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Research Paper

Evaluating and Comparing Wastewater Treatment Technologies: Performance, Costs, and Sustainability

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ABSTRACT:*The necessity of constructing wastewater treatment facilities employing the most recent emerging treatment methodologies is paramount in addressing the escalating issue of water contamination at a global level, especially in areas where obtaining access to clean water proves to be a challenging feat. Traditional methods of treating wastewater have exhibited a decline in effectiveness when confronted with the mounting volumes of wastewater, resulting in heightened energy consumption and frequent operational breakdowns. These infrastructures, often engulfed by urban expansions, eventually become unsustainable in the long term due to their extensive land requirements and dwindling efficacy.*

In order to enhance the efficacy of service provision, particularly within the realm of urban sanitation, a series of standardized benchmarks for service levels have been devised to combat pollution predicaments. The National Green Tribunal (NGT) has taken a firm stance regarding pollution in drains, streams, and rivers, actively monitoring the quality of these aquatic ecosystems. The primary aim of this research endeavor is to undertake a comprehensive comparative evaluation of various technologies implemented in wastewater treatment plants and delineate a set of criteria for selecting the most suitable technology. Within the proposed research framework, sewage treatment plants (STPs) utilizing Sequencing Batch Reactor (SBR) technology have been chosen based on the refined criteria. SBR technology is capable of generating top-notch effluent that complies with regulatory benchmarks, exhibiting satisfactory overall treatment efficiency in terms of eliminating Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Suspended Solids (SS), Ammonia Nitrogen (N), Total Kjeldahl Nitrogen (TKN), and Total Phosphorous (TP).

KEYWORDS: Technologies, effectiveness, standards

I. INTRODUCTION

Wastewater is composed of a diverse array of organic and inorganic elements, which renders it a notable contributor to environmental decline owing to its chemical, toxic, and bacteriological constituents. The presence of such components underscores the importance of proper wastewater treatment before discharging it into water bodies, a critical step in upholding public health and averting the spread of diseases. Particularly in developing nations, a key obstacle in wastewater management today lies in the adoption of cost-effective treatment technologies capable of generating efficacious effluent that complies with established regulatory benchmarks for household, agricultural, and industrial uses. Moreover, within wastewater lie valuable resources like water, carbon, and nutrients that could be reclaimed or repurposed through the implementation of a well-crafted sewage treatment infrastructure.

Priority must be given to curbing disease transmission, reclaiming essential nutrients, reusing water, and safeguarding water reservoirs. It is imperative to ensure that the treated water attains enhanced quality levels to meet the standards for reuse or discharge into water bodies, aligning with the most recent directives from the esteemed National Green Tribunal (NGT). The pronouncement by the NGT underscores the necessity for top-notch effluent quality, underscoring the significance of recycling or reusing treated wastewater with minimal further treatment to stave off potential water scarcities and mitigate environmental harm.

II. SIGNIFICANCE OF STUDY

Wastewater is composed of harmful substances that pose a significant threat to aquatic ecosystems, human health, and overall environmental well-being. Inadequate regulations, substandard management practices, and the use of inappropriate technologies serve as obstacles that impede the efficient treatment of wastewater. Consequently, there is a pressing need for sustainable enhancements to be implemented in order to comply with evolving standards and safeguard the environment.

The primary objective of the research is to conduct a thorough evaluation and comparison of different treatment technologies in order to establish a set of guidelines that can aid in the selection of the most appropriate method based on considerations of sustainability, efficiency, and reliability. By scrutinizing and contrasting various treatment options, the study aims to provide valuable insights that can inform decision-making processes related to wastewater treatment practices.

Through the identification and assessment of conventional treatment methodologies, the research will place a specific emphasis on evaluating their efficiency, cost-effectiveness, and land requirements. This comprehensive analysis is crucial in ensuring that wastewater is treated effectively and that the discharge of reclaimed water meets the necessary standards. By focusing on these key criteria, the study seeks to contribute to the development of improved wastewater treatment strategies that are both environmentally sound and economically viable.

III. CRITERIA FOR CHOOSING APPROPRIATE SEWAGE TREATMENT TECHNOLOGY

Essentially, the selection of the most suitable treatment technology for wastewater treatment requires evaluation based on three key criteria: performance, cost, and sustainability.

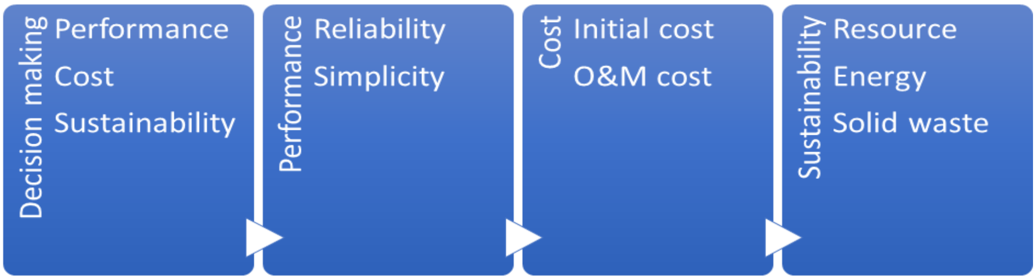

Figure 1: selection criteria for appropriate sewage treatment technology

IV. SCENARIO OF EXISTING SEWAGE TREATMENT PLANT IN INDIA

In order to evaluate the current situation regarding wastewater generation, it is crucial to thoroughly examine the actual conditions of water and wastewater treatment operations in India. This particular segment of the report focuses on the comprehensive evaluation of Sewage Treatment Plants across India, a task undertaken by the Central Pollution Control Board (CPCB) during the fiscal year 2020-21. The information gathered includes details on the geographical locations of these plants, their respective capacities, as well as the total count of plants utilizing different treatment methodologies, all of which are utilized to identify the predominant technology being effectively implemented nationwide. The allocation of treatment capacities across various states is visually represented in Figure-2, providing a clear depiction of the distribution percentages. Furthermore, the report also presents the distribution of Sewage Treatment Capacity according to different technologies employed in the treatment process.

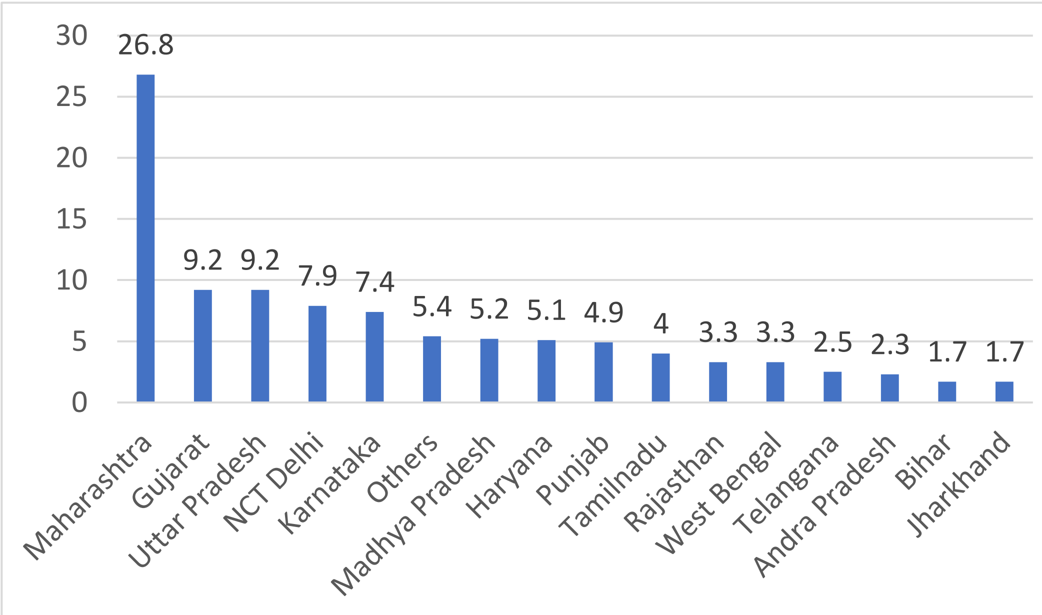

Figure 2: Sewage treatment capacity of different states of India (in percentage)

It is inferred that States of Maharashtra, Gujarat, Uttar Pradesh, NCT of Delhi and Karnataka have installed 26.8%, 9.2%, 9.2%, 7.9% and 7.4 % sewage treatment plant. It is clearly understood from figure-2 that, Maharashtra is come out as leading state in India as sewage treatment is concern.

It is observed that Sequential Batch Reactor (SBR) and Activated Sludge Process (ASP) are the most prevailing technologies adopted in India. (Figure-3)

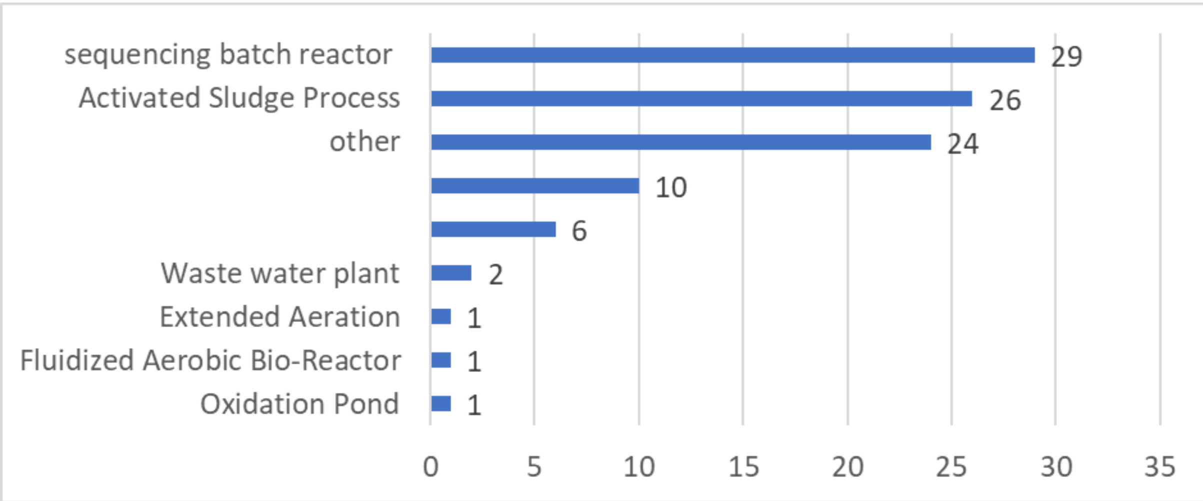

Figure 3: chart showing technology-wise distribution (in percentage)

V. COMPARATIVE STUDY OF SEWAGE TREATMENT TECHNOLOGY COMPARING DIFFERENT DISCHARGE STANDARDS OF VARIOUS GOVERNING BODY

The standards for the discharge of treated effluent are critical to ensuring environmental protection and public health. Various regulatory bodies have laid down these standards, including the CPHEEO, MoEF & CC, CPCB, PPCB, and NGT. Here is a review of these standards are as follow; The standards for the discharge of treated effluent are critical to ensuring environmental protection and public health. Various regulatory bodies have laid down these standards, including the CPHEEO, MoEF & CC, CPCB, PPCB, and NGT. Here is a review of these standards based on the study:

Central Public Health and Environmental Engineering Organization (CPHEEO): CPHEEO provides guidelines for the design and operation of sewage treatment plants to ensure that the treated effluent meets the required quality standards for safe discharge or reuse.

The Ministry of Environment, Forest and Climate Change (MoEF & CC) sets national standards for effluent discharge to protect water bodies from pollution. These standards are periodically updated to address emerging environmental challenges and ensure sustainable water management.

Central Pollution Control Board (CPCB) is responsible for setting and enforcing standards for the discharge of treated effluent into water bodies. These standards are designed to minimize the impact of pollutants on aquatic ecosystems and human health. CPCB standards typically include limits on parameters such as Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), and nutrient levels like nitrogen and phosphorus.

Punjab Pollution Control Board (PPCB) sets regional standards for effluent discharge, which may be more stringent than national standards to address local environmental conditions and pollution levels. PPCB standards ensure that treated effluent does not adversely affect the water quality of rivers, lakes, and other water bodies in Punjab.

National Green Tribunal (NGT) plays a crucial role in monitoring and enforcing compliance with effluent discharge standards. It has taken a serious view of pollution in water bodies and has issued orders to ensure that treated effluent meets the required quality standards before discharge. NGT's guidelines emphasize the need for high-quality effluent to prevent environmental degradation and promote the reuse of treated wastewater to address water scarcity issues. These standards collectively aim to ensure that treated effluent is safe for discharge into water bodies or for reuse in various applications. Compliance with these standards is essential for protecting the environment and public health, and for promoting sustainable water management practices.

By adhering to these standards, wastewater treatment plants can effectively reduce the pollution load on water bodies, conserve water resources, and contribute to overall environmental sustainability. The comparison table is shown in table -1.

Table-1 comparison of different parameters standardized by various governing bodies.

Sr. No.	Parameters	CPHEEO manual	MoEF & CC	PPCB	NGT
1	pH	-	6.5 to 9.0	6.5 to 9.0	5.5 to 9.0
2	BOD5 (at 20 degree C) mg/l	<10 mg/l	<20 (for metros area) <30 (for other Area)	≤10	≤10
3	COD in mg/l	-	-	≤50	≤50
4	Total Suspended solids in mg/l	<10	<50 (for metros area) <100 (for other Area)	≤10	≤20
5	Faecal Coliform MPN/100 ml	<230	<1000	Permissible ≤230 Desirable ≤100	Permissible ≤230 Desirable ≤100
6	Phosphorous in mg/l	<2	-	≤2	≤1
7	Ammonical Nitrogen as N in mg/l	-	-	≤5	-
8	N-Total in mg/l	<1-0	-	≤10	≤10

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STUDY OF DIFFERENT TECHNOLOGIES FOR WASTEWATER TREATMENT AND ITS EFFLUENT PROPERTIES

A comprehensive analysis has been conducted to compare various technologies utilized for the treatment of wastewater, taking into account essential factors like effectiveness, efficiency, operational and maintenance costs, energy consumption, and land utilization requirements. The research work presented is founded on a thorough examination carried out by multiple institutions in the year 2010, with detailed discussions provided subsequently. The study delves into the intricate details of each technology's performance and cost implications, shedding light on the diverse approaches adopted by different organizations in the field of wastewater treatment.

Table-2 Performance after secondary treatment of different prominent technologies

Sr. No.	Parameters	Prominent Technologies					
		ASP	MBBR	SBR	UASB+ EA	MBR	WSP
1	Effluent BOD, mg/l	<20	<20	<10	<20	<5	<40
2	Effluents SS, mg/l	<30	<30	<10	<30	<5	<100
3	Faecal coli. Removal log unit	Up to 2<3	Up to 2<3	Up to 3<4	Up to 2<3	Up to 5<6	Up to 2<3
4	T-N removal Efficiency, %	10-20	10-20	70-80	10-20	70-80	10-30

The examination of how different technologies are utilized in Sewage Treatment Plants to evaluate their performance reveals that STPs designed with MBR Technology exhibit the highest level of removal of BOD and SS, achieving values lower than 5 mg/l. Subsequently, the use of SBR Technology leads to a decrease in BOD and SS levels, reaching values below 10 mg/l. MBR Technology attains the maximum removal of Faecal Coliform, ranging between 5-6 log units, followed by SBR Technology, which can eliminate Faecal Coliform up to 3-4 log units. The highest efficiency in T-N removal is observed in SBR and MBR Technologies, with a value of 70-80%, while other technologies such as ASP, MBBR, UASB, and WSP demonstrate a removal efficiency of 10-20%. Among these, WSP exhibits the poorest water effluent quality. Consequently, Sewage Treatment Plants that are based on MBR and SBR technologies are prevalent in the field.

Table-3 Requirement of area for establishing various technologies

Sr. No.	Parameters	Prominent Technologies					
		ASP	MBBR	SBR	UASB+ EA	MBR	WSP
1	Average Area, m^2 per MLD	900	450	1000	450	450	6000
2	Average Capital cost, *lacs*/MLD	68	68	75	68	300	23
3	Civil works, % of total capital costs	60	60	30	65	20	90
4	E&M works, % of total capital cost	40	40	70	35	80	10

the average capital cost of Sewage Treatment Plants (STP) utilizing Membrane Bioreactor (MBR) Technology is observed to be 300 lakhs per Million Liters per Day (MLD), making it less favorable in terms of cost efficiency. In addition, Waste Stabilization Ponds (WSP) are defined by a requirement for civil construction works that make up 90% of the total capital outlay, whereas Activated Sludge Process (ASP), Moving Bed Biofilm Reactor (MBBR), and Upflow Anaerobic Sludge Blanket (UASB) systems need approximately 60-65% of the total project costs. On the other hand, STPs based on Sequential Batch Reactor (SBR) Technology entail 30% of the overall costs for civil works, whereas MBR Technology involves 20% of the total expenses. Consequently, STPs utilizing SBR or MBBR technologies emerge as more cost-effective options. Moreover, the electromechanical (E&M) works costs for STPs employing WSP Technology are notably low, constituting only 10% of the total expenditures, followed by UASB combined with Enhanced Aeration (EA) at 35% of the total costs. ASP and MBBR necessitate 40% of the total outlay, while SBR Technology commands 70% of the total costs, comparable to MBR Technology's requirement of 80% of the total expenses. Analysis from Chart-5 reveals that WSP Technology demands an average area of approximately 6000 square meters per MLD for STP construction, signifying a considerable land footprint. In contrast, MBBR, SBR, and MBR technologies offer more space-efficient solutions with a minimal footprint of 450 square meters per MLD for the treatment facility, followed by ASP and UASB combined with EA requiring 900 and 1000 square meters per MLD, respectively.

Table 4: Comparison of Operation & Maintenance cost of various technologies

Sr. No.	Parameters	Prominent Technologies					
		ASP	MBBR	SBR	UASB+ EA	MBR	WSP
1	Yearly power cost, *lacs pa*/MLD	4.07	4.90	3.37	2.75	6.65	0.49
2	Repair cost						
	2.1 Civil works maintenance, *lacs pa*/MLD	1.94	1.30	1.04	2.11	-	1.70
	2.2 E&M works maintenance, *lacs pa*/MLD	0.43	0.65	0.81	0.38	-	0.06
	2.3 Annual repair cost, *lacs pa*/MLD	2.37	1.95	1.85	2.49	-	1.76

it is commonly known that the operational cost of energy per million liters per day (MLD) to operate the wastewater treatment plant is at its lowest when utilizing the WSP Technology, amounting to only 0.49 lakh rupees per year per MLD. On the contrary, the highest energy cost is accrued with the MBR Technology, reaching as high as 6.65 lakh rupees per year per MLD. The energy expenditure for running the plant is fairly reasonable in cases where sewage treatment plants (STPs) are configured with the SBR Technology, costing around 3.37 lakh rupees per year per MLD, and the UASB+ EA Technology, which amounts to 2.75 lakh rupees per year per MLD. In terms of repair expenses, the SBR Technology incurs a cost of 1.85 lakh rupees per year per MLD, while for STPs based on ASP and UASB technologies, the repair costs are approximately the same at 2.37 and 2.49 lakh rupees per year per MLD, respectively (Table-4)

VI. CONCLUSION

The conclusion drawn from the study mentioned above is that both Stabilization Pond and UASB technologies are deemed unsuitable due to their inability to achieve the desired quality of treated water. In contrast, the Activated Sludge process and Moving Bed Bio Reactor process (MBBR) have the capability to generate the required water quality, but they necessitate downstream filtration. As a result, the overall system becomes costly in terms of both initial investment and ongoing operational expenses. Although a Membrane reactor can deliver superior effluent quality, the operational and capital costs associated with a plant utilizing MBR technology are exceptionally high. Hence, considering factors such as outstanding performance, minimal area requirement, and economical capital costs, the SBR technology emerges as the most suitable option based on the aforementioned study. SBR Technology has the ability to consistently produce the desired quality of treated water, making it a favorable choice for water treatment applications.

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