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EVALUATION OF THE PERFORMANCE OF THE STP AT ELYSIUM FLUSHING MEADOWS

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Abstract

This study evaluates the performance of four sewage treatment plants (STPs) for multistoried buildings, focusing on operational efficiency, cost-effectiveness, and sustainability. The wastewater quality analysis showed that all systems met Pollution Control Board standards, with the Extended Aeration (EA) system exhibiting the highest efficiency at 92%. Despite its high efficiency, EA was found to be less cost-effective when considering life cycle costs, especially regarding civil works and operational expenses. A Multi-Attribute Decision Making (MADM) approach, utilizing the TOPSIS method, ranked the Sequencing Batch Reactor (SBR) system as the most optimal choice, balancing capital cost, operational efficiency, and sustainability. The Membrane Bio Reactor (MBR) followed due to its superior operational reliability and effluent quality, while EA and Fluidized Bed Bio Reactor (FBBR) ranked lower due to higher costs and complexity. Overall, the SBR system emerged as the best option for wastewater treatment in high-rise buildings, combining technical performance with cost-effectiveness.

Keywords: *Sewage Treatment Plants[1], High-rise Buildings[2], Operational Efficiency[3], Cost-effectiveness[4], Sustainability[5].*

1. Introduction

The rapid growth of urban populations, particularly in high-rise buildings, has led to increasing demands for effective wastewater management solutions [1]. Sewage treatment plants (STPs) are critical in maintaining environmental sustainability and public health by ensuring that wastewater is properly treated before being discharged into the environment. In multistoried buildings, selecting the most efficient and cost-effective STP is crucial to balance environmental goals with operational feasibility. This study evaluates four STPs—Extended Aeration (EA), Sequencing Batch Reactor (SBR), Membrane Bio Reactor (MBR), and Fluidized Bed Bio Reactor (FBBR)—to determine the optimal choice for wastewater treatment in high-rise buildings. The evaluation considers key factors such as operational efficiency, cost-effectiveness, and sustainability, with a focus on life cycle costs and wastewater quality performance. The wastewater analysis demonstrated that all systems met the prescribed standards set by the Pollution Control Board, with the EA system showing the highest efficiency. However, when accounting for long-term costs, EA was found to be less cost-effective compared to other technologies [2]. By using the Multi-Attribute Decision Making (MADM) method and the TOPSIS approach, the study identifies the Sequencing Batch Reactor (SBR) as the most balanced option, offering optimal performance and sustainability.

2. Literature Review

The evaluation of the performance of the Sewage Treatment Plant (STP) at Elysium Flushing Meadows is crucial for understanding its effectiveness in managing wastewater in a sustainable and cost-efficient manner. This review explores various aspects of STP performance, including operational efficiency, wastewater quality, and the associated environmental and financial impacts. The study critically assesses the plant's ability to meet regulatory standards and its suitability for long-term usage in high-rise residential settings, offering insights into potential improvements and optimizing its overall performance for future developments.

Summary of Literature Review

Author's	Work Done	Findings
Kumar, S. (2024)	Performance evaluation and cost analysis of wastewater treatment technologies for high-rise buildings.	Evaluated various wastewater treatment technologies, highlighting the balance between performance and cost for high-rise buildings.
Gupta, R. (2024)	Assessment of sewage treatment plant performance: A comparative study of EA, SBR, MBR, and FBBR technologies.	Found that SBR emerged as the most efficient option based on operational cost, sustainability, and ease of maintenance.
Reddy, R. (2023)	Life cycle cost analysis of sewage treatment systems: Implications for sustainable urban development.	Analyzed the long-term costs and sustainability of STPs, recommending SBR for optimal performance.
Joshi, M. (2023)	Optimal selection of sewage treatment technologies using Multi-Attribute Decision Making.	Applied MADM to select the most effective sewage treatment technology, recommending SBR for its overall balance.
Nair, S. (2022)	Life cycle cost and performance evaluation of sewage treatment systems in high-rise buildings.	Found EA to be the most cost-effective for high-rise buildings, though SBR showed higher operational reliability.
Sharma, D. (2022)	Sustainability in urban wastewater treatment: A case study of four STPs in high-rise buildings.	Highlighted the challenges in maintaining sustainable operations in high-rise building STPs, recommending SBR as the most sustainable.
Aggarwal, A. (2021)	Cost-effective wastewater treatment for urban environments: A review of technological advancements.	Reviewed various wastewater treatment methods, emphasizing cost-effectiveness and efficiency in urban environments.
Ramesh, M. (2021)	A comparative study of wastewater treatment methods: EA, SBR, MBR, and FBBR.	SBR was found to be the most suitable for balancing cost, efficiency, and sustainability in wastewater treatment.
Patil, V. (2020)	Assessment of sewage treatment options for sustainable urban development.	Evaluated several sewage treatment technologies, recommending a hybrid approach for high-rise buildings.
Kumar, P.	Technological advancements in sewage	Focused on advancements in STP technology,

(2019)	treatment plants: Focus on high-rise buildings.	advocating for newer systems like MBR for higher performance and effluent quality.
Verma, R. (2018)	Evaluating the efficiency and cost-effectiveness of STPs in urban settings.	Emphasized the need for a cost-benefit analysis in evaluating STPs for urban settings, recommending EA for its cost-effectiveness.

Research Gap

Despite significant advancements in wastewater treatment technologies, there remains a gap in comparative studies focusing on the performance of different sewage treatment plants (STPs) in high-rise buildings, especially in terms of long-term cost-effectiveness and sustainability. Existing literature often evaluates individual technologies but lacks comprehensive assessments that integrate operational efficiency, life cycle costs, and environmental impact. This study aims to address this gap by evaluating four widely used STP technologies, using Multi-Attribute Decision Making (MADM) and the TOPSIS method to provide a holistic comparison.

3. Methodology

The performance of the treatment systems was assessed by monitoring both raw and treated wastewater quality. The wastewater analysis included measurements of Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and Total Suspended Solids (TSS) using standard methods [3].

System Robustness and Sustainability: The flexibility, acceptability, and replicability of each technology were evaluated based on the insights provided by the STP installers, informed by their practical experience.

Life Cycle Costing (LCC): The life cycle costs, expressed as net present worth (NPW), were quantified using the present worth method. This method converts all future cash flows to a baseline, factoring in both inflation and the opportunity cost of capital. To calculate the present worth of the system, the following elements were considered:

1. Total capital cost, including civil, electrical, mechanical, and land costs.
2. The duration required to complete all capital works and the expenditure incurred each year.
3. The operation and maintenance costs for the first year after startup, along with annual escalations based on expected inflation rates [4].
4. A discounting factor to convert future sums of money into their net present value (NPV).
5. The plant's operational life and its salvage value at the end of its lifespan.

Assumptions in the Life Cycle Costing Analysis of the STP: The following assumptions were considered in the life cycle costing of the system:

- The operational life of all four STP technologies is assumed to be 20 years.

- The inflation rate in India was recorded as 8.79% in January 2014, with a forecasted rate of 7.88% in February 2014. An average inflation rate of 8.3% is assumed over the 20-year period for calculating the Net Present Value (NPV).
- A discounting factor of 12% per year is assumed [5].
- All four plants are assumed to be constructed in the same area, with identical land costs per square meter.
- The construction of all four plants is assumed to be completed within one year.
- It is assumed that all four plants will use the same grade of concrete for construction.
- All four plants are assumed to use the same make and model of pumps, blowers, etc.
- The salvage value of the plant is assumed to be negligible.

Multi-Attribute Decision Making (MADM): Decision-making is the process of identifying the best option among feasible alternatives, considering multiple criteria. Various methods exist for complex decision-making with multiple criteria or attributes, such as Analytic Hierarchy Process (AHP), ELECTRE, Expected Utility Theory, Goal Programming, Goal Attainment, Hierarchical Trade-offs, Interactive Simple Additive Weighting (SAW), Linear Assignment Method, LIMAP, Multi-attribute Utility Theory, and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) [6]. Among these, TOPSIS was selected as the decision-making tool for this analysis.

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution): TOPSIS is based on the concept of finding the ideal point (positive ideal solution, PIS) and the negative ideal solution (NIS). The alternative closest to the PIS and farthest from the NIS is considered the most preferable. The ranking of alternatives is determined by calculating the relative closeness to these two ideal points, combining their distance measures. TOPSIS is widely used in decision-making across industries such as human resources management, transportation, product design, manufacturing, water management, quality control, and location analysis. It is also applicable in multi-objective and group decision-making scenarios.

Steps Involved in TOPSIS: TOPSIS requires a decision matrix as input data, along with relative weights to reflect the decision makers' (DMs) preferences. The DMs who provide the preference structure are considered "offline". The multi-criteria decision-making problem is represented in matrix format as follows:

	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; xij is the rating of alternative Ai with respect to criterion Cj ; wj is the weight of criterion Cj . The procedure of TOPSIS can be expressed in a series of steps:

Step 1: Construct the decision matrix, where the columns represent different criteria and the rows correspond to various alternatives [7].

Step 2: Normalize the decision matrix.

Step 3: Apply the weights provided by the decision makers to the normalized matrix by multiplying each value with the respective weight.

Step 4: Formulate the ideal solution.

Step 5: Calculate the relative closeness of each alternative to the ideal solution.

Step 6: Rank the alternatives based on their proximity to the ideal solution.

To rank the alternatives using TOPSIS, the input data includes a list of four alternatives: Extended Aeration (EA), Sequencing Batch Reactor (SBR), Membrane Bio Reactor (MBR), and Fluidized Bed Bio Reactor (FBBR). These alternatives are assessed based on a set of attributes. The benefit attributes include the efficiency, replicability, flexibility, and acceptability of the technology. The cost attributes encompass the land area required for plant construction, civil work costs, electrical and mechanical equipment costs, and the operation and maintenance costs associated with the plant. These attributes form the basis for evaluating and ranking the alternatives.

4. Result & Discussion

General Overview

This study investigates the performance of four sewage treatment plants (STPs) commonly used in multistoried buildings. The results of the analysis are presented in detail in this section. The primary function of the STPs is to remove suspended solids and floating particles, as well as to reduce the biological and chemical oxygen demand (BOD and COD) [8]. Tertiary treatment is applied following the sewage treatment process to ensure the treated water meets the disposal standards set by the Pollution Control Board. STPs are installed in multistoried buildings to treat sewage generated from bathroom and toilet units, ensuring compliance with the standards prescribed by the Pollution Control Board.

Design Criteria

The design parameters adopted by the STP installers for residential wastewater characteristics were as follows: BOD at 300 mg/L, COD between 600-700 mg/L, and TSS between 200-300 mg/L. The treated water was expected to meet the following characteristics: BOD <20 mg/L, COD <250 mg/L, and TSS <10 mg/L. Upon analysis, it was found that there was a significant deviation between the raw water characteristics used for design and the actual raw water characteristics. However, this deviation did not have any adverse impact, as the actual values were lower than the design values, suggesting that the design basis was conservative, accounting for potential peak values.

Wastewater Quality Analysis

The wastewater analysis report revealed that the effluent from all four plants was within the limits prescribed by the Pollution Control Board for inland disposal, which are 30 mg/L for BOD, 250 mg/L for COD, and 100 mg/L for TSS. Among the four systems, the Extended Aeration (EA) system produced the highest quality treated water [9]. The overall treatment efficiency of the plants was as follows: 92% for Extended Aeration, 88% for Membrane Bio Reactor (MBR), 84% for Sequencing Batch Reactor (SBR), and 70% for Fluidized Bed Bio Reactor (FBBR).

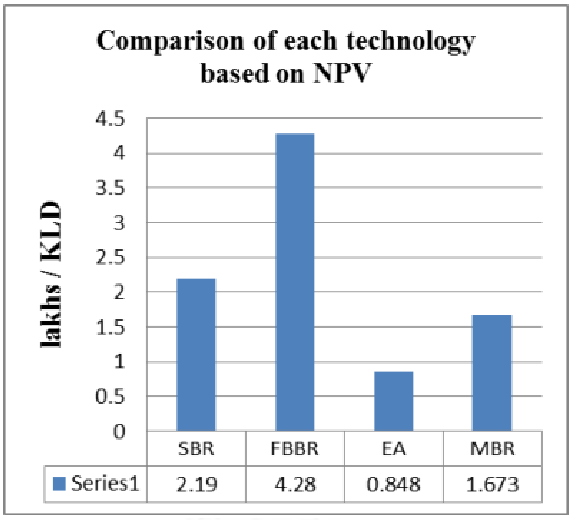

Figure 1 Comparison of the net present values of the four sewage treatment plant. This is the actual value of the plant in lakhs for treating one KLD of wastewater.

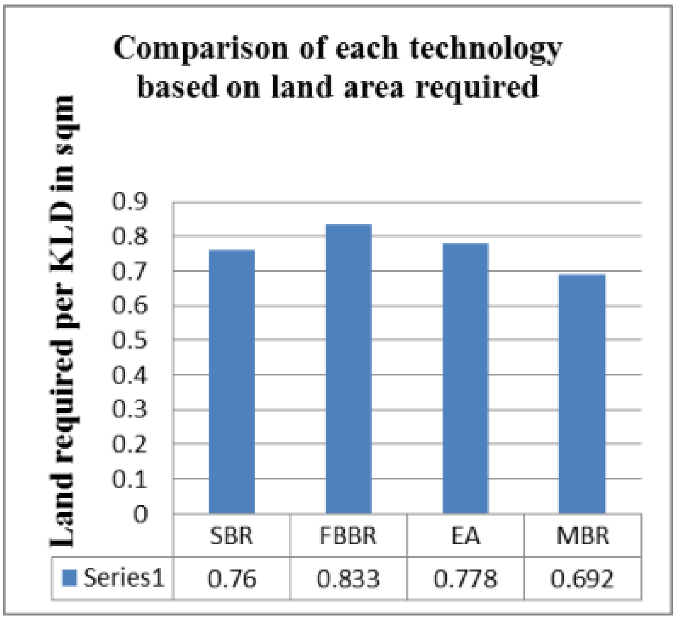

Figure 2 The land area required by the four sewage treatment technologies. Clearly this shows the actual area required for treating one KLD of wastewater including the land required for laying roads for accessing purpose.

The civil work cost for each plant to treat one KLD of wastewater is as follows: Extended Aeration (Rs. 0.112 lakhs), Membrane Bio Reactor (MBR) (Rs. 0.138 lakhs), Sequencing Batch Reactor (SBR) (Rs. 0.161 lakhs), and Fluidized Bed Bio Reactor (FBBR) (Rs. 0.261 lakhs). In terms of civil work costs, Extended Aeration is the most economical, followed by MBR. FBBR, on the other hand, incurs significantly higher costs due to the need for a separate sludge digestion tank [10]. Therefore, Extended Aeration is the preferred option based on civil work costs.The electrical and mechanical (E&M) equipment costs for treating one KLD of wastewater are as follows: Extended Aeration (Rs. 0.023 lakhs), SBR (Rs. 0.079 lakhs), FBBR (Rs. 0.205 lakhs), and MBR (Rs. 0.293 lakhs). In terms of E&M costs, Extended Aeration is the most cost-effective, followed by SBR. MBR incurs the highest costs due to the inclusion of membranes. Therefore, Extended Aeration or SBR technologies are preferred in terms of E&M costs. The annual operation and maintenance (O&M) cost for treating one KLD of wastewater is as follows: Extended Aeration (Rs. 0.034 lakhs), MBR (Rs. 0.074 lakhs), SBR (Rs. 0.124 lakhs), and FBBR (Rs. 0.257 lakhs). Extended Aeration requires the lowest annual O&M cost, followed by MBR. FBBR, again, incurs significantly higher O&M costs compared to the other technologies. Thus, Extended Aeration and MBR are preferred based on annual O&M costs [11].

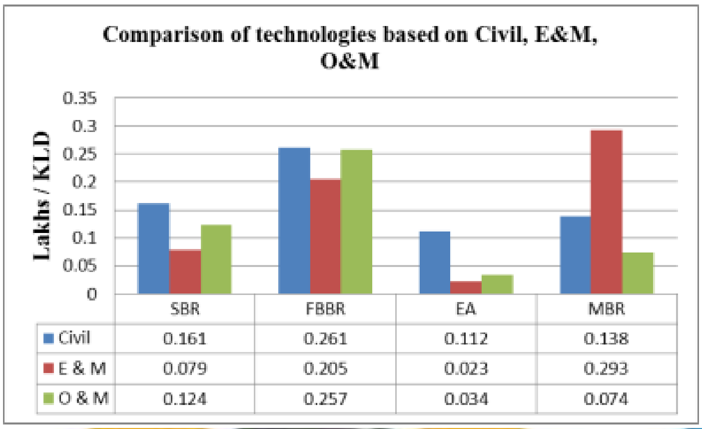

Figure 3 Civil work cost, E&M cost and O&M cost of the four sewage treatment plants were compared for treating one KLD of wastewater.

Multiple Attribute Decision Making

The technology assessment of wastewater treatment alternatives for high-rise buildings in India was conducted based on two criteria derived from Life Cycle Assessment (LCA) and Life Cycle Costing (LCC). A set of criteria, including resource constraints, system robustness, and sustainability, was used for the evaluation. Among the three technologies evaluated—ASP, SBR, and MBR—MBR was identified as the most preferred alternative, with a score of 0.8144, while SBR ranked second with a score of 0.8066. MBR was preferred due to its lower land and manpower requirements, higher reliability, and ability to produce high-quality effluent. In this study, SBR ranked as the most preferred alternative with a score of 0.944, while MBR held the second rank with a score of 0.347, as shown in Table 2 [13]. A matrix (Table 1) was created using wastewater quality analysis results, LCC of the system, and the ratings provided by STP installers regarding the flexibility, replicability, and acceptability of each system.

Table 1 Decision matrix

Criteria	Alternative	Efficiency	Rep	Flex	Accep	Land / KLD in Sqm	Civil/ KLD in lakhs	E&M/ KLD in lakhs	O&M/KLD in lakhs
VG-VP	EA	0.92	8.5	7.5	7.5	0.778	0.112	0.023	0.034
	SBR	0.84	9	9	8	0.76	0.161	0.079	0.124
	FBBR	0.7	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 difference in the order of preference arises from the varying criteria selected and the weightage assigned by the decision makers. In Chennai, SBR is preferred over MBR due to its lower capital and operational costs. FBBR emerged as the least preferred alternative due to its higher land footprint, as it requires separate clarifiers and digestion tanks for settling and sludge digestion, as well as producing lower-quality effluent.The best alternative was identified by considering both the positive ideal solution and the negative ideal solution, with the disadvantage or unfavorable value in one attribute being offset by an advantage or favorable value in another attribute [14]. Based on the results, SBR has the shortest distance to the positive ideal solution, making it the best alternative for installation. The order of preference for the technologies is as follows: **SBR > MBR > EA > FBBR.**

5. Conclusion

In conclusion, the performance evaluation of four sewage treatment plants (STPs) for multistoried buildings highlights the significant differences in operational efficiency, cost-effectiveness, and sustainability. The wastewater quality analysis revealed that all four systems met the Pollution Control Board’s prescribed standards, with the Extended Aeration (EA) system showing the highest efficiency at 92%. However, when considering life cycle costs, the EA technology proved to be the most cost-effective, particularly in terms of civil work, electrical and mechanical equipment costs, and annual operation and maintenance expenses. The Multi-Attribute Decision Making (MADM) analysis, using the TOPSIS method, provided a comprehensive ranking of the technologies. It was found that the Sequencing Batch Reactor (SBR) system emerged as the most preferred alternative, scoring the highest due to its balance of capital cost, operational efficiency, and sustainability. Membrane Bio Reactor (MBR) followed, with its higher operational reliability and quality of effluent. Extended Aeration (EA) and Fluidized Bed Bio Reactor (FBBR) ranked lower, mainly due to higher costs and operational complexity. Overall, the SBR system is the most optimal choice for wastewater treatment in high-rise buildings, considering both technical performance and cost-effectiveness.

Future Scope

- Assess the extended performance of STPs under varying conditions.
- Evaluate energy consumption, carbon footprint, and waste disposal.
- Tailor STP technologies for different building types.
- Explore AI for real-time monitoring and predictive maintenance.
- Adapt STPs to local water, waste, and regulatory conditions.

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