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Selection of an Appropriate Wastewater Treatment Technology: A Scenario-Based Multiple-Attribute Decision-Making Approach

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Abstract

Many technological alternatives for wastewater treatment are available, ranging from advanced technologies to conventional treatment options. It is difficult to select the most appropriate technology from among a set of available alternatives to treat wastewater at a particular location. Many factors, such as capital costs, operation and maintenance costs and land requirement, are involved in the decision-making process. Sustainability criteria must also be incorporated into the decision-making process such that appropriate technologies are selected for developing economies such as that of India. A scenario-based multiple-attribute decision-making (MADM) methodology has been developed and applied to the selection of wastewater treatment alternative. The four most commonly used wastewater treatment technologies for treatment of municipal wastewater in India are ranked for various scenarios. Six scenarios are developed that capture the regional and local societal priorities of urban, suburban and rural areas and translate them into the mathematical algorithm of the MADM methodology. The articulated scenarios depict the most commonly encountered decision-making situations in addressing technology selection for wastewater treatment in India. A widely used compensatory MADM technique, TOPSIS, has been selected to rank the alternatives. Seven criteria with twelve indicators are formulated to evaluate the alternatives. Different weight matrices are used for each scenario, depending on the priorities of the scenario. This study shows that it is difficult to select the most appropriate wastewater treatment alternative under the "no scenario" condition (equal weights given to each attribute), and the decision-making methodology presented in this paper effectively identifies the most appropriate wastewater treatment alternative for each of the scenarios.

Keywords: Life Cycle Assessment; Life Cycle Costing; Sustainability; Multiple-attribute Decision-making; TOPSIS; Wastewater Treatment

1. Introduction

Selection of appropriate wastewater treatment technologies that enable sustainable development presents a challenge to national, regional and local policy makers. A decision support tool for wastewater treatment technology selection is urgently needed in developing countries, such as India, particularly because there is no such tool available at the present time that is suitable for use in the context of a growing economy and increasing burdens on existing environmental resources. The need for this type of tool in India is prominent because in India, there is a large gap between municipal wastewater (sewage) generation and available treatment capacity. Of the 35,254 million liters per day (MLD) of sewage generated in urban areas, only 11,777 MLD receives secondary-level treatment (CPCB, 2009). In the future, there will be tremendous efforts and investment by the government of India to fill this gap through the implementation of appropriate wastewater treatment technologies. This paper presents a decision-support framework for selection of wastewater treatment technologies.

Recent developments in wastewater treatment technologies provide many options for the treatment of wastewater. Since the 19th century, many technologies have been developed for the treatment of wastewater. The most widely used of these is the conventional activated sludge process (ASP). Many other technologies have been developed that employ various treatment processes, both aerobic and anaerobic, highly mechanized to not highly mechanized, including trickling filters and biotowers, upflow anaerobic sludge blanket (UASB) reactors, rotating biological contactors (RBC), aerated lagoons, sequential batch reactor (SBR), and others (Metcalf and Eddy, 2003). Apart from these, a set of natural wastewater treatment systems (NTSs) are also successfully applied in India and other tropical countries (Arceivala and Asolekar, 2007). Some of the NTSs are waste stabilization ponds, duckweed ponds, constructed wetlands (CWs), etc.

The challenge in wastewater management is selection of the best available technology for the particular wastewater treatment objective at a particular site. Many factors, such as capital costs, operation and maintenance (O&M) costs, and land requirements, are involved in the decision-making process. It is also necessary to develop a decision-making framework that incorporates sustainability indicators to help developing countries, such as India, in selecting the appropriate technologies for wastewater management.

The concept of appropriate technology (AT) was introduced by E. F. Schumacher, a British economist, in his famous book *Small Is Beautiful* (Schumacher, 1973). The AT concept is now well accepted in the scientific community. The definition of AT expands on the conventional concept of appropriateness and suggests that AT is always contextual and situational. It is a strategy that enables men and women to rise out of poverty and improve their economic situation by meeting their basic needs through developing their own skills and capabilities while making use of their available resources in an environmentally sustainable manner (Murphy et al., 2009). A highly mechanized technology can be appropriate for a given situation, depending on the technological level of the community, labor and resource availability, and other factors. Many researchers have developed criteria and indicators for the appropriateness of a technology (Clarke, 1973; Henderson, 1975; Reddy, 1977; Bowonder, 1979; Date, 1984; Wicklein, 1998). Multiple factors (criteria) need to be considered in selecting the appropriate technologies which pose the problem as a Multiple-attribute Decision-making (MADM) problem.

1.1 Multiple-Attribute Decision-Making (MADM)

The science of decision making has a long history, and many methods are available for decision making. Decision making deals with systematic modeling of a decision maker's preferences for the purposes of making a choice among options involving a number of often conflicting objectives. Alternatives usually have to be selected based on more than one criterion. Thus, in practice, decision-making problems are often referred to as multiple-criteria decision-making (MCDM) problems. More than 50 MCDM techniques are documented in the literature, ranging from the highly sophisticated to simple rating systems (Hwang and Masud, 1979; Hwang and Yoon, 1981; Figueira et al., 2005).

MCDM methods use a structured and logical approach to model the complex decision-making problems. Hwang and Masud (1979) place MCDM methods in two categories: MADM and multiple-objective decision-making (MODM). Discrete decision problems involving a finite set of well-defined alternatives are handled by MADM methods. There are well defined alternatives available in MADM methods which have to be evaluated using set of attributes. Continuous decision problems involving an infinite number of feasible alternatives are handled by MODM. In MODM, the alternatives are not predefined; rather, alternatives have to be determined using MODM methods. MODM methods are multiple-objective mathematical programming models in which a set of conflicting objectives are optimized and subjected to a set of defined constraints. In this study, we will focus on MADM methods.

Since the 1950s, a large number of MADM methodologies have been developed and applied in various fields, such as management, economics, social sciences and environmental sciences. MADM refers to making preference decisions by evaluating and prioritizing alternatives that are usually characterized by multiple conflicting attributes (Zhou et al., 2006). MADM methods are management decision aids used to evaluate competing and conflicting alternatives based on selected attributes.

The various MADM methodologies that have been developed are based on variety of approaches (based on how attribute information is to be processed) and representation of the logic of the human decision-making process. There are two major approaches to attribute information processing: non-compensatory and compensatory processing (Hwang and Yoon, 1981). Non-compensatory models do not permit tradeoffs between attributes. In these models, a disadvantage (or an unfavorable value) in one attribute cannot be offset by an advantage (or favorable value) in some other attribute. Thus, comparisons are made on an attribute-by-attribute basis. A few examples of non-compensatory MADM methods are dominance, maximin, maximax, conjunctive constraint, disjunctive constraint and lexicographic methods. A compensatory model permits tradeoffs between attributes. Compensatory models are cognitively more demanding but may lead to outcomes that are closer to the optimal outcome or are at least more rational choices than are identified by non-compensatory models (Yoon and Hwang, 1995). Compensatory models are further divided into three subgroups: (i) scoring models (selection of an alternative with the highest score or maximum utility, considering all of the attributes together at one time), e.g., simple additive weighting; (ii) compromising models (selection of the alternative that is closest to the ideal solution), e.g., TOPSIS; and (iii) concordance models (arrangement of the set of preference rankings that best satisfies a given concordance measure), e.g., ELECTRE.

Many MADM methods have been developed. A comprehensive review and classification of these methods was conducted by Hwang and Yoon (1981). Yoon and Hwang (1995) presented an extended classification of MADM methods that included several new MADM methods. The basis for these classifications was type (ordinal or cardinal) and the nature of the information available. The majority of the methods summarized in these reviews were developed for processing information available in the cardinal form.

One of the most commonly used MADM methods is weighted summation (Howard, 1991). In weighted summation, the criteria are represented on a commensurate scale (usually 0 to 1, where 1 represents the best performance), multiplied by weights, and then summed to estimate the overall utility or score. The more complex utility function can be used to capture the preferences of decision makers in the form of utility of the various attributes. Multi-attribute utility theory (MAUT), which uses this concept and is one of the most commonly used MADM methods, aims to produce a complete ranking of alternatives. Huber (1974) and

Keeney (1975) developed various models applying multi-attribute utility theory. Most MUAT models use additive and multiplicative forms of utility measurement. The simple multi-attribute rating technique (SMART) is the simplest form of an MAUT method.

Another set of MADM methods is based on an outranking approach. In outranking methods, it is assumed that the decision maker can express a strict preference or indifference or a weak preference when comparing one alternative to another for each criterion (Seppala, 2004). The two most popular groups of outranking methods are the following: (a) the elimination and choice translating reality (ELECTRE) methods and (b) the preference ranking organization method for enrichment evaluation (PROMETHEE) methods. The ELECTRE method was originally introduced by Benayoun, Roy and Sussman in 1966 (Benayoun et al., 1966). Since then, ELECTRE methods have been developed and improved by Roy (1973), Nijkamp and van Delft (1977) and Voogd (1983). ELECTRE methods classify preferred alternatives and nonpreferred ones by establishing outranking relationships. To date, ELECTRE families have included ELECTRE I, II, III, and IV as well as some improved ELECTRE methods. The ELECTRE approach uses concordance and discordance indices and threshold values to analyze the outranking relations among the alternatives. The PROMETHEE method was first developed by Brans in 1982 (Brans et al., 1982). This approach also uses the outranking principle to rank the alternatives, but is easier to use and less complex than the ELECTRE approach. The PROMETHEE approach is well suited to problems where a finite number of alternatives are to be ranked with respect to several sometimes conflicting criteria. Brans et al. (1986) have offered six generalized criteria functions for reference, namely, a usual criterion, a quasi criterion, a criterion with linear preference, a level criterion, a criterion with linear preference and indifference area, and a Gaussian criterion. The details of the PROMETHEE method and various applications of it were recently reviewed by Behzadian et al. (2010).

There are few methods other than these two broad groups of methods that have their own mathematical foundation. Analytical hierarchy process (AHP) is one such very popular method which has its own mathematical foundation (Marshell and Oliver, 1995; Vaidya and Kumar, 2006). AHP was proposed by Prof. T. L. Saaty (1977). The basic idea of the approach is to convert subjective assessments of relative importance to a set of overall scores or weights (Saaty, 1980). AHP is a quantitative comparison method used to select a preferred alternative using pairwise comparisons of the alternatives based on their relative performance against each criterion. The basis of this technique is that humans are more capable of making relative judgments than absolute judgments. AHP is a systematic procedure that represents the elements of any problem hierarchically. AHP uses a well-defined scale to capture the preferences of the decision maker, and the consistency of preferences can also be checked. AHP is most widely used for weight elicitation of attributes in most of the MADM methods.

Another method with its own mathematical basis is the technique for order preference by similarity to ideal solutions (TOPSIS), developed by Hwang and Yoon (1981). TOPSIS is a utility-based compensatory approach to MADM. This method uses a distance-based approach to quantify and compare the preferences of the alternatives over the set of attributes. Logical mathematical algorithm used by TOPSIS results in a straightforward ranking that can be depicted graphically. This is one of the most widely used MADM methods for cases when information on attributes is available on a cardinal scale.

1.2 MADM application for selection of wastewater treatment alternatives

MADM had widespread application to environmental decision-making problems. The applications cover many types of problems in the field, such as selecting appropriate transmission line corridors (Nair and Sicherman, 1980), environmental planning (Madu, 1999), soil cleaning technology selection (Hokkanen et al., 2008), landfill site selection (Chang et al., 2008), and ranking different contaminated areas according to their need for sediment management (Alvarez-Guerra et al., 2009). Kiker et al. (2005) and Huang et al. (2011) conducted a comprehensive review of applications of multi-criteria decision analysis in environmental decision-making. The MADM approach has also been used to address the problem of wastewater treatment alternative selection. Tecle et al. (1988) was the first to apply MADM to the selection of wastewater treatment alternatives. Three MADM methods, namely, compromise programming (CP), cooperative game theory (CGT) and ELECTRE-I were used for the analysis. All three methods identified the same alternative as the best alternative, based on the ten criteria used in the study. That study did not, however, take into consideration energy requirements and many other sustainability criteria. AHP was used by Ellis and Tang (1991) to build a hierarchy model to rank wastewater treatment alternatives that were tested using data from four wastewater treatment plants (Tang and Ellis, 1994). Twenty criteria were used, and eight alternatives were evaluated. Zeng et al. (2007) combined AHP with grey relational analysis (GRA) and applied it to the selection of optimal wastewater treatment alternatives. Four wastewater treatment alternatives (A2/O, triple oxidation ditch, anaerobic single oxidation ditch and SBR) were evaluated and compared against various criteria. Unfortunately, the grey analysis does not ensure a stable feasible range for the decision space (Rosenberg, 2009). These studies show that efforts have been made to address the problem of wastewater treatment alternative selection; however, the complete information available to the decision maker (DM) is not utilized in the decision-making process. Additionally, indicators or attributes derived from life cycle assessment (LCA) and life cycle costing (LCC) have not been used in any of these studies. Another reason that a scenario-based MADM method should be applied to the selection of wastewater treatment alternatives is that this type of decision-making method can address the priorities of urban, suburban and rural areas in the decision-making process. Therefore, a scenario-based MADM method that considers the indicators derived from LCA and LCC of wastewater treatment technologies is believed to be a more logical approach to technology selection.

1.3 Problem Definition

In this study, the four most commonly used wastewater treatment technologies for municipal wastewater treatment in India, *viz.*, a conventional activated sludge process (ASP), an upflow anaerobic sludge blanket reactor followed by a facultative aerated lagoon (UASB-FAL), a sequential batch reactor (SBR) and constructed wetlands (CWs) are evaluated and ranked. Primary data are collected from field-scale plants, and wherever primary data are not available, secondary data are used. The selection of wastewater treatment alternative is inherently a discrete decision problem with a finite set of alternatives; thus, the present study is focused on the application of MADM methods to this problem. Five quantitative criteria derived from LCA, LCC having five indicators and two qualitative sustainability criteria having seven indicators, are used to rank the four alternatives. Furthermore, scenarios (sets of attribute weights) have been articulated to model actual decision-making situations that are commonly encountered in the field. A “no scenario” condition (assuming equal weights for all indicators) is also tested to observe the ranking of the alternatives.

2. Methodology

The review of MADM methods suggests that AHP and TOPSIS are the competing and most widely used methods. AHP is preferred when the information on attributes is available on Saaty’s scale, which results in comparison of alternatives in the form of priority. AHP is not useful when information on attributes is available on a cardinal scale. A major limitation of AHP is that the maximum number of alternatives should be kept to less than seven to achieve consistency in the preferences, which makes TOPSIS a better option when there are a large number of alternatives. In this study, TOPSIS is preferred for evaluation because the available information on attributes is on a cardinal scale. Another reason to use TOPSIS is that the algorithm can easily be implemented computationally and can be made available as a decision support tool for the end users. The target end users can be engineers from urban local bodies (ULBs), officials from developmental authorities, policy makers, planning officials, etc. The following subsections describe the criteria and indicators used for the evaluations, the articulated scenarios and the application of TOPSIS for selection of wastewater treatment alternatives.

2.1 Criteria and Indicators

The wastewater treatment alternative selection problem involves decision making based on a finite number of alternatives and criteria. Researchers have identified a number of relevant criteria covering technical, economical, societal, and other aspects. These criteria can be quantitative or qualitative in nature. In MADM, there are two ways of measuring preference for a particular alternative under a given attribute, one with ordinal scales and the other with cardinal scales (Hwang and Yoon, 1981). With ordinal scales, no numerical properties, such as ratios or intervals, are used; characterization of objects is purely relational, and objects are rank ordered. Intensity of preference is not apparent from ordinal scales. Ordinal scales can be expressed in terms of numbers or verbal rankings, e.g., 1, 2, 3, 4, etc. or “bad,” “good,” “excellent,” etc. Cardinal scales assign numerical values (numbers, intervals, ratios, etc.) to objects.

It should also be noted that attributes can be of three types, as described by Yoon and Hwang (1995).

Benefit attributes: These offer increasing monotonic utility. That is, the greater the attribute value, the more it is preferred. An example is fuel efficiency.

Cost attributes: These offer decreasing monotonic utility. That is, the greater the attribute value, the less it is preferred. An example is production cost.

Non-monotonic attributes: These offer non-monotonic utility, with maximum utility located somewhere in the middle of the attribute range. Examples are room temperature in an office and blood sugar level in a human body. For these attributes the maximum utility lies somewhere in between the attribute range.

Recent frameworks for technology assessment also include sustainability criteria. Incorporation of sustainability concerns in environmental decision making is a challenging task. There are many methodological issues associated with quantifying and operationalizing sustainability in decision making. To translate the appropriateness of the technology, various sustainability criteria and indicators have been proposed by researchers (Mels et al., 1999; Ashley et al., 1999; Foxon et al., 2002; Balkema et al., 2002; Palme et al., 2005; Arceivala and Asolekar, 2007; Mokropoulos et al., 2008; Muga and Mihelcic, 2008; Singhirunnusorn and Stenstrom, 2009). A structured way of comparing wastewater systems with respect to sustainability has been defined by Balkema et al. (2001). Similar to LCA, a three-phase procedure has been defined for sustainability assessment of wastewater treatment plants (WWTPs): (i) goal and scope definition, (ii) inventory, and (iii) optimization. Sustainable wastewater treatment options can be selected using integer programming with the objective function defined as a weighted sum of sustainability indicators.

The criteria or indicator set based on which technologies are compared should be judicially selected because a large number of criteria will require more data, and thus, obtaining a solution will require more time and cost. The selected criteria or indicators should also characterize all of the aspects of the technologies to be evaluated. In this study, seven criteria have been chosen to rank wastewater treatment alternatives. Each of the criteria has one or more indicators (attributes), as shown in **Table 1**. The scores for indicators are obtained from primary data collected from field-scale municipal WWTPs. Although the environmental and human health toxicity indicators are important for the assessment, unavailability of quantitative data on these indicators restrains inclusion of these indicators in this study. Anyway it is important to note that no toxicity impact indicators are included in the assessment, since the four technologies evaluated are designed for organic and nutrient removal. Process design details of these technologies revealed that toxic pollutants such as heavy metals are not target pollutants in the design of these technologies.

The first two criteria [quantified with global warming potential (GWP) and eutrophication potential (EP) indicators] are derived using life cycle assessment (LCA). The global warming criterion represents primarily energy consumption during the operational phase of the plants over their life cycles. Similarly, the eutrophication criterion represents the performance of the plant based on release of organics and nutrients in treated wastewater. Historically, LCA has been a useful tool for computation of the environmental footprint of a given wastewater treatment technology (Tillman et al., 1998; Hospido et al., 2004; Gallego et al., 2008). Studies on LCA of wastewater treatment plant (WWTPs) have shown that construction and end-of-life or demolition phases of WWTPs have negligible impacts compared to operation phase (Emersion et al., 1995; Tillman et al. 1998; Lundin et al., 2000; Karrman and Jonsson 2001; Machado et al., 2007). Kalbar et al. (2012) have confirmed the same by carrying out LCA of WWTPs with Indian inventories. Following that, the indicators used in the present work are derived by studying only operation and maintenance (O&M) phase of the WWTPs. This approach is in agreement with a similar study on sustainability assessment of wastewater treatment technologies (Muga and Michlec, 2008).

The LCA indicators are estimated as per CML 2 baseline 2000 methodology, commonly used for LCA studies on WWTPs (Tillman et al., 1998; Hospido et al., 2004; Machado et al., 2007; Gallego et al., 2008). The CML 2001 characterization factors have been used from Ecoinvent data base v2.1 (Swiss Centre for Life-Cycle Inventories, 2009). To estimate LCA indicators following generic equation is used (Guinee et al., 2001):

$$Indicator = \sum_i Characterization\ \ Factor_i \times m_i \qquad [1]$$

where m is the mass of the ith substance (or pollutant). For example, in the case of indicator GWP, relative contributions of different gases to climate change are commonly compared in terms of carbon dioxide equivalents (kg CO_2-Eq) using GWPs. Methane has characterization factor for GWP_{100} indicator of 25 kg CO_2-Eq., which implies that 1 kg of the methane has the same cumulative climate change effect as 25 kg of carbon dioxide over a 100 year time period. Similarly EP indicator is expressed in kg PO_4^{3-}-Eq. The eutrophication potentials of all pollutants are obtained from Ecoinvent database and cumulative eutrophication potentials of each of the wastewater treatment technology estimated as per Eq. [1] are reported in Table 1.

Table 1 Criteria with respective indicators and scores used for selection of appropriate wastewater treatment technology

Sr No.	Criteria	Indicator	ASP	SBR	UASB-FAL	CWs
1	Global warming[a]	Global warming potential (kg CO_2-Eq / p.e.-year)	18.20	31.97	7.67	-3.86
2	Eutrophication[a]	Eutrophication potential (kg PO_4^{3-}-Eq/ p.e.-year)	3.76	1.38	5.85	3.40
3	Life Cycle Costs[b]	Net Present Worth (Rs. Lakh / MLD)	137	127	103	242
4	Land requirement	Land requirement (m^2 / MLD)	1400	353	1123	8500
5	Manpower requirement for operation	Number (for operation of medium scale plant)	10	6	14	4
6	Robustness of the System[c]	Reliability	80	80	60	40
		Durability	80	60	60	40
		Flexibility	80	60	40	30
7	Sustainability[c]	Acceptability	30	30	50	90
		Participation	30	30	50	80
		Replicability	40	40	40	80
		Promotion of Sustainable Behavior	40	40	60	90

[a] Estimated using ISO 14040: 1997 as described in Guinee et al. (2001) using CML 2 baseline 2000 methodology, only operation phase is considered for the analysis
[b] Life cycle costs estimated as per the present worth method prescribed in IS 13174, (1994)
[c] These indicators do not have units as they are qualitative in nature. To quantify these indicators, a cardinal scale of 0 and 100 is used with 0 being the worst score and 100 the best score.

The third criterion life cycle costs (LCC) having net present worth (NPW) as indicator is quantified as per the present worth method, prescribed in Indian Standards, IS 13174, Part II (1994). It requires conversion of all future cash flows to a baseline considering both inflation and opportunity cost of capital. NPW represents the capital and operation and maintenance (O&M) costs of the plant. Capital costs include the cost incurred for civil works, electromechanical equipment and the cost of land. O&M costs include electrical energy and chemicals costs required to operate the plant, labor costs, spare parts and maintenance costs. The fourth criterion is land requirement expressed in terms of m^2/MLD. The fifth criterion, manpower requirement for operation of the plant represents a resource constraint indicated by number of staffs. The actual land requirement and manpower requirement are estimated by studying field-scale WWTPs.

The next set of indicators, *viz.*, reliability, durability and flexibility, quantifies the robustness of the technology, and thus, these three 'qualitative' indicators are grouped under one criterion called ‘robustness of the system.’ The sustainability of the wastewater treatment alternative has been quantified using four indicators, *viz.*, acceptability/simplicity, participation/responsibility, replicability and promotion of sustainable behavior, grouped under the criterion ‘sustainability.’ Muga and Michlec (2008) reported that the qualitative indicators are usually difficult to estimate. Most of the widely accepted approaches to quantify qualitative indicators are based on consultation with experts (Palme et al., 2005; Singhirunnusorn and Stenstrom, 2009). In this study authors have given scores to each wastewater treatment technology based on their experience with these technologies in India. The following subsections briefly describe these indicators.

Reliability: For the purposes of this study, reliability of the system is defined as the possibility of achieving adequate performance for a specific period of time under specific conditions (Von Sperling and Oliveira 2007). Singhirunnusorn and Stenstrom (2009) considered two major aspects of reliability for the wastewater treatment process: plant performance and mechanical reliability. Reliability of the treatment system can be assessed by the following: (1) the variability of treatment effectiveness under normal and emergency operation, (2) the probability of mechanical failures, and (3) the impact of failures upon effluent quality (Eisenberg et al., 2001).

Durability: For the purposes of this study, durability is defined as the technological life time, which is one of the important criteria in selection of a wastewater treatment technology. The technology should have at least 40–50 years of technological life with minimal maintenance and spare part requirements.

Flexibility**:** It is often necessary to upgrade an existing treatment plant to increase its additional hydraulic and/or organic load. This particular criterion attempts to account for the indigenous nature of a given type of technology to undergo the upgrade easily. The technology should be sufficiently flexible that minimal changes will be required to the infrastructure of the plant to undertake additional hydraulic and/or organic load.

***Acceptability*:** In different cultures, people have different perceptions of waste and sanitation, which result in different habits. New sanitation concepts, including changes in toilet systems, may encounter social and cultural resistance in implementation (Balkema et al., 2002). The acceptability criterion deals with this aspect of acceptance of technology from the point of view of socio-economic culture. Acceptability also takes into consideration the issues such as simplicity of wastewater treatment technology and odor related problems to community which are crucial attributes in the selection of wastewater treatment systems, particularly for developing countries. In countries where unskilled labor is cheap and available, construction costs can be reduced with community participation (Choguill, 1996). However, a lack of skilled workers represents a major constraint when decision makers choose to implement a sophisticated treatment system in remote areas. Operational and maintenance simplicity should be a prime concern because simplicity can determine the long-term operating success of the system (Singhirunnusorn and Stenstrom, 2009).

Participation: Public participation is often neglected when selecting the most appropriate wastewater treatment technology for a particular community. While some regulations designate a specific technology through a ‘‘best technology’’ process, the perceptions and preferences of the public toward the selection and implementation of a particular technology is important if the technology is to be integrated with local and broader sustainability concerns (Muga and Mihelcic, 2008). The technology should promote public participation and make the community responsible for the success of the implementation of the project.

Replicability: This indicator is intended to capture the simple design, implementation and operational features of the technology. For countries such as India, where most of the population lives in rural areas, the technology installed at one place should be able to be replicated to other places very easily. The involvement of technical experts should be required only for the first few implementations. Thereafter, the features of the technological solution should be sufficiently familiar that it can be easily replicated in other places without reliance on specific technical expertise.

Stimulation of Sustainable Behavior: Sustainable behavior can be stimulated by tailoring the technological design (e.g., pisciculture, biogas recovery, etc.) such that sustainable behavior is promoted. Other ways to stimulate sustainable behavior involve increasing the end user's awareness, participation, and responsibility (Balkema et al., 2002). The technology should promote sustainability in the community.

2.2 Decision-making Scenarios

Real-life decisions are always challenging because the type of information available to decision makers (DMs) may vary in quality and scale. For example, in the selection of wastewater treatment alternatives, there can be primary (first-level) information available to DMs, such as the location of the plant, the objective of the treatment and land availability in the region. Another type of information essential for decision making is the number of alternatives available, which is referred to in this study as secondary or second-level information. The third level of information reflects the scores of the alternatives with respect to individual criteria or indicators. The fourth level of information reflects the weights associated with criteria or indicators, which can be assumed to be equal in the absence of information on how they should be weighted. Making use of all of the types of information available to the DMs and translating it into a mathematical form should be the objective of an efficient MADM algorithm.

In conventional MADM methods, there are well-defined procedures for using the second, third and fourth levels of information available to DMs; however, most of the time, the first level of information is neglected, due to lack of clarity. In this study, a scenario-based decision-making procedure has been developed to incorporate the first level of information into MADM methods. Scenarios are basically sets of weights of attributes that capture the local and regional priorities of a given decision-making situation. The six most commonly encountered scenarios relevant to the selection of wastewater treatment alternatives in India have been identified.

It is argued in this study that the concept of scenario-based decision making facilitates the selection of wastewater treatment alternatives efficiently. Information on the preference of an alternative for a given scenario can be embedded into the weights of the scenario. It also becomes easy to elicit weights of the criteria for a particular scenario. For example, **Table 2** shows the six scenarios and the associated weights assigned to each scenario.

Scenarios I and II represent the decision-making situation in which the wastewater treatment plant location is in an urban area where the availability of suitable land is a constraint. In India, apart from cities (where the population > 0.1 million), any human settlements with a population in between 5000 and 0.1 million are considered to be urban areas (Census of India, 2011). In 2011, 31.16 % of India's population (approximately 377 million people) resided in urban areas. Scenario I considers a situation in which treated wastewater is discharged into a body of surface water, which is the present practice in most urban areas in India. However, as surface water bodies in urban regions become more stressed and eutrophic, this practice for disposing of treated wastewater needs to be abandoned. Scenario II represents a decision-making situation similar to Scenario I in an urban area but with the objective of recycling treated wastewater, which is the preferred practice in India. Treated wastewater can be given further treatment and used for various applications, such as toilet flushing, gardening, car washing, fire fighting, air conditioning, etc.

Scenarios III and IV represent decision-making situations in which a wastewater treatment plant is located in a suburban area. The outlying areas adjoining urban areas that have some rural and some urban characteristics are referred to as suburban areas (Sundaravadivel and Vigneswaran, 2001). In India, almost 30% of the population resides in suburban areas. In suburban areas, there is no constraint on land availability. Scenario III assumes that treated wastewater shall be discharged into bodies of surface water. Scenario IV represents a similar decision-making situation as Scenario III, except that in Scenario IV, it is assumed that the treated wastewater will be recycled or given further treatment.

Scenarios V and VI represent decision-making situations in which a wastewater treatment plant is located in a rural area (where the population < 5000). In 2011, 68.84 % of India's population, approximately 833 million people lives in about 0.64 million villages (Census of India, 2011). In rural areas, there is absolutely no constraint on land availability. Scenario V assumes that treated wastewater will be discharged into a body of surface water. Scenario VI represents the same decision-making situation except that in Scenario VI it is assumed that the treated wastewater will be recycled or given further treatment.

The various decision-making scenarios described above help DMs to characterize the situation of a particular case study being considered. In one scenario, an attribute can be a *cost attribute*, while in another scenario, the same attribute can be a *benefit attribute* due to the physical and/or economic conditions applicable to the scenario. Table 2 shows the weights corresponding to each attribute for all six of the scenarios identified in the present study. The weights are expressed in cardinal scores between 0 and 100, with 0 as the lowest preference and 100 as the highest preference.

Table 2: Six scenarios and associated weights assigned

Indicators ↓	**Scenario I** Urban Area / Land Constraint / Disposal to Surface Water Body		**Scenario II** Urban Area / Land Constraint / Treated Water for Reuse		**Scenario III** Sub-urban Area / No Land Constraint / Disposal to Surface Water Body		**Scenario IV** Sub-urban Area / No Land Constraint / Treated Water for Reuse		**Scenario V** Rural Area / No Land Constraint / Disposal to Surface Water Body		**Scenario VI** Rural Area / No Land Constraint / Treated Water for Reuse	
	Weight	Type of criteria	Weight	Type of criteria	Weight	Type of criteria	Weight	Type of criteria	Weight	Type of criteria	Weight	Type of criteria
Global warming potential (kg)	20	cost	20	cost	20	cost	20	cost	20	cost	20	cost
Eutrophication potential (kg)	20	cost	80	cost	30	cost	80	cost	30	cost	80	cost
Net present worth (Rs. Lac)	20	cost	20	cost	60	cost	60	cost	90	cost	90	cost
Land requirement (m^2)	80	cost	80	cost	40	benefit	40	benefit	80	benefit	80	benefit
Number	10	cost	10	cost	40	benefit	40	benefit	80	benefit	80	benefit
Reliability	40	benefit	40	benefit	40	benefit	40	benefit	40	benefit	40	benefit
Durability	40	benefit	40	benefit	40	benefit	40	benefit	40	benefit	40	benefit
Flexibility	40	benefit	40	benefit	40	benefit	40	benefit	40	benefit	40	benefit
Acceptability	10	benefit	10	benefit	30	benefit	30	benefit	80	benefit	80	benefit
Participation	10	benefit	10	benefit	30	benefit	30	benefit	80	benefit	80	benefit
Replicability	20	benefit	20	benefit	40	benefit	40	benefit	80	benefit	80	benefit
Promotion of sustainable behavior	10	benefit	10	benefit	40	benefit	40	benefit	80	benefit	80	benefit

2.3 Application of TOPSIS for Selection of Wastewater Treatment Alternatives

As mentioned earlier, the wastewater treatment alternative selection problem involves decision making based on a finite number of alternatives and criteria, which can be solved using MADM methods. In the set of criteria used for ranking, some criteria are quantifiable (e.g., land requirements, costs), and some criteria are qualitative in nature (e.g., acceptability, durability). A cardinal scale of 0 to 100 (0 as the worst and 100 as the best) is used to transform qualitative criteria into quantitative criteria. TOPSIS is used to rank the alternatives based on the similarities to a positive ideal solution (PIS), i.e., the relative distance a positive ideal and from a negative ideal. In practical situations, ideal solutions cannot be achieved because of continual technological innovation. Thus, for all-practical purposes, the lowest score of an attribute is considered its PIS, and the highest score is considered its negative ideal solution (NIS) for *cost attributes* and vice versa for *benefit attributes*.

Hwang and Yoon (1981) extended the theory of ideal solutions (Zeleny, 1974) to develop TOPSIS. This method is based on the concept that the chosen alternative should be the shortest distance from the positive ideal solution and the greatest distance from the negative ideal solution. The concept of similarity to ideal in TOPSIS solves the reference-selection problem between the positive ideal solution and the negative ideal solution (Yoon, 1987). Utility can be estimated by comparing each alternative directly, depending on data in the decision matrices and weights. The compensatory approach of TOPSIS attempts to mimic the nature of human decision making, in which a disadvantage or unfavorable value of one attribute can be offset by an advantage or favorable value of some other attribute. According to Kim et al. (1997) and Shih et al. (2007), the advantages of TOPSIS are as follows: (i) a sound logic that represents the rationale of human choice; (ii) a scalar value that simultaneously accounts for both the best and worst alternatives; (iii) a simple computation process that can be easily programmed into a spreadsheet; and (iv) performance measures for all alternatives with respect to attributes that can be visualized as a polyhedron, at least for any two dimensions.

These advantages make TOPSIS a major MADM technique compared with other related techniques. Zanakis et al. (1998) have reported that TOPSIS has the fewest rank reversals among eight similar MADM approaches. TOPSIS has disadvantages as well, such as not providing weight elicitation and consistency checking for judgments.

The distance measure in TOPSIS is not only a geometric concept but is also used as a proxy for human preference. The method assumes that each attribute has a monotonically increasing or decreasing utility, which makes it easy to locate the ideal and negative ideal solutions. Sometimes the chosen alternative, which has the minimum Euclidean distance from the ideal solution, can have a shorter distance from the negative ideal. For example, reliability (X1) and flexibility (X2) of wastewater treatment alternatives are the attributes in TOPSIS for evaluating two treatment alternatives, ASP (A1) and SBR (A2), using Euclidian distance (d2), as shown in **Fig. 1**. A1 is the choice based on the positive ideal (A^+), whereas A2 is the choice based on the negative ideal (A^-). This conflict is resolved by considering the distance from the positive ideal (dp^+) and the distance from the negative ideal (dp^-) simultaneously in TOPSIS.

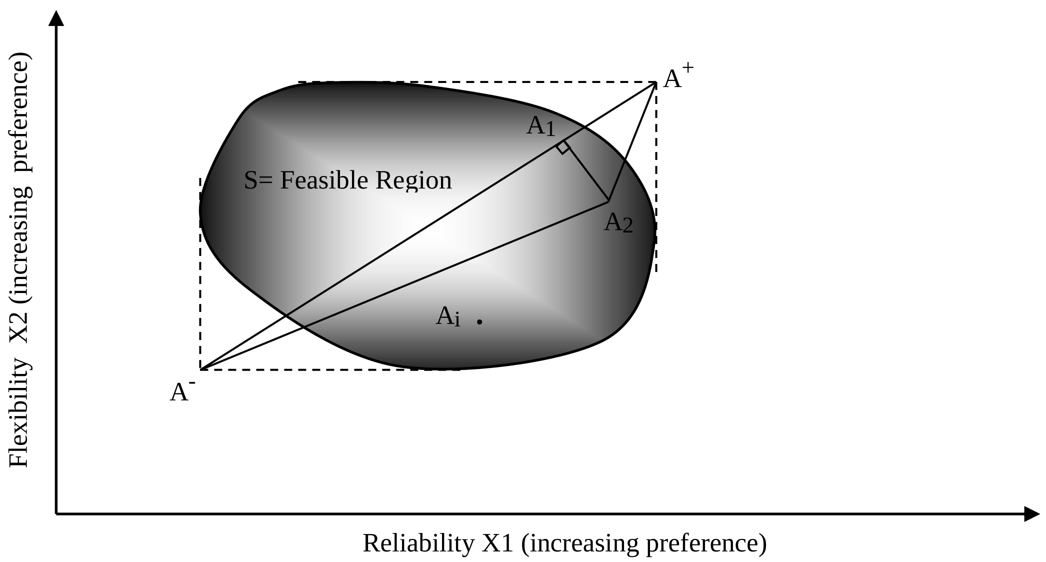

Fig. 1. Euclidean distances to the ideal and non-ideal solutions in two dimensional space (adapted from Yoon, 1987)

The step-by-step exposition of the TOPSIS methodology for selection of appropriate wastewater treatment alternatives, as described by Yoon and Hwang (1995), is presented below.

Step 1: *Calculate the Normalized Ratings*

The first step is normalization because attribute information is available in different scales in the current problem. Among the many normalization methods available, vector normalization is the most recommended method for TOPSIS because it minimizes the chances of rank reversals (Hwang and Yoon, 1981; Milani et al., 2005; Chakraborty and Yeh, 2009). **Table 3** shows the normalized weighted scores of the attributes for four alternatives for Scenario I (Urban Area / Land Constraint / Treated Water Disposal to Surface Water Body). In vector normalization, the normalized score matrix (r_{ij}) is determined as follows:

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

where x_{ij} is the score of j^{th} indicator for i^{th} alternative, and there are n indicators (or attributes) and m alternatives. For the present problem, there are 4 alternatives and 7 criteria (with 12 indicators or attributes).

Step 2: *Calculate the Weighted Normalized Ratings*

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 j^{th} attribute. There are many methods available for weight elicitation, e.g., AHP, the Eigenvector method, etc.

Table 3 shows the normalized positive and negative ideals used for Scenario I for each attribute. This matrix is used to estimate the distance matrices and relative distance from the positive and negative ideals. A similar procedure is followed for the remaining five scenarios.

Step 3: *Identification of Positive Ideal (PIS) and Negative Ideal (NIS) Solutions.*

$$PIS = \left\{a^{+}{}_{1}, a^{+}{}_{2}, \ldots\ldots\ldots\ldots, a^{+}{}_{j}, \ldots\ldots\ldots, a^{+}{}_{n}\right\} \\ = \left\{(\max_{i} a_{ij} \middle| j \in J_1), (\min_{i} a_{ij} \middle| j \in J_2) \middle| i = 1, \ldots\ldots\ldots, m\right\} \quad [4]$$

$$NIS = \left\{a^{-}{}_{1}, a^{-}{}_{2}, \ldots\ldots\ldots\ldots, a^{-}{}_{j}, \ldots\ldots\ldots, a^{-}{}_{n}\right\} \\ = \left\{(\min_{i} a_{ij} \middle| j \in J_1), (\max_{i} a_{ij} \middle| j \in J_2) \middle| i = 1, \ldots\ldots\ldots, m\right\} \quad [5]$$

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.

For example, as shown in Table 3 for Scenario I, the positive ideals for all quantitative attributes (GWP, EP, NPW, land requirement and manpower requirement) are minimum scores for the respective indicators because these are c*ost attributes*. For all other qualitative attributes, which are *benefit attributes,* the maximum scores for the respective indicators formulate the set of positive ideals.

Step 4: *Calculate Separation Measures*

The separation (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:

$$D^{+}_{i} = \sqrt{\sum_{j=1}^{n}(a_{ij} - a^{+}_{j})^{2}} \text{ , } i = 1, \ldots\ldots, m \qquad [6]$$

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

$$D^{-}_{i} = \sqrt{\sum_{j=1}^{n}(a_{ij} - a^{-}_{j})^{2}} \text{ , } i = 1, \ldots\ldots, m \qquad [7]$$

Step 5: *Calculate Similarities to Positive Ideal Solution*

$$R^{*}_{i} = \frac{D^{-}_{i}}{(D^{+}_{i} + D^{-}_{i})}, \quad i=1, \ldots\ldots, m \qquad [8]$$

Note that $0 \leq R^{*}_{i} \leq 1$, where $R^{*}_{i} = 0$ when $D_i = D^{-}$, and $R^{*}_{i}=1$ when $D_i = D^{+}$.

Table 3 shows the separation measures for each of the alternatives for Scenario I. Similar results are derived for the other five scenarios as well.

Table 3 Normalized weighted scores of the attributes for four alternatives for Scenario I

Scenario I Urban Area / Land Constraint / Disposal to Surface Water Body														
Type of Criteria	Cost	Cost	Cost	Cost	Cost	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit	Benefit		
Indicators → Alternative ↓	Global warming potential (kg)	Eutrophication potential (kg)	Net Present Worth (Rs. Lakh)	Land requirement (m²)	Number	Reliability	Durability	Flexibility/Adaptability	Acceptability/Simplicity	Participation/Responsibility	Replicability	Promotion of Sustainable behavior	D^{+}_{i}	D^{-}_{i}
ASP	0.0316	0.0299	0.0265	0.0403	0.0168	0.0745	0.0811	0.0894	0.0084	0.0091	0.0236	0.0102	0.0603	0.2213
SBR	0.0513	0.0110	0.0246	0.0102	0.0101	0.0745	0.0608	0.0671	0.0084	0.0091	0.0236	0.0102	0.0694	0.2444
UASB-FAL	0.0165	0.0465	0.0200	0.0323	0.0235	0.0559	0.0608	0.0447	0.0140	0.0151	0.0236	0.0154	0.0767	0.2189
CWs	0.0000	0.0270	0.0469	0.2444	0.0067	0.0373	0.0406	0.0335	0.0253	0.0242	0.0472	0.0230	0.2490	0.0673
PIS*	0.0000	0.0110	0.0200	0.0102	0.0067	0.0745	0.0811	0.0894	0.0253	0.0242	0.0472	0.0230		
NIS*	0.0513	0.0465	0.0469	0.2444	0.0235	0.0373	0.0406	0.0335	0.0084	0.0091	0.0236	0.0102		

3. Results and Discussion

In this study, wastewater treatment alternatives are ranked for six scenarios and a "no scenario" case. **Table 4** shows the relative distance matrix (score) for each of the four alternatives, with their respective ranks under each scenario. For the "no scenario" case, for which all indicators are assumed to have equal weights, the alternatives have almost equal scores, resulting in difficulty in selection of the most appropriate alternative. Equal scores suggest that all of the alternatives are equidistant from the ideal and non-ideal solutions, which can be clearly conceptualized from **Fig. 2**. The "no scenario" radar plot in Fig. 2 shows that the PIS and NIS cover opposite areas. The alternative that is most preferred should cover the maximum area under the PIS, i.e., it should be the alternative with the greatest similarity to the PIS. The results for the “no scenario” case highlight the need for a scenario-based decision-making approach such as that proposed in this study.

Table 4: Relative distance metric for each scenario and rank of each alternative in particular scenario.

Alternative	**No Scenario** Equal Weights to Attributes		**Scenario I** Urban Area / Land Constraint / Disposal to Surface Water Body		**Scenario II** Urban Area / Land Constraint / Treated Water for Reuse		**Scenario III** Sub-urban Area / No Land Constraint / Disposal to Surface Water Body		**Scenario IV** Sub-urban Area / No Land Constraint / Treated Water for Reuse		**Scenario V** Rural Area / No Land Constraint / Disposal to Surface Water Body		**Scenario VI** Rural Area / No Land Constraint / Treated Water for Reuse	
	Score (R^*_i)	Rank	Score (R^*_i)	Rank	Score (R^*_i)	Rank	Score (R^*_i)	Rank	Score (R^*_i)	Rank	Score (R^*_i)	Rank	Score (R^*_i)	Rank
ASP	0.5066	4	0.7857	1	0.7081	2	0.4277	3	0.4355	3	0.3244	3	0.3359	4
SBR	0.5087	2	0.7789	2	0.8017	1	0.3715	4	0.4910	2	0.2686	4	0.3445	3
UASB-FAL	0.5083	3	0.7404	3	0.5816	3	0.4452	2	0.3754	4	0.4228	2	0.3982	2
CWs	0.5271	1	0.2127	4	0.2822	4	0.5506	1	0.5501	1	0.6262	1	0.6214	1

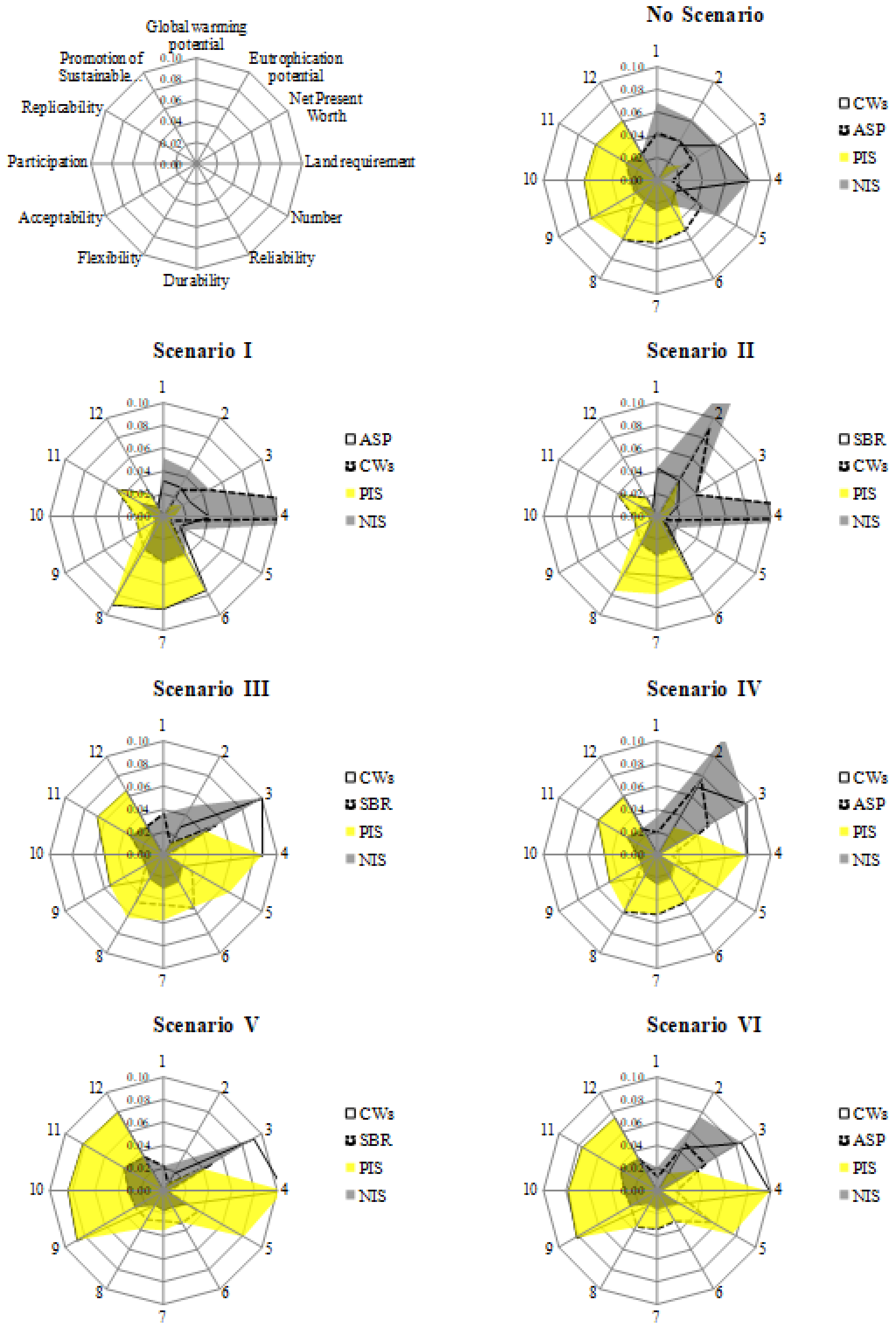

Fig. 2. Radar plots showing the feasible area of Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS) for each of the scenario. The most and least preferred alternatives for each scenario are also shown. The alternative which covers maximum areas of the PIS is the most preferred alternative (shown with _____) and the alternative covers maximum area of NIS is the least preferred alternative (shown with _ _ _ _).

3.1 Analysis of alternative ranking generated under six scenarios

In Table 4, ASP is ranked as the most preferred alternative (with a score of 0.7857), while SBR holds the second rank (with a score of 0.7789) for Scenario I. This outcome is reasonable for Scenario I as it depicts a situation in which a wastewater treatment plant is located in an urban area with constrained land availability and in which treated water is assumed to be discharged into a surface water body. ASP has a small land requirement and satisfactory performance in terms of meeting the discharge standards for the surface water body. The radar plot for Scenario I in Fig. 2 shows that ASP covers the maximum area of the PIS and is thus the most preferred, which agrees with the results in Table 4. Scenario II is similar to Scenario I, but in Scenario II, it is assumed that the treated water has to be recycled; therefore, it is expected that the quality of the water will be better than in Scenario I. SBR is found to be the best alternative under Scenario II, as shown in the third column of Table 4, which is consistent with the priorities of the scenario. SBR produces a better quality of effluent and requires less land than ASP. At the same time, the effluent released from SBR has more recycling potential. The radar plot for Scenario II in Fig. 2 shows that the SBR covers the maximum area under the PIS and is thus preferred. It should be noted that for both Scenarios I and II, the technologies selected (ASP and SBR), through the decision-making framework proposed here, are those that are more mechanized and have smaller land requirements than the other alternatives and are best at providing the desired quality of treated water in the respective scenarios. The ranking provided by the methodology is suitable for an urban setting.

Scenarios III and IV capture the priorities of suburban area as defined earlier. Under Scenario III, CWs (with a score of 0.5506) is the preferred alternative, followed by UASB-FAL (with a score of 0.4452). CWs and UASB-FAL can both produce effluent meeting the quality criteria for discharge into inland surface water and can be adopted where land availability is not a constraint, which are exactly the priorities of Scenario III. Because there is no constraint on land requirements in suburban area in Scenario III, NTSs such as CWs are the preferred option, which is clearly identified by the decision-making methodology, as shown in Fig. 2. Scenario IV situation demands reuse of treated wastewater, so technologies with potential for producing good treated water quality will be selected by the decision-making methodology. The results show that CWs (with a score of 0.5501) are ranked first, followed by SBR (with a score of 0.4910). CWs are preferred whenever the availability of land is not limited, whereas if land is not available then mechanized treatments such as SBR can be selected, which is the exact outcome of the ranking.

Priorities of rural areas, such as employment generation, public participation, replicability of the solution and promotion of sustainable behavior, are given more importance in Scenarios V and VI. In addition, the technology selected for rural areas should be low in cost, simple to operate, and may have higher land requirements, which should not be a constraint in a rural area. The only technology that can meet all of the requirements for both of these scenarios is CWs in the set of NTSs. CWs are preferred for both Scenarios V and VI, with scores of 0.6262 and 0.4228, respectively. UASB-FAL is selected as the second-best alternative, which may be due to its simplicity of operation. For Scenarios V and VI, Fig. 2 shows that CWs covers the maximum area of the PIS and matches almost all of the points of the radar plot. ASP and SBR are less preferred in these two scenarios, due to their higher capital and O&M costs and because they are more mechanized operations. It should also be noted that for Scenario V, ASP is ranked third, and SBR is ranked fourth; for Scenario VI, SBR is ranked third, and ASP is ranked fourth. This is because the assumption in Scenario V is discharge of treated water into the surface water body and ASP can meet this requirement. SBR produces better-quality effluent that can be directly recycled, which is the assumption of Scenario VI; thus, SBR is preferred over ASP.

The alternative nearest to the ideal solution and farthest from the non-ideal solution is selected by TOPSIS, which is the actual requirement in environmental decision making. In real-life environmental problems, where many stakeholders are involved, it is essential to balance the priorities of all of the stakeholders, although they may have opposing viewpoints. TOPSIS mimics the nature of this type of decision-making problem and thus identifies the best alternative for each scenario. These results suggest that there is no perfect technology that will satisfy all of the requirements of the various scenarios. In the practical application of MADM, a compromise solution (the best available alternative) will be chosen from a set of available alternatives. This study also shows that a logical structuring of a decision-making problem helps in effective application of MADM methods.

3.2 Sensitivity Analysis

In this study, criterion weights are assigned to each of the scenarios by the authors in the context of the priorities of each scenario. It is essential to analyze how sensitive each of the criterion weights is in all six of the scenarios such that the resulting rankings can be considered reliable. Sensitivity analysis will also identify the range of weights for which the ranking will not be affected. In this study, the approach to sensitivity analysis of the MADM method developed by Triantaphyllou and Sanchez (1997) is used. The results of the sensitivity analysis of the criterion weights are presented in Table 5. The boldfaced value in each row in Table 5 is the minimum relative percent variation allowed for the particular criterion weight. For example, the indicator GWP is most sensitive in Scenario I, and any relative decrease more than 34% in the value of the weight will affect the ranking. There is no change in ranking if the weight is increased, meaning that there is no sensitivity to higher weights. There are some criterion weights that are not critical (NC) in many scenarios, suggesting that the ranking is governed mostly by criteria with high weights. Similar findings were reported by Triantaphyllou and Sanchez (1997).

A similar sensitivity analysis, using the method suggested by Triantaphyllou and Sanchez (1997), is performed for criterion scores. The results show that up to a 50% relative percent change in any criterion score does not affect the ranking for any alternatives in any of the scenarios, except for Scenario I. In scenario I, a 10% relative change in any criterion score will not affect the ranking. The results from the sensitivity analyses for criterion weights and criterion scores show that the ranking in each scenario is stable. The ranges within which each of the criterion weights and scores can vary are also estimated.

Table 5: Sensitivity analysis for different indicator scores

Indicators ↓	**Scenario I** Urban Area / Land Constraint / Disposal to Surface Water Body	**Scenario II** Urban Area / Land Constraint / Treated Water for Reuse	**Scenario III** Sub-urban Area / No Land Constraint / Disposal to Surface Water Body	**Scenario IV** Sub-urban Area / No Land Constraint / Treated Water for Reuse	**Scenario V** Rural Area / No Land Constraint / Disposal to Surface Water Body	**Scenario VI** Rural Area / No Land Constraint / Treated Water for Reuse
	Percent Change* (%)					
Global warming potential (kg)	**-34**	NC†	-162	-180	NC	NC
Eutrophication potential (kg)	+35	-146	+99	-142	NC	**-28**
Net Present Worth (Rs. Lakh)	NC	NC	**-124**	NC	+355	+168
Land requirement (m^2)	**+22**	-167	NC	-79	NC	+71
Number	NC	NC	-92	NC	-350	**+40**
Reliability	NC	NC	**+131**	NC	NC	NC
Durability	NC	NC	+121	NC	NC	**+105**
Flexibility	**-30**	NC	+55	NC	NC	+96
Acceptability	NC	NC	NC	NC	NC	NC
Participation	NC	NC	NC	NC	NC	NC
Replicability	NC	NC	NC	NC	NC	NC
Promotion of Sustainable behavior	NC	NC	NC	NC	NC	NC

* Positive and negative signs are decided based on the type of the criteria (*benefit* or *cost*) in each scenario. Positive sign indicates increase in the weight while negative indicates decrease in the weight
† NC: Not a critical indicator for this particular scenario

4. Conclusions

The problem of selecting an appropriate wastewater treatment alternative is addressed in this study, and a scenario-based MADM method has been developed. Six scenarios are articulated, depicting the most commonly encountered decision situations and addressing the technology options for wastewater treatment in India. The methodology developed in this work effectively captures regional and local societal priorities in terms of weights for criteria for each scenario and translates them into the mathematical algorithms of the MADM methodology. Seven criteria (twelve indicators) are used for evaluating alternatives that represent the characteristics of appropriate technologies for each scenario. The methodology developed efficiently identifies the appropriate technology for each of the scenarios.

For the “no scenario” case (equal weights for all indicators), it is difficult to identify the most appropriate wastewater treatment alternative. For the scenarios considered in the study, the alternatives are ranked according to the priorities of urban, suburban and rural areas. It should also be noted that it is not possible to achieve the optimal solution for each scenario because there are a finite number of alternatives available. Therefore, the best available solution has to be selected. TOPSIS mimics the nature of this type of environmental decision-making problem and is found to be efficient in identifying the best alternative for each of the scenarios.

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