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Original Research Paper

Performance Evaluation of Sewage Treatment Plants (STPs) in Multistoried Buildings

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ABSTRACT

The enormous generation of wastewater in a relatively small area i.e., in a multistoried building, makes mandatory to have a mini Sewage Treatment Plant (STP) inside the premises itself. In a developing country like India, where competition for freshwater supplies will continue to increase, it is better to reuse the treated wastewater to meet the demand. Many treatment technologies are available currently, hence it is essential to find an appropriate technology for treating the wastewater. This study is to know about the different STP's installed in the multistoried buildings, to analyse the performance of each technology, its design concepts and the life cycle costing of each system. Four technologies, namely Extended Aeration, SBR, MBR and FBBR were selected for the study. From the study, it was observed that, extended aeration is a preferred technology as per as the efficiency of the plant in treating the wastewater. From this study, it is concluded that, even though efficiency of the system is very important, a decision is made in finding an appropriate technology based on its relative closeness to its both, positive ideal solution and negative ideal solution (using TOPSIS) and found that SBR is a best technology based on the criteria selected.

INTRODUCTION

The development of the high-rise buildings has followed the growth of the city closely. The process of urbanization, that started with the age of industrialization, is still under progress in developing countries like India. Industrialisation causes migration of people to urban centres where job opportunities are significant. The land available for buildings to accommodate this migration is becoming scarce, resulting in a rapid increase in the cost of land. The result is multistorey buildings, as they provide a large floor area in a relatively small area of land in urban centres.

In order to check rampant tapping of groundwater and re-use wastewater generated by households, Water Supply and Sewerage Board officials have to construct the mini Sewage Treatment Plants (STPs) on the premises of multi-storied buildings. Even after the worldwide successfulness of centralized wastewater treatment, the concept has shown its limits in some developing and transition countries like India, especially for the fast-growing cities with limited water resources the concept is now being challenged (Jahanshahloo et al. 2006). Decentralized sanitation with its modular character is considered to be an effective way in tackling rapid urban growth (Gallego et al. 2008) and with its potential to reuse the treated wastewater within the premises.

Sewage treatment plants (STP), which were once regarded as an add-on facility and adopted by a few building complexes in the city fringes (EPA 1997), has now become mandatory in large scale constructions that lack sewerage network. The second master plan has made STP mandatory in residential developments of more than 50 houses or commercial area of 2,500 sqm.

Several new companies have now entered the arena offering low cost maintenance technologies to treat sewage (EPA 1997). The builders have a number of options to choose from according to their requirement. More companies have now begun to take up annual maintenance of the products.

MATERIALS AND METHODS

Wastewater management is a comprehensive process which includes identifying the need for the wastewater treatment, selecting appropriate technology 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 sustaina-bility (Farabegoli et al. 2009).

Study Area

1st Area:

Location :	Guduvancherry
Designed Capacity/day:	580 KLD
Actual treatment/day :	450 KLD
Existing population :	1500
Sewage Treatment Technology:	Extended Aeration

2nd Area:

Location :	Semmancherry
Designed Capacity/day:	30 KLD
Actual treatment/day :	28 KLD
Existing population :	192
Sewage Treatment Technology:	FBBR

3rd Area:

Location :	Perungudi
Designed Capacity/day:	50 KLD
Actual treatment/day :	43 KLD
Existing population :	288
Sewage Treatment Technology:	SBR

4th Area:

Location :	Nolambur
Designed Capacity/day:	120 KLD
Actual treatment/day :	112 KLD
Existing population :	750
Sewage Treatment Technology:	MBR

Performance of the Different Treatment Units

Method of analysis: The performance of the treatment schemes was evaluated by monitoring the quality of the raw wastewater and treated wastewater. The wastewater analysis includes COD (open reflux method), BOD (IS:3025-Part 44) and TSS (gravimetric method).

Robustness and sustainability of the system: The flexibility, acceptability, replicability of each technologies was given by the STP installers based on their experience.

Life cycle costing (LCC): Life cycle costs having net present worth (NPW) as an 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. The following points are necessary to determine the present worth of a system:

1. Total capital cost (civil, electrical and mechanical and land cost).
2. Number of years it would take to complete all the capital works and the expenditure in each year.
3. Operation and maintenance cost in the first year after start up and the escalated cost per year thereafter, depending on the expected inflation rates from year to year.
4. Discounting factor to convert a later sum of money to its net present value (NPV).
5. Life of the plant and its salvage value at the end of its life.

Assumptions made in the life cycle costing analysis of STP: The following assumptions were made in the life cycle costing of the system:

1. The life of all the four STP technology is assumed as 20 years.
2. The inflation rate in India was recorded as 8.79% in January 2014 and the forecast inflation rate in February 2014 as 7.88%, as reported by the ministry of commerce and industry. Hence, an average inflation rate of 8.3% is assumed as an inflation rate for the 20 years for calculating the Net Present Value(NPV).
3. Discounting factor is assumed as 12% per year.
4. All the four plants were assumed to be constructed in the same area having same land cost per sqm.
5. All the four plants were assumed to be constructed within one year.
6. All the four plants were assumed to use the same grade of concrete for the construction purpose.
7. All the four plants were assumed to have a same make pumps, blowers etc.
8. The salvage value of the plant is neglected.

Multiple attribute decision making (MADM): Decision making problem is the process of finding the best option from all of the feasible alternatives. In almost all such problems the multiplicity of the criteria for judging the alternatives is pervasive. There are many methods available for making complex decisions and choosing the most preferable choice with multi criterias or multi attributes, like Analytic Hierarchy Process (AHP), ELECTRE (Elimination and Choice Translation Reality), Expected Utility Theory, Goal Programming, Goal Attainment, Hierarchical Tradeoffs, Interactive Simple Additive Weighting (SAW), Linear Assignment Method, LIMAP (Linear programming for Multidimensional Analysis of Preference), Multi-attribute Utility Theory, Multi-dimensional Scaling, Parametric Method, Permutation Method, Physical Programming, SAW, and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution). Among these, TOPSIS is selected as a multi criteria decision making tool.

***TOPSIS (Technique for Order Preference by Similarity to Ideal Solution)*:** The basic concept behind the TOPSIS is displaced ideal point from which the compromise solution has the shortest distance and further propose that the ranking of alternatives will be based on the shortest distance from the (positive) ideal solution (PIS) and the farthest from the negative ideal solution (NIS). TOPSIS simultaneously considers the distances to both PIS and NIS, and a preference order is ranked according to their relative closeness, and a combination of these two distance measures.

TOPSIS has been deemed as one of the major decision making techniques within the Asia Pacific region. In recent years, TOPSIS has been successfully applied to the areas of human resources management, transportation, product design, manufacturing, water management, quality control, and location analysis. In addition, the concept of TOPSIS has also been connected to multi-objective decision making and group decision making (Shih et al. 2007).

Steps involved in TOPSIS: Topsis requires a decision matrix as the input data and relative weights to represent the DM's (Decision makers) preference information. Here the DM's who provide the preference structure, are "off line" (Sun & Li 2007). The multi criteria decision making problem is expressed in matrix format as:

	C_1	C_2	…	C_n
A_1	X_{11}	X_{12}	…..	X_{1n}
A_2	X_{21}	X_{22}	…..	X_{2n}
A_m	X_{m1}	X_{m2}	…..	X_{mn}

$$W = [w_1, w_2, \ldots w_n]$$

where A1, A2, . . . , Am are possible alternatives among which decision makers have to choose; C1, C2, . . . , Cn are the criteria with which the alternative performance is measured; x_{ij} is the rating of alternative A_i with respect to criterion C_j; w_j is the weight of criterion C_j. The procedure of TOPSIS can be expressed in a series of steps:

Step 1: Create decision matrix, with the columns being different criteria and the rows being different alternatives.

Step 2: The decision matrix to be normalized.

Step 3: The normalized matrix to be further weighted by being multiplied by the weights given by the decision makers.

Step 4: The ideal solution will be formed.

Step 5: The relative closeness of alternatives to the ideal solution is calculated.

Step 6: The alternatives will be ranked according to their closeness to the ideal solution.

Ranking the alternatives using TOPSIS: Following are the input data required for ranking the alternatives:

List of Alternatives

1. Extended Aeration (EA)
2. Sequencing Batch Reactor (SBR)
3. Membrane Bio Reactor (MBR)
4. Fluidized Bed Bio Reactor (FBBR)

List of Attributes

i. Benefit Attributes
   1. Efficiency of the plant
   2. Replicability of the technology
   3. Flexibility of the technology
   4. Acceptability of the technology

ii. Cost Attributes
   1. Land area required for the plant construction
   2. Civil work cost for the plant construction
   3. Electrical & mechanical equipment cost for the plant
   4. Operation and maintenance work cost

RESULTS AND DISCUSSION

General: In the present study, investigations were carried out to analyse the performance of four STPs commonly in practice in the multistoried buildings. The results obtained from the analysis are discussed in detail in this section. The STPs are provided to remove the suspended solids, floating particles and to reduce the biological and chemical oxygen demand (BOD and COD). Tertiary treatment is provided after sewage treatment plant to treat the sewage to meet the disposable quality of the pollution control board (PCB) norms. Sewage treatment plants are installed in multistoried buildings to treat the sewage generated from their bathroom and toilet units to meet the standards prescribed by the Tamil Nadu Pollution Control Board.

Design criteria: The design basis adopted by the STP installers for the residential wastewater characteristics were: 300mg/L for BOD, 600-700mg/L for COD and 200-300 mg/L for TSS. And the treated water characteristics were <20mg/L for BOD, <250mg/L for COD and <10mg/L for TSS.

It was found that there is a large deviation from the raw water characteristics taken for design from the actual value of the raw water characteristics after analysis. But there is no adverse impact, because the actual values were lesser than the adopted values for design, showing that the design basis is overestimated compared with the actual values to meet the unexpected peak values.

Wastewater quality analysis: The wastewater analysis report is given below. It was found that the outlets from all the plants were within the limits prescribed by the Tamil Nadu Pollution Control Board for inland disposal (30mg/L

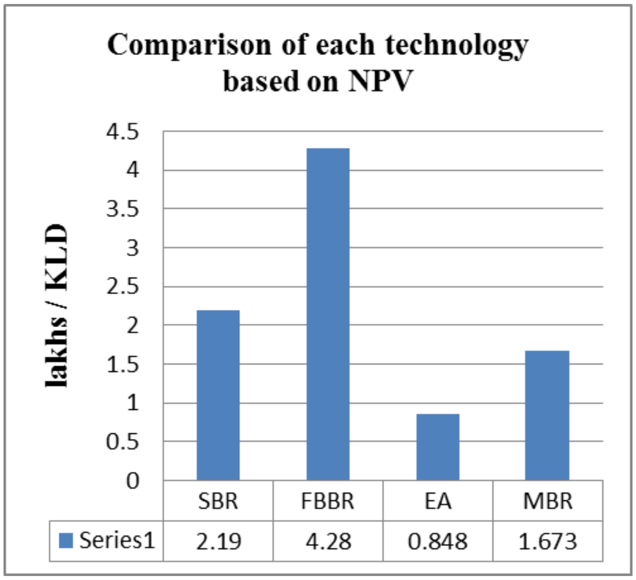

Fig. 1. Comparison of the net present values of the four sewage treatment plant. This is the actual value of the plant in lakhs for treating one KLD of wastewater.

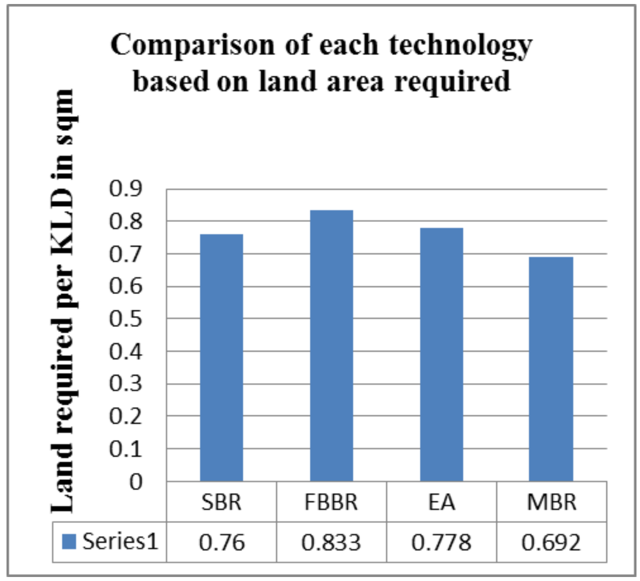

Fig. 2. The land area required by the four sewage treatment technologies. Clearly this shows the actual area required for treating one KLD of wastewater including the land required for laying roads for accessing purpose.

for BOD, 250mg/L for COD and 100mg/L for TSS) (CPHEEO 2012).

It was found that the Extended Aeration treated water quality was best compared with the other three STPs. The overall efficiency of the plants was 92% - Extended Aeration, 88% - MBR, 84% - SBR, and 70% - FBBR.

Life cycle costing analysis: The life cycle costing of the plant was worked out based on the NPV. The Net Present Value (NPV) (Arceivala & Asolekar 2006) of each plant was calculated for the treatment of one KLD of wastewater. Based on this, the order of preference of the appropriate technology is: Extended Aeration (Rs.0.848 lakhs), MBR (Rs.1.673 lakhs), SBR (Rs.2.190 lakhs), FBBR (Rs.4.280 lakhs) as shown in the Fig.1.

The land required for each plant in sqm for treating one KLD of wastewater is: MBR (0.692 sqm), SBR (0.76 sqm), Extended Aeration (0.778 sqm), FBBR (0.833 sqm) as shown in the Fig. 2. As per the land requirement is concerned, MBR technology requires less footprint compared to others. Even though fill, react, settling and decanting taking place in the same tank in SBR technology, SBR technology comes next to MBR because SBR technology requires a tertiary treatment after the secondary treatment (Cases et al. 2011), but the MBR technology does not require any tertiary treatment. FBBR technology requires more footprint compared to others because it requires a separate secondary clarifier and also a separate sludge digestion tank since complete digestion is not taking place in the aeration tank. Hence if the availability of land is the only constraint, adopting MBR technology may be appropriate for that scenario.

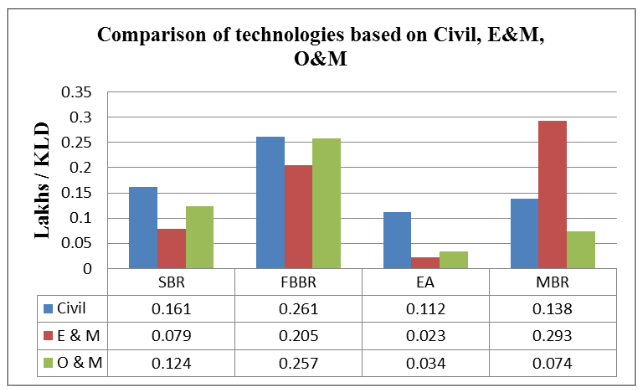

Fig. 3 Civil work cost, E&M cost and O&M cost of the four sewage treatment plants were compared for treating one KLD of wastewater.

The civil work cost of each plant for treating one KLD wastewater is: Extended Aeration (Rs.0.112 lakhs), MBR (Rs.0.138 lakhs), SBR (Rs.0.161 lakhs), FBBR (Rs.0.261 lakhs) . As far as the civil work cost is concerned Extended Aeration requires less cost compared to others. Next to EA, MBR technology requires less cost. FBBR requires very high cost compared to others because it requires a separate sludge digestion tank for digestion of the sludge. Hence Extended Aeration is a preferable technology as per as the civil work cost is concerned.

Table 1: Decision matrix.

Alternative	Criteria							
	Efficiency	Rep VG-VP	Flex VG-VP	Accep VG-VP	Land / KLD in Sqm	Civil/KLD in lakhs	E&M KLD in lakhs	O&M KLD in lakhs
EA	0.92	8.5	7.5	7.5	0.778	0.112	0.023	0.034
SBR	0.84	9	9	8	0.760	0.161	0.079	0.124
FBBR	0.70	8.5	7.5	7.5	0.833	0.261	0.205	0.257
MBR	0.88	8	8	8	0.692	0.138	0.293	0.074

Table 2: Scores and ranking generated using TOPSIS.

Alternative	Score	Rank
SBR	0.944	1
MBR	0.347	2
EA	0.265	3
FBBR	0.22	4

The electrical and mechanical equipment cost of the plant for treating one KLD wastewater is: Extended Aeration (Rs. 0.023 lakhs), SBR (Rs. 0.079 lakhs), FBBR (Rs. 0.205 lakhs), MBR (Rs. 0.293 lakhs). As far as the electrical and mechanical equipment cost is concerned Extended Aeration technology requires less cost compared to others. Next comes the SBR technology. MBR technology requires very high cost because of the membranes. Hence, EA or SBR technology is preferred as per the E & M cost is concerned.

The anual O & M cost of the plant for treating one KLD wastewater is: Extended Aeration (Rs. 0.034 lakhs), MBR (Rs. 0.074 lakhs), SBR (Rs. 0.124 lakhs), FBBR (Rs. 0.257 lakhs) as shown in the Fig. 3. As far as the annual O & M cost is concerned, Extended Aeration requires less cost compared to others followed by MBR technology. FBBR technology requires very high cost compared to the other technologies. Hence, as far as annual O & M cost is concerned, EA and MBR technologies are preferred.

Multiple attribute decision making: Technology assessment of wastewater treatment alternatives for high rise buildings in India based on two criteria were derived from LCA and LCC. A set of criteria accounting for resource constraints, robustness of the system and sustainability were used for the evaluation. Among the three technologies (ASP, SBR, MBR) evaluated, MBR was identified as the most preferred alternative (with a score of 0.8144) while SBR holds the second rank (with a score of 0.8066), for the wastewater recycling in high rise buildings, because MBR has lower land requirement, a lower manpower requirement, higher reliability and at the same time can produce good effluent quality (Kalbar et al. 2012).

This study shows that SBR is ranked as the most preferred alternative (with a score of 0.944) while MBR holds the second rank (with a score of 0.347) as shown in Table 2.

A matrix (Table 1) was formed by using the wastewater quality analysis results, LCC of the system, and the ratings given by the STP installers for the flexibility, replicability and acceptability of the system. The ranking of these alternatives was calculated based on the weights given by the decision makers for each criteria selected for analysis.

The difference in the order of preference of the technology is due to the different criteria selected and weightage given by the decision makers. Also, in Chennai, SBR is preferred to MBR (Lin & Cheng 2001) because of the higher capital cost and the O&M cost. FBBR is identified as the least preferred alternative owing to the fact that it has a higher land foot print area compared to others, because it requires separate clarifier and digestion tank for settling and digestion of sludge, and also, it produced lower quality effluent.

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 attributes.

Based on the results, it was found that SBR has the shortest distance to the positive ideal solution, thus, it is the best alternative to be installed. The order of preference of the technology is: SBR > MBR > EA > FBBR.

CONCLUSION

Now-a-days separate STP inside the premises is a must for a high rise building or multistorey building. In any sewage treatment plants, the designed quantity of wastewater and maintaining the treated water quality standards are very important for its reuse purposes like gardening, car washing, flushing etc., which do not require potable water quality. The conclusion is made not only considering the benefits of the system, but it is made by calculating its relative closeness from its positive ideal solution and the negative ideal solution and the study reveal that SBR (Sequencing Batch

Reactor) is the most appropriate technology for the multistoried buildings.

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