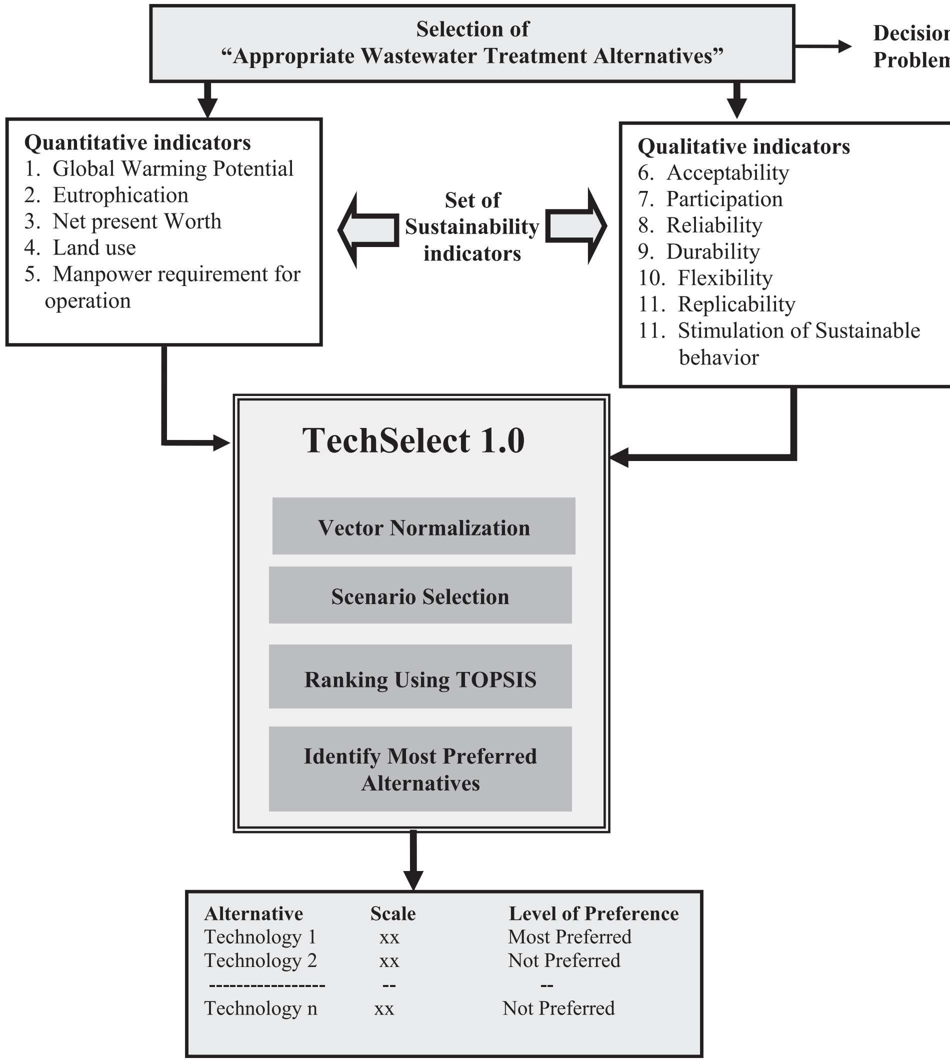

Fig. 1. Methodology used in TechSelect 1.0 for ranking of alternatives.

2.2.2. *Data transformation and normalization*

The next step after the formulation of decision matrix is data transformation. Most the field data are raw and may contain negative values or qualitative indicators. The negative values are transformed into positive values by considering the maximum negative value as zero and adding the absolute value of the greatest negative number to all the remaining positive numbers. The cardinal or ordinal scale can be used to transform qualitative indicators.

After data transformation, data normalization is carried out. The indicator scores in the decision matrix are available in different measurement units; hence it becomes necessary to perform normalization before proceeding to the real application of the MADM method. The vector normalization method has been employed in TechSelect 1.0 for normalization, as it is proven to minimize the chances of rank reversal when applied to TOPSIS (Hwang and Yoon, 1981; Milani et al., 2005; Chakraborty and Yeh, 2009). In vector normalization, the normalized score matrix (r_{ij}) is determined as follows:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}},\ i = 1, ..., m;\ j = 1, ..., n. \qquad [2]$$

where x_{ij} is the score of the jth indicator for ith alternative, and there are n indicators (or attributes) and m alternatives.

2.2.3. *Estimation of weighted normalized matrix*

As emphasized in Kalbar et al. (2012a) it is important to apply an appropriate weighing set for scenario-based decision-making. The weighted normalization matrices (a_{ij}) are calculated as follows:

$$a_{ij} = w_j r_{ij} \qquad [3]$$

where w_j is the weight of the jth attribute.

2.2.4. *Formulation of positive ideal (PIS) and negative ideal (NIS) solutions*

$$PIS = \left\{a_1^+, a_2^+, ..., a_j^+, ..., a_n^+\right\} = \left\{(\max_i a_{ij} | j \in J_1), (\min_i a_{ij} | j \in J_2) | i = 1, ..., m\right\} \qquad [4]$$

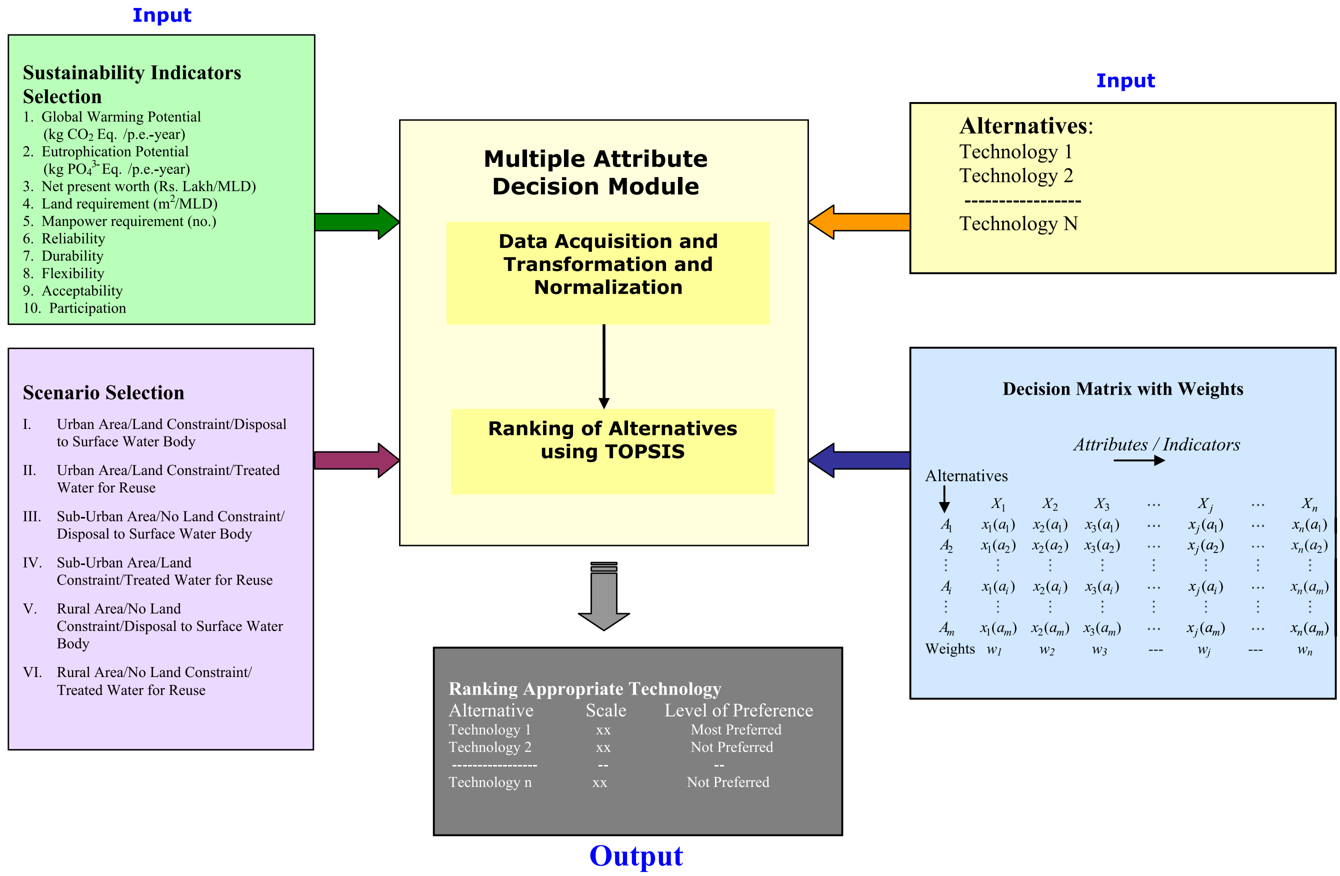

Fig. 2. Architecture of TechSelect 1.0.

$$NIS = \left\{a_1^-, a_2^-, \ldots\ldots\ldots, a_j^-, \ldots\ldots\ldots, a_n^-\right\}$$
$$= \left\{(\min_i a_{ij} | j \in J_1), (\max_i a_{ij} | j \in J_2) | i = 1, \ldots\ldots\ldots, m\right\} \quad [5]$$

where J_1 is a set of *benefit attributes*, J_2 is a set of *cost attributes* and $J_1 + J_2 = n$, i.e., the total number of attributes.

2.2.5. Determination of separation measures

The separation (i.e. distance) between attributes is measured by the n-dimensional Euclidean distance. The separation of each alternative from the positive ideal solution, D^+, is given by the following equation:

$$D_i^+ = \sqrt{\sum_{j=1}^{n} \left(a_{ij} - a_j^+\right)^2}, \; i = 1, \ldots, m \quad [6]$$

Similarly, the separation from the negative ideal solution, D^-, is given by the following equation:

$$D_i^- = \sqrt{\sum_{j=1}^{n} \left(a_{ij} - a_j^-\right)^2}, \; i = 1, \ldots, m \quad [7]$$

2.2.6. Calculation of similarities to the positive ideal solution

$$R_i^* = \frac{D_i^-}{\left(D_i^+ + D_i^-\right)}, \; i = 1, \ldots, m \quad [8]$$

Note that $0 \le R_i^* \le 1$, where $R_i^* = 0$ when $D_i = D^-$, and $R_i^* = 1$ when $D_i = D^+$.

2.3. Architecture of TechSelect 1.0

TechSelect 1.0 uses Microsoft Excel to take input from the users and to display the results. Hence, it can be accessed from a personal computer without any additional software. Visual Basic for Applications (VBA) programming has been employed to make TechSelect 1.0 more user-friendly to end-users. This also makes it easier to integrate this tool into the formal decision-making process of ULBs. TOPSIS has been utilized for identifying the most-preferred alternative.

The user must first enter the various alternatives to be compared. A form will be displayed where choices have to be entered. Following this, the user must enter various criteria against which alternatives are to be compared. An automatically selected default list option will be presented on the form. The user can also input his/her own criteria. Fig. 2 exhibits the overall architecture of TechSelect 1.0. The easy user interface will help the end-users to integrate this tool into the formal decision-making process of ULBs effectively. The working of TechSelect 1.0 has been described in the

Supplementary Information, along with screenshots of various features provided in the tool (Figs. S1 and S2).

2.4. Application of scenario-based decision-making approach in case studies

Kalbar et al. (2012a) defined scenarios as a set of indicator weights and types of indicator (e.g. cost types or benefit types of indicator, as given in Table 1). The physical constraints, treatment objectives and other preferences of stakeholders can be accounted for through the indicator weights and types. The weights and types of indicator address the priorities of local decision-making situations into the mathematical framework of MADM. Real-life decisions are always complex in nature; one of the challenges faced by DMs is the availability of information that may vary both in quality and scale. The use of scenarios facilitates the definition of the decision-making problem in a more structured manner, which has been one of the essential parts of developing MADM approaches (Janssen, 2001; Hajkowicz and Higgins, 2008; Kalbar et al., 2015). Table 1 shows the six realistic scenarios proposed by Kalbar et al. (2012a). These scenarios are designed to be utilized in their current form, or could be modified easily as per the new decision situations. The idea of the proposed scenarios is to convert a complex decision-making problem into comparatively less complex decision-making problems. The application of these scenarios through the TechSelect 1.0 tool is demonstrated with two case studies, which represent common decision situations in India. However, there is no rational framework to address such situations.

Multiple stakeholders' dialogues were conducted to choose a suitable scenario for decision-making by considering local conditions, concerns and field constraints. A detailed explanation of the proposed scenario-based decision support tool (TechSelect 1.0), including the queries related to the selection of criteria and indicators, was also provided to the stakeholders. Based on these stakeholders' dialogues, a set of suitable scenarios for decision-making was chosen from Table 1 for each case study. The scenario-based decision-making was conducted for two case studies using five different wastewater treatment technologies. The five treatment technologies were: Activated Sludge Process (ASP), Sequencing Batch Reactor (SBR), Membrane Bio-reactor (MBR), Up-flow Anaerobic Sludge Blanket reactor followed by Facultative Aerobic Lagoon (UASB-FAL) and Constructed Wetlands (CWs). Although the first three, i.e. ASP, SBR and MBR, are mechanized treatment technologies, the wastewater treatment efficiencies of SBR and MBR are better than conventional ASP (Metcalf and Eddy, 2003; Arceivala and Asolekar, 2007). However, SBR and MBR require higher capital investment, and may have higher energy and chemical consumptions based on operating conditions (Kalbar et al., 2013b). To supplement the performance, an anaerobic treatment technology combined with an aeration process, i.e. UASB-FAL, was selected as the fourth treatment technology, which provides an opportunity to produce energy from biogas generated in the reactor. However, this technology requires rigorous monitoring and operational efforts to keep the treatment stable and for the successful generation of bio-gas (Tare and Bose, 2009). Consequently, one natural treatment solution, Constructed Wetlands (CWs), was also included in the study as the fifth treatment technology. This treatment technology does not require electricity for operation of the plant; however, the land requirement is high. The different aspects of all these technologies, in the form of limitations and advantages, were evaluated with indicators obtained from tools such as LCA and Life cycle costing, (LCC) and other sustainability indicators as reported in Kalbar et al. (2012b, 2013b).

Table 1
Six scenarios and associated weights assigned (adapted from Kalbar et al., 2012a).

Scenarios		Indicators											
		Global warming potential	Eutrophication potential	Net present worth	Land requirement	Number	Reliability	Durability	Flexibility	Acceptability	Participation	Replicability	Promotion of sustainable behavior
Scenario I Urban Area/Land Constraint/Disposal to Surface Water Body	Weight	20	20	20	80	10	40	40	40	10	10	20	10
	Type of criteria	Cost	Cost	Cost	Cost	Cost	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit
Scenario II Urban Area/Land Constraint/Treated Water for Reuse	Weight	20	80	20	80	10	40	40	40	10	10	20	10
	Type of criteria	Cost	Cost	Cost	Cost	Cost	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit
Scenario III Sub-urban Area/No Land Constraint/Disposal to Surface Water Body	Weight	20	30	60	40	40	40	40	40	30	30	40	40
	Type of criteria	Cost	Cost	Cost	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit
Scenario IV Sub-urban Area/No Land Constraint/Treated Water for Reuse	Weight	20	80	60	40	40	40	40	40	30	30	40	40
	Type of criteria	Cost	Cost	Cost	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit
Scenario V Rural Area/No Land Constraint/Disposal to Surface Water Body	Weight	20	30	90	80	80	40	40	40	80	80	80	80
	Type of criteria	Cost	Cost	Cost	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit
Scenario VI Rural Area/No Land Constraint/Treated Water for Reuse	Weight	20	80	90	80	80	40	40	40	80	80	80	80
	Type of criteria	Cost	Cost	Cost	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit

3. Results

The results obtained from the application of TechSelect 1.0 in two different case studies are presented in the following subsections.

3.1. Case study 1: technology selection for residential townships

The TechSelect 1.0 tool was used as DST for wastewater treatment technology selection for an upcoming township project in the suburbs of Mumbai, India. The stakeholders for this case study were project developers of the township project, expert decision-makers, technology providers, residents of the township, the pollution control board and city planning authorities.

The developers of the project were keen on water conservation and wanted to recycle wastewater for various purposes in the township. However, the major constraint was availability of land for WWTP, due to high land prices in nearby areas of Mumbai. After understanding the field conditions and objectives of the stakeholders, it was mutually decided by the stakeholders and authors to choose Scenario II (Kalbar et al., 2012a) in TechSelect 1.0. Scenario II was found to be best-suited for this situation, since it gives more preference (i.e. criteria weights) to technologies that produce a better quality of effluent and have a smaller land footprint.

Three technologies were considered for the evaluation: ASP, SBR and MBR. The default indicator scores available in the TechSelect 1.0 were used for the analysis as shown in Table 2 (see Fig. S3 for screenshots). After undertaking technology ranking using TOPSIS, the TechSelect 1.0 generated a report as shown in Table 3 (see Fig. S4 for screenshots). The report concludes that SBR with a score of 0.8528 and MBR (score of 0.8508) were the most preferred technologies for the proposed township. ASP (score of 0.1479) was not preferred because of a lower performance and higher land requirement compared to the other two.

3.2. Case study 2: technology selection for lake rejuvenation

Unplanned growth in urbanization without proper infrastructure support has stressed water bodies in most urban areas in India. In many places, surface water bodies (e.g. lakes and rivers) are in a eutrophic state (Asolekar et al., 2014). This has created a need for undertaking lake rejuvenation projects in many cities in India. In one such lake rejuvenation project in the suburbs of Thane, India, TechSelect 1.0 was used as the DST for identifying appropriate technologies for wastewater treatment. The identified stakeholders for this case study were the municipal authority, local residents, elected representatives, decision-makers, technology providers, pollution control board authorities and city planning authorities.

In this case study, three technologies were considered: ASP, UASB-FAL and CWs. The main objective of the wastewater treatment was to use treated water to replenish the lake. Hence, it was imperative that the selected technology produce a good quality of treated effluent, such that fewer organic and nutrient loads were added to the lake. The municipal authority expressed concerns over cost of the WWTP and energy consumption for the operational phase of the plant. However, since the location of the WWTP was to be in suburban areas, there was no land availability constraint. Furthermore, after a stakeholders' dialogue, it was decided to choose Scenario VI (Kalbar et al., 2012a) from TechSelect 1.0, which captured the priorities of the decision situation mentioned above. The inputs for this case study in TechSelect 1.0 are shown in Table 2 (see Fig. S5 for screenshots).

The results of the ranking (Table 3 and see Fig. S6 for screenshots) clearly show that CWs (with a score of 0.6092) was the most-preferred alternative for the lake rejuvenation project as against

Table 2
Data used for analyzing case studies 1 and 2 (Kalbar et al., 2012a, 2012b).[a]

		Indicators											
		Global warming potential (kg)	Eutrophication potential (kg)	Net present worth	Land requirement (m2)	Manpower requirement (no.)	Reliability	Durability	Flexibility	Acceptability	Participation	Replicability	Promotion of sustainable behavior
Case study 1													
Alternatives	ASP	18.20	3.76	137	1400	10	80	80	80	30	30	40	40
	SBR	31.97	1.38	127	353	6	80	60	60	30	30	40	40
	MBR	42.44	1.34	160	300	4	100	60	60	30	30	40	40
Scenario II	Weights	20	80	20	80	10	40	40	40	10	10	20	10
	Type of indicator	1	1	1	1	1	0	0	0	0	0	0	0
Case study 2													
Alternatives	ASP	18.20	3.76	137	1400	10	80	80	80	30	30	40	40
	UASB-FAL	7.67	5.85	103	1123	14	60	60	40	50	50	40	60
	CWs	−3.86	3.40	242	8500	4	40	40	30	90	80	80	90
Scenario VI	Weights	20	80	90	80	80	40	40	40	80	80	80	80
	Type of indicator	1	1	1	0	0	0	0	0	0	0	0	0

[a] Note: In the last row of each case study data, numbers1 and 0 designates cost type and benefit type of indicators respectively.

Table 3
Results obtained from TechSelect 1.0 for case studies 1 and 2 (see the screen shots in the Supplementary material).

Alternatives	Overall scores of the alternatives	Level of preference
Case study 1		
SBR	0.8528	Most Preferred
MBR	0.8508	Most Preferred
ASP	0.1479	Not Preferred
Case study 2		
CWs	0.6092	Most Preferred
UASB-FAL	0.4236	Not Preferred
ASP	0.3480	Not Preferred

UASB-FAL (0.4236) and ASP (0.3480). With CWs being a low-cost, low-energy technology compared to other mechanized treatment technologies, it was a logical choice.

4. Discussion

An enormous amount of investment has been planned for infrastructure development in the near future by the Government of India (HPEC, 2011). A large portion of this investment will be directed to wastewater treatment. This highlights the need for decision support to policy-makers and planning officials. The selection of an appropriate wastewater treatment technology is a multidimensional problem involving multiple stakeholders such as the end-user community, ULBs, technology providers, decision-makers (DMs) and many others. There is no rational framework that exists in India for technology selection for wastewater treatment. At present, technologies are selected using a few criteria (e.g. compliance with stipulated regulatory standards and technology cost). The consequence of such decision-making is long-term wastage of financial and natural resources. Kalbar et al. (2012a) and Garrido et al. (2013) have emphasized the need to incorporate sustainability criteria in multiple criteria decision-making processes, while selecting the most appropriate wastewater treatment technology. The comprehensive framework based on MADM for wastewater treatment technology assessment has been reported by Kalbar et al. (2012a, 2012b).

Various categories of data must be processed in the technology selection problem. Kalbar et al. (2012a) identified and classified the information accessible to the DMs and concluded that including this information within a mathematical framework should be the goal of an efficient MADM algorithm. Kalbar et al. (2012a) developed such an efficient scenario-based decision-making procedure to consider all types of information into MADM algorithms.

In the context of the need for DST for real-life applications, it is acknowledged that the selection of appropriate wastewater treatment technologies has been the most challenging task. The policy-makers and elected representatives, particularly in the less developed countries, require rationalization of their decisions, so that investments in the wastewater treatment sector can justifiably be supportive of sustainable development of the community. Thus, there is an urgent need for a DST for wastewater treatment technology selection in developing countries.

TechSelect 1.0 fulfills this need and is best-suited for providing decision support to ULBs and planning agencies. The tool provides an easy-to-use platform for assessing technologies with a set of criteria and indicators. The tool will formalize the decision-making process of the infrastructural investments in the wastewater treatment sector.

Although the application of TechSelect 1.0 has been demonstrated through two case studies, there are certain limitations to be overcome for full utilization of the tool. To ensure a robust output from TechSelect 1.0, the involvement of multiple stakeholders in the decision-making process is essential. However, participation of a large group of stakeholders may sometimes be difficult in real life, due to various practical and local political situations. Also, to articulate new scenarios in TechSelect 1.0, participation of stakeholders may create an opportunity to generate alternative preferences with more field information.

The tool was well received by the stakeholders involved in the decision-making process for the presented case studies. However, difficulties were reported for understanding the underlying mechanisms of ranking of the alternatives. The criteria and indicator set was found to be appropriate for the decision-making problem.

Another limitation of the tool may be the risk of choosing an incorrect set of indicators and providing greater weights to certain indicators. This may lead to a biased decision for the particular chosen scenario. Hence, it is recommended that the indicators and weights always be chosen based on the six scenarios (Table 1) provided in TechSelect 1.0. This will avoid any overriding effect on the final outcome from the tool, as shown by a comprehensive sensitivity study conducted by Kalbar et al. (2012a), which assured a stable ranking result from TechSelect 1.0.

5. Conclusions

Under complex realistic situations, a scenario-based decision-making tool in a robust computational platform can provide decision support to ULBs for suitable wastewater treatment technology selection. However, this platform needs an efficient and user-friendly decision support tool (DST). Hence, a DST TechSelect 1.0 was developed, which provides an easy-to-use platform for end-users/stakeholders, and also promotes the concept of scenario-based decision-making (Kalbar et al., 2012a) for wastewater treatment technology selection.

The developed tool is based on a popular MADM-based approach (TOPSIS) for prioritizing alternatives. Microsoft Excel combined with VBA programming was used to develop TechSelect 1.0, which helped to provide a computationally efficient and easy-to-use platform.

TechSelect 1.0 was tested and validated with an application in two real-life case studies. Multiple stakeholders were involved while applying TechSelect 1.0 for selecting different alternatives under different scenarios. The involvement of stakeholders in the decision-making process helped to better understand the local conditions, concerns and field constraints. Based on the stakeholders' dialogue, a suitable scenario for decision-making was chosen from Table 1 for each case study.

In the first case study, under a complex decision-making situation, SBR and MBR were selected with scores of ~0.85 out of 1 for treating wastewater in a Mumbai township. The selected technologies for this case study needed to be compact and efficient, as the proposed WWTP location was in a highly dense and urbanized area. The second case study dealt with selecting a suitable technology for rejuvenating a suburban lake by preventing nutrient pollution to check eutrophication. Here, CWs (with a score of 0.6092) was identified as the most preferred alternative. CWs are proven for better nutrient removal and have a low construction cost, matching with the local situation.

The experience of applying TechSelect 1.0 suggests that the tool is efficient, simple, user-friendly and capable of providing decision support to ULBs and other organizations for selecting the appropriate wastewater treatment technology. While using the tool for the two case studies, a need for involving more stakeholders in the discussion was found, which will create an opportunity to articulate new scenarios. The tool may be applied in other wastewater management problems that require a scenario-based decision-making approach, because of its simplicity and user-friendliness. Future enhancements in TechSelect 1.0 are being investigated to include a module for scenario-based group decision-making (Kalbar et al. 2013a) for eliciting weights of the criteria and indicators. Also, efforts can be made in future to make the TechSelect tool completely web-based, for greater accessibility to ULBs and planning authorities throughout the globe.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jclepro.2016.01.036.

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