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Technology assessment for wastewater treatment using multiple-attribute decision-making

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ABSTRACT

A framework for technology assessment for wastewater treatment is proposed in this work. A case study of technology selection for high rise buildings in urban centres of India is used for evaluation and to test this framework. The multiple-attribute decision-making technique is used for ranking the alternatives. The three most commonly used wastewater treatment technologies viz., activated sludge process (ASP), sequencing batch reactors (SBR) and membrane bio-reactor (MBR) are evaluated. Seven criteria having indicators derived from life cycle assessment (LCA), life cycle costing (LCC) and criteria accounting for resource constraints, robustness of the system and sustainability are used for the evaluations. The technology assessment framework used in this work will help identify appropriate wastewater treatment technologies for various decision-making situations encountered while managing wastewaters. Importantly, this study validates the theory that it is the decision situation which decides the appropriateness of the technology and not the technology itself. Hence, the definition of appropriate technology given by Murphy et al. [4] is more convincing for water and sanitation technologies.

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1. Introduction

Water resources management in the past few decades has focused on meeting needs of the community by directly harnessing natural resources. Newer approaches in water resources management incorporate concepts like sustainable development, life cycle assessment and public participation. Water recycling has been emerging lately as an attractive option where the current water supply through natural resources is already exhausted and cannot meet the demands of urban and industrial development.

Furthermore, wastewater management is one of the biggest challenges faced by developing countries like India. It is estimated that about 36,600 million litres per day (MLD) of domestic wastewater is generated from urban centres in India [1]. However, the treatment capacity available for domestic wastewater is only 11,500 MLD. These values show that, there is a big gap in the treatment needs for domestic wastewater. In the coming years, the government of India has a mandate to fill this gap through investing in wastewater treatment technologies.

In India, water resources have not been utilized efficiently. The available quantity of water is insufficient to cater to the human population in the entire country. For each type of use, the same quality of water (i.e. drinking quality of water) is used. The best management practice is to provide a different quality of water for various purposes. For example water used for toilet flushing or land irrigation can be easily obtained from treating sewage. The matter is more serious in this scenario as often municipalities choose the wrong technologies which impacts efficiency, cost and the appropriate water quality. Increasingly, metropolitan municipalities are gravitating toward multiple locations for the treatment of wastewater as opposed to the practice of pumping all the sewage to a centralized location and

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providing a mega treatment facility. It has been concluded by Arceivala and Asolekar [2] that the cost effectiveness of wastewater collection, transportation, pumping, treatment and disposal can in fact be optimized by offering treatment after the localized collection of wastewater (10–100 MLD capacity) through treatment plants planned all over landscape of large metropolitan area and the cluster of several suburban communities.

Recently in India, the advanced wastewater treatment technologies such as sequencing batch reactors (SBR) and membrane bio-reactor (MBR) are gaining preference. However, the treated water generated from these high-tech plants are disposed off in nearby surface water bodies. This good quality treated water could be easily put back into the urban water cycle by providing minimal further treatment along with disinfection. This situation suggests that there is a need for decision support to the urban local bodies (municipal corporations, municipal councils) and developmental authorities so that the appropriate kind of technology can be selected for a given situation and problem.

The eminent challenge in wastewater management lies in the selection of the best available technology for a particular type of wastewater treatment objective. The selection of wastewater treatment technology is a multicriteria analysis task. Many factors (criteria) are involved in the decision-making process, and data is available only for a few of these criteria. There can be many candidate technologies for treating particular types of wastewater. Therefore, selecting the “appropriate technology” is the biggest challenge faced by experts in the wastewater management.

The concept of “appropriate technology” was firstly introduced by E.F. Schumacher, a British Economist in his famous book *Small Is Beautiful* [3]. The early perception about appropriate technology was limited to include technologies which are small-scale, labor intensive, low capital investment per worker, energy efficient, environmentally sound, and controlled and maintained by the local community [4]. However, with the present development targets, it is essential to revisit the notion of appropriate technology and include some more properties or characteristics to this appropriate technology definition and theory.

Recently, Murphy et al. [4] presented a comprehensive approach for appropriate technology for water and sanitation in the developing world. Their study reported that in the context of water and sanitation, the definition of appropriate technology is not limited to the physical properties (referred to as “hard aspects”) of the technology but it also includes the knowledge transfer mechanisms, capacity building and communication methods as well as social, cultural, and gender implications of technology implementation (referred to as soft aspects). This study which expanded the theory of appropriate technology defined appropriate technology as a strategy that enables men and women to rise out of poverty and increase 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 friendly manner. Based on this theoretical foundation, the concept of appropriate technology can be further expanded beyond the conventional definition and it can be argued that it is not technology which is appropriate but rather the situation which determines the “appropriateness” of the technology [4]. This theoretical expansion is validated in the present study by developing a technology assessment framework for wastewater treatment.

A high-tech mechanized technology can be appropriate for a given situation depending upon the factors such as the technological level of the community, labor and resource availability. In the context of wastewater treatment technologies, the concept of appropriate technology needs to be understood more deeply and re-defined more clearly so that selection of technology will be more rational. The success of implementation and operation of public sanitation facilities including wastewater treatment plants depends upon many stakeholders such as community, urban local bodies and technical experts (who devise a treatment strategy for a particular situation).

This highlights the need to develop a decision support tool that can help decision-makers to select appropriate technology from available wastewater treatment technologies. The decision support tool should provide the rationale behind selecting the appropriate technology based on the decisive factors such as sustainability, life cycle assessment (LCA) and life cycle costing (LCC). The multicriteria decision-making techniques can be efficiently used to evaluate the alternatives.

1.1. Multiple-attribute decision-making application for wastewater treatment technology selection

Multicriteria decision-making (MCDM) deals with continuous and discrete problems encountered to select the best strategy or alternative. The MCDM methods use a structured and logical approach to model complex decision-making problems. Hwang and Masud [5] distinguish MCDMs into mainly two categories – multiple-attribute decision-making (MADM) and multiple objective decision-making (MODM). Discrete decision problems involving a finite set of alternatives are handled by MADMs. There are well-defined alternatives available in MADMs which have to be evaluated using a set of attributes. MODM deals with continuous decision problems involving an infinite number of feasible alternatives. In MODM, the alternatives are not predetermined; rather the alternatives have to be developed using MODMs. MODM methods are multiple objective mathematical programming models in which a set of conflicting objectives are optimized and subjected to a set of mathematically defined constraints. In the present study, the problem is of a discrete nature, hence the MADM approach is adopted to solve the problem.

MADM has wide applications in environmental decision-making problems. Kiker et al. [6] and Huang et al. [7] give a comprehensive review of application of multicriteria decision analysis in environmental decision-making. MADM approach has also been used to address the problem of wastewater treatment alternative selection. Tecle et al. [8] firstly applied MADM for selection of wastewater treatment alternative. Three MADM methods, namely, compromise programming (CP), corporative game theory (CGT) and ELECTRE-I were used for the analysis.

All three methods produced the same alternative as the most preferred alternative based on 10 criteria used in the study. This study does not take into consideration energy requirements and many other sustainability criteria for the selection. The Analytical Hierarchy Process (AHP) was used by Ellis and Tang [9] to build a hierarchy model to rank wastewater treatment alternatives which were tested using four wastewater treatment plant data [10]. Twenty criteria were used and eight alternatives were evaluated. These studies show that efforts have been made to address the problem of wastewater treatment alterative selection. However, the indicators or attributes derived from LCA and LCC have not been used in decision-making. There is no rational framework of technology assessment which will identify the appropriate technology for a variety of decision situations encountered while selecting wastewater treatment technologies.

1.2. Problem definition

The wastewater treatment technology selection is a multidimensional problem. The decision factors are chosen based on the technologies in question. These factors should truly quantify the appropriateness of the technology for the considered situation of decision-making. In this study, a framework for technology assessment for wastewater treatment technologies is developed. The framework will help in selecting the appropriate technologies for various situations encountered while managing wastewaters. A case study of technology selection for high rise buildings situated in the urban centres of India is analyzed. Due to increased growth in the urban centres in India there is fresh water scarcity. Therefore, it is becoming mandatory for high rise buildings to go for recycling of domestic wastewater and use it for the secondary purposes such as toilet flushing, car washing, fire fighting and air conditioning. The three most commonly used wastewater treatment technologies viz., the activated sludge process (ASP), sequencing batch reactors (SBR) and membrane bio-reactor (MBR), are evaluated for assessing appropriateness for this decision situation. The multiple-attribute decision-making technique is used for ranking the alternatives in the context of this decision situation. Seven criteria having indicators derived from life cycle assessment (LCA), life cycle costing (LCC) and criteria accounting for resource constraints, robustness of the system and sustainability are used in the evaluations. Table 1 gives the list of criteria used in this research along with respective indicators. The sustainability indicators and indicators quantifying the robustness of the system are also incorporated into the decision-making process.

2. Methodology

Wastewater management is a comprehensive process which includes identifying the need for the wastewater treatment, selecting appropriate technologies to meet the need, implementing the selected technology and making sure that the technology is operating to produce the desired results. In this study, a technology assessment framework is developed to address the problem of selecting appropriate technologies.

In India, technologies are selected based on past experience and there is no rational framework available to select the wastewater treatment technologies. Selection of appropriate technology is the first step toward achieving sustainability. The incorporation of aspects of sustainability in an environmental decision-making process is challenging because there are many methodological issues in quantifying sustainability. Various qualitative and quantitative criteria and attributes/indicators, which capture technical, economic, and societal priorities, have been developed by researchers to quantify the sustainability of technologies [11–14], which will help in making appropriate environmental choices.

Arceivala and Asolekar [2] outlined three key tests of ‘affordability, acceptability and manageability’, to be met by a process or treatment defined as “Appropriate Technology” for wastewater treatment. The following are the key tests:

1. The *Affordability criteria* addresses the community’s financial ability as well as the land and energy requirement availability with the community for which the treatment plant to be constructed.
2. The *Acceptability criteria* accounts for parameters such as treatment efficiency, performance of the technology, and operational issues (such as odor problems in the local vicinity).
3. The *Manageability criteria* accounts for factors such as the operation and maintenance of the plant and the required skill level of the plant operator.

In order to quantify the technologies on the basis of these three key tests, it is essential to incorporate newer elements of technology assessments such as LCA, LCC and the sustainability criteria. The proposed technology assessment framework for selection of appropriate wastewater treatment alternative is shown in Fig. 1. The first task in the technology assessment problem is to identify the criteria and their indicators based on which technologies will be evaluated. The selected criteria and indicators are then used to prioritize all the important characteristics of the technologies such as resources consumption, environmental footprint and sustainability.

To characterize the environmental performance of the technology, LCA is the best suited tool. LCA has been widely used for evaluations of the wastewater treatment technologies. LCA captures impacts associated with resource consumption and emissions caused by any given technology for treating the wastewater over the life cycle. However, it does not take into consideration any cost related criteria. Therefore, Life cycle costing (LCC) specifically deals with the cost issue. All the costs incurred over the life cycle of a technology such as capital cost and operation and maintenance costs can be represented by using a single indicator known as net present worth (NPW).

The sustainability criteria attempts to account for the local, regional priorities, and institutional aspects. This criteria also quantifies whether the technology is suitable for a given decision situation. Conventionally, sustainability is assessed using the following criteria (indicators): environmental (e.g., quality of effluent, quality of sludge), economic (e.g., capital costs, operation and maintenance

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

Sr no.	Criteria	Indicator	Weights[a]	ASP	SBR	MBR
1	Global warming[b]	Global warming potential (kg CO_2-eq./p.e.-year)	40	18.2	31.97	42.44
2	Eutrophication[b]	Eutrophication potential (kg PO_4^{3-}-eq./p.e.-year)	90	3.76	1.38	1.34
3	Life cycle costs[c]	Net Present Worth (Rs. lakh/MLD)	20	137	127	160
4	Land requirement	Land requirement (m^2/MLD)	90	1400	353	300
5	Manpower requirement for operation	Number (for operation of medium scale plant)	40	10	6	4
6	Robustness of the system[d]	Reliability	90	80	80	100
		Durability	40	80	60	60
		Flexibility	40	80	60	60
7	Sustainability[d]	Acceptability	20	30	30	30
		Participation	20	30	30	30
		Replicability	20	40	40	40
		Promotion of sustainable behavior	20	40	40	40

[a] Criteria weights are given using a cardinal scale of 0 and 100, with 0 being the lower preference and 100 the highest preference.

[b] Estimated using ISO 14040: 1997 [28] using CML 2 baseline 2000 methodology [29], only operation phase is considered for the analysis.

[c] Life cycle costs estimated as per the present worth method prescribed in IS 13174 [30].

[d] 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.

costs), and societal (e.g., public participation, acceptability) [11–14]. In the methodology proposed in this research, environmental criteria are substituted with LCA and economic criteria are substituted with LCC.

It is necessary to use a mathematical framework to aggregate the above criteria (indicators) and then rank the alternatives based on these criteria. MADM is the most widely used approach for processing such information. MADM deals with discrete problems where a finite set of alternatives are evaluated based on pre-defined criteria and indicators. Large numbers of MADM methods are available in the literature for ranking the alternatives such as the weighted sum method, the Analytical Hierarchy Process (AHP), compromise programming, technique for order preference by similarity to ideal solutions (TOPSIS), and outranking methods (ELETREE, PROMETHEE). A comprehensive review of MADM methods can be found in Hwang and Yoon [15]. The recent development and classification are reported by Figueira et al. [16].

TOPSIS was selected as the method to solve this decision-making problem because the available information on attributes is on a cardinal scale. Furthermore, the

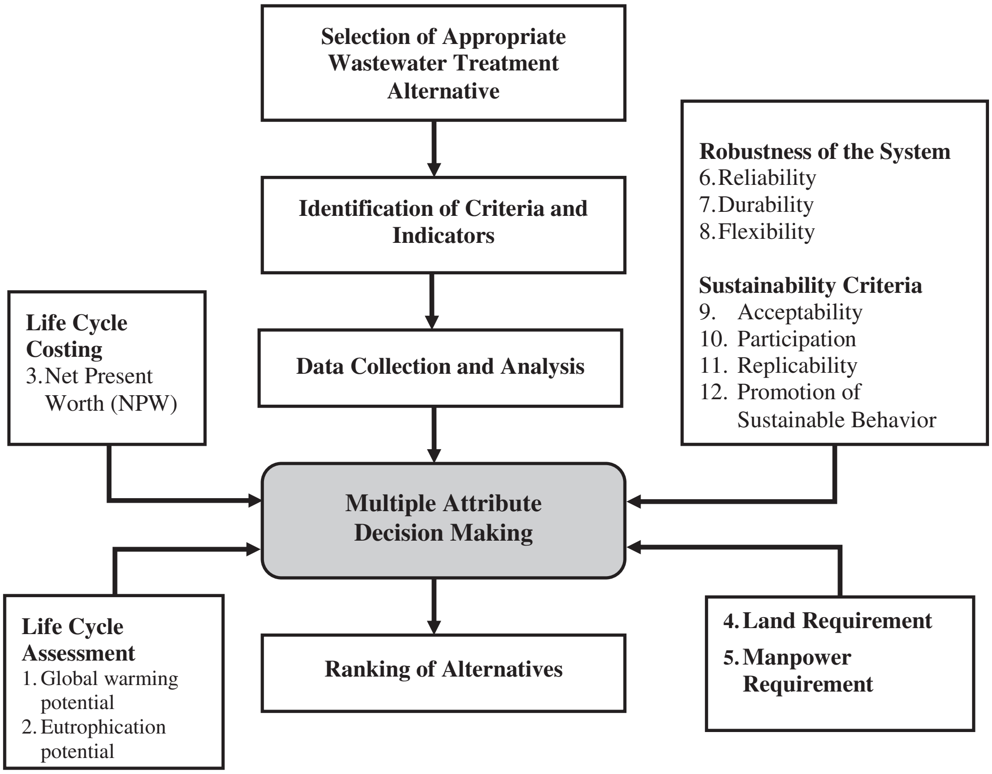

Fig. 1. Framework for selection of appropriate wastewater treatment technology.

TOPSIS algorithm can be readily implemented computationally and made available as a decision support tool for the end users – a critical issue in the decision-making process. The target end users may be engineers from urban local bodies, officials from developmental authorities, policy makers, and planning officials.

TOPSIS ranks or scores a finite number of alternatives $A_i = (A_1, A_2, \ldots, A_m)$, based on a set of attributes/criteria/indicators, $X_j = (X_1, X_2, \ldots, X_n)$. The information available from the decision-makers can be represented in the form of matrix called a decision matrix which is shown below.

$$\begin{array}{lccccccccc}
 & & & & \textit{Criteria/Attributes} & & & & \\
 & & X_1 & X_2 & X_3 & \cdots & X_j & \cdots & X_n \\
 & A_1 & x_1(a_1) & x_2(a_1) & x_3(a_1) & \cdots & x_j(a_1) & \cdots & x_n(a_1) \\
\textit{Alternatives/Options} & A_2 & x_1(a_2) & x_2(a_2) & x_3(a_2) & \cdots & x_j(a_2) & \cdots & x_n(a_2) \\
 & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
 & A_i & x_1(a_i) & x_2(a_i) & x_3(a_i) & \cdots & x_j(a_i) & \cdots & x_n(a_i) \\
 & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
 & A_m & x_1(a_m) & x_2(a_m) & x_3(a_m) & \cdots & x_j(a_m) & \cdots & x_n(a_m)
\end{array} \qquad (1)$$

After formulation of the decision matrix, it is necessary to transform the attribute data to take care of any qualitative attributes and negative values. Qualitative indicators are transformed using a cardinal or ordinal scale. Many of the compensatory MADM methods such as maximin, simple additive weighting, TOPSIS, ELECTRE require the normalization of data. Many normalization methods to obtain normalized decision matrix are available for different MADM methods and also to deal with different types of attributes [15,17]. In the present research, the vector normalization method is used. Furthermore, a weighted normalized matrix is obtained by multiplying the weights of each attribute with attribute scores. Weights of the attributes can be given using the cardinal or ordinal scale by decision-makers based on their preferences or importance for various attributes.

After developing a weighted normalized decision matrix, the algorithm for TOPSIS was applied. Hwang and Yoon [15] extended the theory of ideal solutions [18,19] and proposed TOPSIS. This method is based on the concept that the chosen alternative should have the shortest distance from the positive ideal solution and longest distance from negative ideal solution.

In real decision-making situations, it is difficult to identify or envisage the true ideal and non-ideal solutions. Therefore, Zeleny [18,19] proposed to use the best and worst values of the scores of the alternatives for each of the criteria as ideal and non-ideal solutions. This is known as "displaced ideal" approach and used by many researchers [20,21]. Mathematically it is represented as follows:

$$\textit{positive ideal solution}(PIS),\ x_{j,b} = \textit{best value of } x_{ij},\ \forall j = 1,\ldots,n \qquad (2)$$

$$\textit{negative ideal solution}(NIS),\ x_{j,w} = \textit{worst value of } x_{ij},\ \forall j = 1,\ldots,n \qquad (3)$$

TOPSIS uses a unique approach for selecting the best alternative. The alternative which is nearest to positive ideal solution, [i.e., the point where $D_i^+ = \sqrt{\sum_{j=1}^{n}(x_{ij}-x_{jb})^2}$, $\forall\ i = 1,\ldots,\ m$ is minimal], and farthest from the negative (non-ideal) solution, [i.e., the point where $D_i^- = \sqrt{\sum_{i=1}^{n}(x_{ij}-x_{jw})^2}$, $\forall\ i = 1,\ldots,m$, is maximum] will be preferred the most. The alternative with the highest relative closeness (R_i^*), estimated as $R_i^* = D_i^-/(D_i^+ + D_i^-)$ will be chosen as the most preferred alternative.

3. Case study of wastewater treatment technology selection for high rise buildings in urban centres of India

India is developing fast with maximum growth at urban centres. In the year 2001, 27.3% of India's population (about 286 millions) were staying in urban areas. The recent census of 2011 reported that, 31.16% of India's population (approximately 377 million people) resided in urban areas [22]. This increase in population exerts tremendous pressure on resource consumption as well as on waste management. One of the solutions is to go vertical i.e. build high rise structures. Many experts argue about broadening the roads, adding some more flyovers, improving and modernizing water supply schemes or installing collection, treatment and disposal systems for urban sewage and garbage. In India, the current trend is to build vertically. Therefore, many high rise building are being constructed in cities and metros. High rise buildings are defined as the structures having more than 21 stories or having a height of more than 70 m.

The construction of more high rise buildings leads to a higher population density in the city and the urban local bodies needed to increase the water supply. To handle this problem, experts are advising urban local bodies in India to go for the mandatory recycling of municipal wastewater generated by high rise buildings [23]. This created a need for a technology assessment framework to select the right kind of technologies having the potential to produce treated water that can be successfully recycled in the high rise buildings. Another reason to require mandatory recycling is that surface water bodies in urban region are increasingly stressed and have become eutrophic, and hence the practice of disposing treated wastewater into these natural receptors needs to be abandoned.

This case study exactly represents the decision-making situation in an urban area where the objective is to recycle treated wastewater, which is the most intended practice in India. The treated wastewater can be given further treatment and used for various applications such as toilet flushing, gardening, car washing, fire fighting and air conditioning. Government authorities are recommending that the sewage generated from the high rise buildings not be discharged directly to municipal sewer lines and instead adequately treated within the high rise buildings premises [23]. Biochemical oxygen demand (BOD) and number of total coliforms in the treated water primarily define the treatment level of wastewater. BOD is a measure of amount of oxygen consumed by microorganisms while decomposing organic matter. The BOD test is carried out for a specified period of time and at a particular temperature (usually 5 days and 20 °C) and it is expressed in mg/L. The total coliforms group includes both fecal and environmental species and includes microorganisms that can survive and grow in water. The total coliforms are expressed in terms of most probable number (MPN) of organisms per 100 mL of sample. Total coliforms test is used to assess efficiency of disinfection and indicate the overall cleanliness and integrity of distribution systems. The recommended values for treated water to be recycled in the high rise buildings of these two parameters are BOD <5 mg/L and total coliforms less than 2 MPN/100 mL [23].

The decision in this case study represents the commonly encountered situation in India. Providing water for various purposes in urban areas such as toilet flushing, air conditioning, landscape irrigation, fire protection and car washing is a challenging task. By adopting the right kind of technologies which will produce the desired quality of treated water, this water demand can be met. The three technologies which are more suitable for this decision situation are ASP, SBR and MBR. These technologies are mechanized systems having the potential to produce a good secondary level of treated effluent. MBR produces exceptional high quality effluent which can be disinfected and directly used for various purposes mentioned above. ASP and SBR produce good quality effluents. However, the effluent requires further treatment such as pressure sand filtration and disinfection to meet the quality objectives of the recycling water.

The criteria scores are estimated based on the primary and secondary data collected during the field visits made to the actual field-scale wastewater treatment plants. The criteria weights are given considering this decision situation of providing recycle wastewater to high rise building in urban areas of India. The appropriate technology for this decision situation should have low land requirements, less manpower requirements, high reliability and at the same time should produce good effluent quality.

The criteria and indicators to be used for the evaluation should be judicially selected. Too many indicators may dilute the purpose and too less in number, may be inadequate to convey the message [24]. Seven criteria were used for evaluating the technologies. The first two criteria, climate change and eutrophication have Global Warming Potential (GWP) and Eutrophication Potential (EP) as indicators, respectively. These indicators are derived from LCA. The LCA methodology used in this research is per the ISO 14040 series (ISO, 1997) as described in the operational guide to ISO 14040 by Guinee et al. (2001). The globally applicable CML 2001 characterization factors were obtained from the Ecoinvent database v2.1 [25]. The GWP primarily represents energy consumption during the operation phase of the plant over the life cycle. Similarly, EP represents the performance of the plant which is estimated based on the release of organics and nutrients in the treated wastewater. The next criterion is derived from LCC carried out as per the present worth method, prescribed in Indian Standards, IS 13174, Part II [30]. The LCC resulted in a single indicator, net present worth (NPW) which represents the capital cost (which includes costs incurred for civil works during construction of the plant and electromechanical equipments as well as includes the cost of land) and operational and maintenance (O&M) costs of the plant. O&M costs include costs for energy, chemicals, manpower. The land requirement (in m^2) and the number of people required for the operation of the plant represent the constraint from the resources point of view.

The next set of indicators (reliability, durability and flexibility) quantifies the robustness of the plant and hence is grouped under one criteria identified as the “Robustness of the System”. The sustainability of the wastewater treatment alternative has been quantified using four indicators (acceptability, participation, replicability and promotion of sustainable behavior). All of these seven qualitative indicators were given scores for each technology based on the experience of these technologies in the Indian context. Finally, while applying MADM methods it is necessary to identify the types of attributes (i.e., cost or benefit types) and accordingly normalize the attributes scores [15]. In this study the GWP, EP, NPW, land requirement and manpower requirement are considered as cost attributes. The remaining seven qualitative indicators were benefit type attributes.

The most commonly used MADM methodology, TOPSIS was used to evaluate these three alternatives for the decision situation described here. The criteria and respective indicators used for the evaluation are shown in Table 1. The criteria score and criteria weights are also given in Table 1. The Microsoft Excel based VBA (visual basic for applications) programme was used for the computation. The scores of the each of alternatives and their ranking are given in Table 2.

4. Results and discussion

As shown in Table 2, MBR is ranked as the most preferred alternative (with a score of 0.8144) while SBR holds the second rank (with score of 0.8066). The ranking is consistent with a decision situation where a wastewater treatment plant location is in the urban area having land

Table 2
Scores and ranking generated using TOPSIS.

Alternative	Score (R_i^*)	Rank
MBR	0.8144	1
SBR	0.8066	2
ASP	0.1849	3

constraints. In this case, the treated water has to be recycled. Therefore, it is expected that the quality of treated water should be better. ASP is identified as least preferred alternative owing to the fact that it has higher land footprint compared to MBR and SBR.

In urban centres, land availability is a constraint and definitely no developer is willing to trade land for utility services. Another reason ASP is not preferred is that a lower quality of effluent is produced from ASP than SBR and MBR. The cost analysis of the technologies shows that MBR has higher capital and O&M costs than SBR and ASP. However, MBR is the preferred alternative for the decision situation since the capital funding availability is not an issue for the high rise buildings project. These projects have very high investment (about 200 million US dollars) and utility services like wastewater treatment will not affect the project economics.

The multicriteria decision-making approach proposed in this work helps urban local bodies to screen the technologies available in the market. The decision-making method clearly identifies the most appropriate alternative among the available ones. The added advantage of this method is that it gives scores which suggest how much each of the technologies considered is preferred compared to the other alternatives. This approach will help urban local bodies to efficiently manage wastewater through selecting appropriate technologies.

The MADM method used in this work is TOPSIS. The method is based on a compensatory approach and utility is estimated by comparing each alternative directly depending on data in the decision matrices and weights. The method assumes that each attribute has a monotonically increasing or decreasing utility. The best alternative is identified by considering both the positive ideal solution and negative ideal solution. The disadvantage or unfavourable value in one attribute is offset by an advantage or favourable value in some other attribute. This mimics human thinking where humans always think of both positive and negative qualities of the alternative and choose the best available among all. The geometric concept of distance measure is used in TOPSIS as a proxy for human preference. This approach is suitable for the decision situation with regard to wastewater management.

According to Kim et al. [26] and Shih et al. [17], advantages of TOPSIS are:

(i) a sound logic that represents the rationale of human choice;
(ii) a scalar value that accounts for both the best and worst alternatives simultaneously;
(iii) a simple computation process that can be easily programmed into a spreadsheet; and
(iv) the performance measures of all alternatives on attributes can be visualized on a polyhedron, at least for any two dimensions.

These advantages make TOPSIS a major MADM technique as compared with other related techniques. It has been reported by Zanakis et al. [27] that TOPSIS has the fewest rank reversals among the eight similar MADM approaches. TOPSIS has disadvantages like not providing weight elicitation and consistency checking for judgments.

The technology assessment framework developed in this work is simple and easy to implement. This approach can easily be applied to a variety of decision-making situations encountered while managing wastewaters in India. The potential areas of applications are identifying appropriate technologies for rural areas, city centres, commercials complexes, industrial complexes, academic institutions. Each of these areas of application have there own priorities and can be taken into account using criteria such as land availability, financial budget, treated water quality objectives and technological savviness of the community. The appropriate criteria and indicators along with their preference weights will rationally select the appropriate technology through the proposed methodology.

5. Conclusions

This research focuses on the development of a framework for technology assessment for wastewater treatment alternatives for high rise buildings in India. Two criteria were derived from LCA, and one criterion was derived from LCC. A set of criteria accounting for resource constraints, robustness of the system and sustainability were used for the evaluations. Among the three technologies (ASP, SBR and MBR) evaluated, MBR was identified as the most preferred alternative for the wastewater recycling in high rise buildings because MBR has lower land requirements, a lower manpower requirement, higher reliability and at the same time can produces good effluent quality.

The technology assessment methodology developed in this work can be applied to various decision-making situations encountered while managing wastewater. The TOPSIS method, used for ranking, was simple to understand and easy to implement in a user-friendly computing environment. TOPSIS was suitable for the decision situation considered in this work since the decision-makers in real-life always consider both the aspects (positive and negative) of the alternatives and select the best available alternative.

The findings shows that technologically advanced alternatives, such as MBR, can be appropriate for the decision situation considered in this study. This validates the theory that it is the decision situation which decides the appropriateness of the technology and not the technology itself. Hence, the definition of appropriate technology given by Murphy et al. [4] is more convincing for water and sanitation technologies. Appropriate technologies are in fact needed to be considered strategically. The implementation of these technologies will help developing countries to achieve sustainable development. This study, while limited through the application of this methodology to just one case, validates the expansion of appropriate technology theory and also provides a practical tool for decision-makers who need to make critical decisions regarding wastewater treatment technology selection.

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