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Comparative Study of Conventional and Modern Sewage Treatment Technologies

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Abstract: This study presents a comprehensive comparative evaluation of six major sewage treatment technologies—Activated Sludge Process (ASP), Moving Bed Biofilm Reactor (MBBR), Sequential Batch Reactor (SBR), Upflow Anaerobic Sludge Blanket with Extended Aeration (UASB+EA), Membrane Bioreactor (MBR), and Bio-Digester & Bio-Remediation (BDBR)—based on key performance indicators including biological oxygen demand (BOD), total suspended solids (TSS), faecal coliform removal, total nitrogen (T-N) removal efficiency, land area requirement, capital costs, energy consumption, and operation and maintenance (O&M) costs. The analysis reveals that while technologies like SBR and MBR show superior treatment efficiencies in terms of BOD, TSS, and nutrient removal, their energy demand and capital investment are significantly higher. In contrast, conventional methods such as ASP and UASB+EA, although cost-effective and simple in design, fail to meet stricter effluent quality norms without post-treatment polishing. MBBR presents a balanced option in terms of footprint and performance but still requires downstream filtration. The BDBR technology emerges as a highly promising alternative, offering excellent effluent quality with BOD and TSS values consistently below 10 mg/L and total nitrogen removal up to 80%, while simultaneously minimizing land requirement, capital investment, energy costs, and operational complexity. Its decentralized applicability, reduced dependency on skilled labor, and capability for biogas generation position it as a sustainable, eco-friendly, and cost-efficient solution, especially for small to medium-sized communities. Thus, the performance comparison highlights that while each technology has its merits, BDBR offers the most optimal combination of environmental and economic viability, making it the most suitable choice for municipal wastewater management in developing regions.

Keywords: Sewage Treatment, Conventional Treatment, Modern Technologies, Wastewater Management, Environmental Impact

I. INTRODUCTION

Water is an essential resource that sustains life on Earth, supports ecosystems, and underpins all socio-economic development. However, the rapid pace of urbanization, industrialization, and population growth has significantly increased the quantity of wastewater generated, particularly in urban areas. Untreated or poorly treated sewage leads to severe environmental degradation, contaminating surface and groundwater, causing the spread of waterborne diseases, and threatening aquatic biodiversity.Sewage, or domestic wastewater, is primarily composed of organic matter, pathogens, nutrients such as nitrogen and phosphorus, suspended solids, and various chemical pollutants. If not treated effectively, these constituents pose serious environmental and public health risks. Therefore, sewage treatment is a fundamental component of urban sanitation systems and environmental protection strategies. It transforms wastewater into an effluent that can be safely discharged into the environment or reused for non-potable purposes.Traditionally, sewage treatment in India has relied heavily on conventional technologies such as the Activated Sludge Process (ASP), Trickling Filters, and Oxidation Ponds. These processes have been in operation for decades and have formed the backbone of municipal sewage treatment infrastructure. However, they often face challenges such as high energy requirements, large land footprint, complex operation, and inefficient nutrient removal. Moreover, many conventional plants in India operate below capacity or fail to meet regulatory standards due to poor maintenance or outdated technology.In recent decades, the advent of modern and advanced sewage treatment technologies has revolutionized the way we treat wastewater. Technologies like Sequential Batch Reactors (SBR), Moving Bed Biofilm Reactors (MBBR), Membrane Bioreactors (MBR), and natural treatment systems like Phytorid technology and constructed wetlands have emerged as sustainable alternatives. These systems are designed to be more compact, energy-efficient, and capable of meeting stricter discharge norms.Given the pressing need to manage sewage in a more effective and sustainable manner, it becomes essential to evaluate and compare these conventional and modern technologies in terms of their treatment performance, environmental impact, economic feasibility, and suitability in diverse contexts.

This comparative understanding will guide policymakers, engineers, and urban planners in selecting appropriate technologies for future sewage treatment infrastructure development.In India, the Central Public Health and Environmental Engineering Organisation (CPHEEO), under the Ministry of Housing and Urban Affairs (MoHUA), serves as the premier technical body for setting standards and providing guidelines for water supply, sewerage, and sanitation services. The CPHEEO Manual on Sewerage and Sewage Treatment, first published in 1993 and later revised in 2013 and 2020, has been instrumental in shaping the design and operational frameworks of sewage treatment systems across urban local bodies (ULBs). These manuals serve as comprehensive documents that detail best practices, treatment technology selection criteria, hydraulic and process design standards, and operational guidelines, keeping in mind the evolving environmental norms and challenges. The latest revisions in the CPHEEO manual reflect the growing emphasis on decentralization, compact treatment units, enhanced nutrient removal, and the reuse and recycling of treated wastewater—particularly relevant in water-stressed urban agglomerations. It highlights a significant paradigm shift from conventional, space-intensive treatment systems toward the adoption of modern, energy-efficient, and modular treatment solutions that can operate within the spatial constraints of urban India.In alignment with these guidelines and in response to the growing urban sanitation crisis, the Government of India launched the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) in 2015. This flagship mission was designed to ensure basic urban infrastructure development across 500 selected cities, with a major focus on improving sewerage and septage management systems. The mission acknowledged that proper sewage treatment is essential not only for public health but also for environmental sustainability, and allocated substantial funds for the construction, rehabilitation, and augmentation of sewage treatment plants (STPs).

II. LITERATURE REVIEW

Anubhav Sharma et al. (2023)"A Review Paper on the Performance Evaluation of STPs Based on Different Technologies ASP, SBR & MBBR", [1] have extensively discussed and evaluated the comparative performance of sewage treatment plants (STPs) operating on three major biological treatment technologies: Activated Sludge Process (ASP), Sequencing Batch Reactor (SBR), and Moving Bed Biofilm Reactor (MBBR). The authors began by emphasizing the critical importance of efficient and sustainable wastewater treatment systems in the face of rapidly increasing urbanization and pollution loads, highlighting the essential role played by STPs in ensuring environmental protection and public health. They reviewed various research studies and experimental findings that investigated key performance indicators such as removal efficiency of pollutants like BOD, COD, TSS, ammonia, nitrates, and phosphates, along with economic parameters including operating cost, energy requirement, and operational complexity. Sharma et al. (2023) found that while ASP remains one of the most widely adopted traditional biological treatment methods, it has certain limitations, particularly in terms of energy usage and space requirement. In contrast, SBR technology offers the advantage of combining equalization, aeration, and sedimentation in a single tank, which not only reduces footprint but also enhances process control, although it can be operationally intensive. Meanwhile, the MBBR system, which utilizes biofilm carriers suspended in the aeration tank, emerged as a more efficient and modern technology, with higher resilience to load fluctuations, superior nutrient removal capabilities, and lower sludge production. The review further observed that among the three, MBBR demonstrated superior adaptability, lower energy consumption per unit of treatment, and consistently higher removal efficiencies under various loading conditions, making it a promising candidate for future STP upgrades. Moreover, Sharma et al. (2023) underscored the significance of continuous monitoring, real-time data acquisition, and periodic performance evaluation of treatment plants to ensure compliance with effluent discharge standards as per regulatory norms. The paper also called for integrating innovative improvements such as automation, hybrid treatment combinations, and the use of advanced sensors and data analytics to further enhance the operational reliability and sustainability of these technologies. In conclusion, the study provided critical insights into the comparative merits and limitations of ASP, SBR, and MBBR systems, contributing to the decision-making framework for selecting appropriate treatment technologies in diverse geographical and economic contexts while considering long-term efficiency, scalability, and environmental impact.

Harpreet Kaur et. al. (2022), "A Comparative Study of Different Sewage Treatment Technologies", [2] emphasized the urgent necessity of adopting advanced and effective sewage treatment technologies that are not only technically sound but also environmentally sustainable. The authors highlighted how the traditional and conventional wastewater treatment systems are increasingly becoming inadequate in the face of rapidly growing urban populations and escalating pollution loads. These outdated systems, while once effective, now often suffer from high energy consumption, frequent operational failures, and space constraints—especially in densely populated urban areas where land availability is severely limited and infrastructure is overstressed.

The paper underlines the importance of developing wastewater treatment strategies that not only focus on treating wastewater efficiently but also align with global and national sustainability goals, including those championed by bodies like the National Green Tribunal (NGT), which has taken a proactive stance on monitoring and improving the quality of rivers and other water bodies in India. Kaur and Sharma (2022) conducted a detailed comparative analysis of various modern sewage treatment technologies and advocated for a shift towards the Sequencing Batch Reactor (SBR) technology due to its operational advantages and high treatment performance. Through their study, it was found that SBR-based sewage treatment plants exhibit high removal efficiency for critical pollutants including Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Suspended Solids (SS), Ammonia Nitrogen (N), Total Kjeldahl Nitrogen (TKN), and Total Phosphorous (TP). The effluent produced from SBR systems consistently met the regulatory discharge standards, making it a viable choice for urban wastewater treatment. Moreover, the authors developed and applied a set of scientifically defined criteria to select the most appropriate treatment technology, which included factors such as space requirement, energy efficiency, capital and operational costs, maintenance requirements, and the ability to handle varying inflow characteristics. The study ultimately concluded that SBR technology stands out not only due to its compact design and ability to treat fluctuating flows effectively, but also due to its sustainability and long-term economic feasibility in Indian urban settings. This work contributes significantly to the ongoing discourse on the modernization of India's wastewater infrastructure by promoting the adoption of newer and more adaptive technologies in response to the country's pressing water and sanitation challenges.

D. S. Thanki et. al. (2021), "Evaluating and Comparing Wastewater Treatment Technologies: Performance, Costs, and Sustainability", [3] present a critical and well-structured evaluation of the evolving landscape of wastewater treatment technologies. The authors assert that the increasing burden of water pollution at both local and global levels necessitates the immediate and strategic implementation of modern treatment methods that are not only technically efficient but also environmentally sustainable. With increasing urbanization, the limitations of traditional wastewater treatment systems have become increasingly apparent—particularly their high energy demands, large land footprints, and frequent operational inefficiencies. Thanki et al. (2021) note that such systems, originally designed to handle lower volumes and simpler waste loads, are now struggling to maintain treatment efficacy amid growing pressures. In their study, the authors emphasize the need for a transition toward advanced technologies that can deliver higher removal efficiencies while optimizing resource use. As part of a wider urban sanitation strategy, they highlight the implementation of standardized Service Level Benchmarks (SLBs) aimed at improving municipal service delivery and pollution mitigation. Furthermore, the role of the National Green Tribunal (NGT) is acknowledged for its active involvement in monitoring and regulating the discharge quality in rivers and water bodies, thereby reinforcing the urgency of effective sewage treatment practices. The research conducted by Thanki et al. (2021) focused on comparing multiple technologies, with specific attention given to Sequencing Batch Reactor (SBR) systems, which were selected based on a refined set of criteria including effluent quality, operational flexibility, energy consumption, and space efficiency. SBR technology, according to their findings, proved capable of producing high-quality effluent that meets regulatory discharge standards. The technology exhibited substantial pollutant removal rates, particularly in terms of Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Suspended Solids (SS), Ammonia Nitrogen (N), Total Kjeldahl Nitrogen (TKN), and Total Phosphorous (TP), making it a robust solution for urban wastewater management. The study underscores that beyond just treatment performance, long-term sustainability, adaptability to site-specific challenges, and cost-efficiency must also be considered when selecting the most appropriate technology. Overall, this paper contributes meaningfully to the growing body of literature advocating for a strategic shift towards advanced and sustainable wastewater treatment solutions in light of mounting environmental, economic, and social demands.

Rama Narayan Sabat et. al. (2020), "A Comparative Study of Different Sewage Treatment Technologies", [4] underscore the growing importance of adopting advanced and emerging wastewater treatment technologies in order to address the severe and escalating water pollution crisis being experienced globally. Their paper highlights that the traditional sewage treatment systems, while once sufficient, are now becoming increasingly inadequate to meet the demands posed by rising wastewater volumes, rapid urbanization, and evolving pollutant characteristics. According to Sabat and Baliarsingh (2020), conventional systems not only struggle with inefficiency in pollutant removal but also suffer from high operational costs, excessive energy consumption, and land-use challenges, rendering them unsustainable in the long term. The authors emphasize the necessity for sewage treatment systems to be designed and operated in an environmentally responsible manner that aligns with sustainability goals and public health priorities. The authors point out that urban expansion further exacerbates these challenges by compressing infrastructure into increasingly congested spaces, often leading to underperformance and a failure to comply with modern regulatory standards. In response to these challenges, they refer to the Service Level Benchmarks developed to guide improvements in urban sanitation services, with a specific focus on pollution control.

The role of the National Green Tribunal (NGT) is acknowledged for its oversight and monitoring of river and stream water quality, adding regulatory impetus to the implementation of advanced treatment solutions. In their comparative analysis, Sabat and Baliarsingh (2020) focus on various treatment technologies but ultimately highlight the Sequencing Batch Reactor (SBR) system as a particularly promising solution. SBR is identified as being capable of producing high-quality treated effluent that complies with environmental standards. Their findings reveal that SBR systems demonstrate superior treatment performance in terms of reducing Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Suspended Solids (SS), Ammonia Nitrogen (N), Total Kjeldahl Nitrogen (TKN), and Total Phosphorous (TP), thereby making it a highly suitable option for urban sewage management. The study effectively bridges the gap between technological performance and environmental compliance, providing critical insights into the factors that must be considered when selecting the most appropriate treatment method. Overall, the work of Sabat and Baliarsingh (2020) makes a significant contribution to the literature by offering a thorough comparison of sewage treatment technologies and reinforcing the need for ongoing innovation, sustainability, and regulatory alignment in the planning and operation of wastewater treatment plants.

Mohd. Najibul Hasan et al. (2019), “Anaerobic and Aerobic Sewage Treatment Plants in Northern India: Two Years Intensive Evaluation and Perspectives”, [5] undertook a robust performance evaluation of seven sewage treatment plants (STPs) across various cities in Northern India over a period of two years. The research included a comparative analysis of two fully aerobic systems — the Sequencing Batch Reactor (SBR) and the Moving Bed Biofilm Reactor (MBBR) — and three hybrid systems combining anaerobic Up-flow Anaerobic Sludge Blanket (UASB) reactors followed by secondary aerobic treatment units such as Polishing Ponds (PP), Aeration + PP, and Down-flow Hanging Sponge (DHS). Their findings revealed that the UASB-based plants followed by simple aerobic units like PP and Aeration + PP consistently failed to meet the surface water disposal standards set by the Ministry of Environment, Forest and Climate Change, Government of India. In contrast, STPs incorporating SBR and MBBR technologies, as well as UASB followed by the DHS process, demonstrated significantly superior treatment efficiency. These systems achieved over 85% removal of Ammonium-Nitrogen (NH4-N) and more than 60% removal of Phosphate-Phosphorus (PO4-P), producing final effluents with concentrations approximating 20 mg/L of BOD_5, 50 mg/L of COD, 20 mg/L of TSS, 10 mg/L of NH4-N, and 5 mg/L of PO4-P. The study also examined methane generation under varying operational conditions, highlighting the energy recovery potential in anaerobic systems. While strictly aerobic technologies like SBR and MBBR yielded higher-quality effluents suitable for surface discharge or reuse, the authors emphasized the practical value of hybrid anaerobic-aerobic systems — particularly the UASB-DHS combination — as cost-effective alternatives for Indian conditions, especially where space and operational simplicity are critical. The research underscores the importance of selecting context-appropriate technologies that balance treatment efficacy, operational cost, and regulatory compliance in urban sanitation planning.

Dharam Vir Singh et. al. (2020), “A Research on Optimized Design of Sewage Treatment Plant (STP)”, [6] explored the essential need for constructing and optimizing sewage treatment plants (STPs) using modern technologies in response to rising environmental challenges, especially the critical shortage of clean water in many Indian regions. The authors highlighted that the increased cement production for conventional infrastructure contributes significantly to CO_2 emissions and environmental degradation, thus necessitating sustainable alternatives like improved STP designs. The study focused particularly on Up-flow Anaerobic Sludge Blanket (UASB), Moving Bed Biofilm Reactor (MBBR), and Sequencing Batch Reactor (SBR) technologies. UASB, once popular for its energy efficiency and biogas generation, has witnessed a decline in adoption due to performance concerns. MBBR, by contrast, combines the advantages of fixed-film and activated sludge processes, using HDPE bio-carriers that promote bacterial growth in a suspended medium, offering high treatment efficiency in compact space with simplified operation. Similarly, SBR technology, which integrates equalization, aeration, and sedimentation within a single reactor basin, is praised for its adaptability to varying flows, and its success in treating both municipal and industrial wastewater. The study primarily assessed the performance of two MBBR-based STPs located in Jhajjar Town, Haryana. Wastewater samples were analyzed for critical physicochemical parameters, including pH, BOD, COD, TSS, turbidity, nitrates, phosphates, total nitrogen (TN), and total phosphorus (TP). The findings confirmed the high efficiency of MBBR systems, with effluent quality consistently meeting discharge standards. Furthermore, treated effluents were reused for agricultural irrigation, and the sludge was effectively repurposed as manure, showcasing environmental and economic benefits. In conclusion, Singh and Jain emphasized the importance of optimized STP design, particularly tertiary treatment, as per National Green Tribunal (NGT) guidelines, to produce high-quality effluent suitable for reuse. Tertiary treatment, as discussed, is capable of removing up to 99% of residual contaminants, including nitrogen and phosphorus, significantly reducing BOD levels and enhancing water quality.

The research supports advanced treatment technologies as critical tools in promoting sustainability, resource recovery, and public health protection through improved sewage management systems.

Ankit Sharma et. al. (2019), "Performance Evaluation of Wastewater Treatment Plant Based on SBR Technology with PLC, SCADA System – A Case Study of Rajeev Awas Yojna, Kiron Ki Dhani, Muhana, Rajasthan (India)",[7] evaluated the efficiency and effectiveness of a sewage treatment plant (STP) operating on the Sequencing Batch Reactor (SBR) technology integrated with Programmable Logic Controller (PLC) and Supervisory Control and Data Acquisition (SCADA) systems. The authors emphasized the growing need for effective wastewater treatment technologies, particularly in regions facing water scarcity and pollution concerns. The study highlights the importance of adopting modern STP technologies that are not only environmentally sustainable but also economically viable and technologically advanced. SBR, as a modern batch treatment system, is known for combining the processes of equalization, aeration, and sedimentation in a single tank. This makes it especially suitable for municipal and industrial wastewater treatment, particularly in areas with variable or intermittent flow. The case study was conducted at the Rajeev Awas Yojna STP in Muhana, Rajasthan, which operates using SBR in conjunction with automation systems such as PLC and SCADA to enhance process control and operational efficiency. Wastewater samples were collected and analyzed for key parameters including pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), phosphate, and Total Kjeldahl Nitrogen (TKN). The results of the performance evaluation indicated that the STP effectively met the discharge standards for all tested parameters. The treated effluent was found to be suitable for agricultural reuse, thereby supporting water conservation practices in the region. Additionally, the sludge generated was repurposed as manure and distributed to farmers, contributing to circular economy practices and reducing solid waste disposal issues. In conclusion, Sharma and Pandey demonstrated that SBR technology, particularly when integrated with automated monitoring and control systems, offers a highly reliable, efficient, and adaptive solution for wastewater treatment. Their study reinforced the potential of such modern systems in ensuring effluent quality compliance, resource recovery, and environmental protection. The integration of PLC and SCADA provides real-time monitoring and control, enhancing operational stability and allowing for prompt corrective actions, which is crucial for long-term sustainability of STPs.

Sudha Sippi et. al. (2025), "Effluent quality-based ranking of sewage treatment plants using multicriteria decision making technique", [8] introduced an innovative framework for evaluating and ranking sewage treatment plants (STPs) in India based on effluent quality performance using a multicriteria decision making (MCDM) approach. The study addresses a critical challenge faced by environmental regulatory agencies—evaluating the performance of numerous STPs across the country in a systematic and scientifically sound manner, especially when direct simulation-optimization models like waste load allocation are impractical due to complexity. The authors proposed a modified Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) as part of their MCDM framework. This technique allowed the researchers to rank 100 STPs across India by integrating both effluent quality indicators and regulatory discharge standards (as specified by the CPCB) within a unified decision matrix. The results demonstrated that small-capacity STPs, especially those using oxidation pond technology, tended to outperform others in terms of effluent quality. Conversely, large-capacity STPs showed improved performance when employing Activated Sludge Process (ASP) technologies. Specifically, the Burhi ka Nagla STP in Agra (1–20 MLD category) and a large-scale STP in Madurai, Tamil Nadu (above 100 MLD) were identified as the best-performing plants in their respective categories. The novelty of this study lies in its integration of regulatory standards with real-time effluent quality metrics in a single analytical framework, allowing for a transparent and comparative assessment of plant performance. To the authors' knowledge, this is the first instance of a modified TOPSIS method being applied in this context. The findings offer valuable insights for pollution control boards and urban planners, enabling data-driven decisions for improving STP management, resource allocation, and compliance with environmental norms.

Mukesh Ruhela et. al. (2020), "Efficiency of Sequential Batch Reactor (SBR) based sewage treatment plant and its discharge impact on Dal Lake, Jammu & Kashmir, India", [9] conducted a comprehensive study on the efficiency of a Sequential Batch Reactor (SBR) based sewage treatment plant (STP) located at BrariNumbal and its discharge impact on the physicochemical properties of Dal Lake, Jammu & Kashmir, India. Dal Lake, being the second largest and a prominent tourist destination in the region, is facing serious water quality deterioration due to increasing domestic wastewater generation driven by rapid population growth. The study involved systematic sampling from the inlet and outlet of the SBR-STP as well as from multiple sites along Dal Lake, including upstream, confluence zone, and downstream locations over a period of five months (November 2019 to March 2020). Using standard analytical methodologies, the researchers evaluated key parameters such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), pH, dissolved oxygen (DO), iron, ammonical nitrogen, and phosphate.

The SBR-based plant demonstrated a maximum removal efficiency for BOD at 79.85%, indicating significant treatment of organic load; however, the treated effluent BOD levels still exceeded prescribed discharge standards, signaling incomplete treatment. The removal efficiency for pH was minimal (3.46%), suggesting that the treatment process had negligible effect on this parameter, whereas dissolved oxygen showed a remarkable increase of 851.55%, reflecting improved aeration and oxidation conditions post-treatment. Despite the treatment efforts, the study found that all sampling sites in Dal Lake were polluted, with the confluence zone and downstream areas experiencing elevated pollution levels directly attributed to the discharge of STP effluent. Notably, BOD and COD concentrations increased by 21.39% and 43.29% respectively, along with substantial increases in iron (80.10%), ammonical nitrogen (65.61%), and phosphate (101%) in the downstream waters compared to upstream levels. The findings also pointed to additional untreated wastewater entering the lake, exacerbating the degradation of water quality. The authors concluded that while the SBR technology provides moderate treatment efficiency, the existing STP configuration and operation require further modifications and enhancements to effectively reduce pollutant loads before discharge. This study is significant as it represents the first assessment of the impact of SBR-STP effluent on Dal Lake's water quality and provides critical insights for policymakers and environmental managers seeking sustainable wastewater management solutions in sensitive lake ecosystems.

Nimeshchandra V. Vashi (2019), "Recent Technologies Adopted for Upgradation of Existing Sewage Treatment Plants and for Sewage Reuse and Recycle in Surat, India", [10] presented a detailed study on the recent technological advancements adopted for the upgradation of existing sewage treatment plants (STPs) and for the reuse and recycling of treated sewage water in Surat, India. The research focuses on the integration of advanced biological treatment processes such as Sequencing Batch Reactor (SBR) and Integrated Fixed Film Activated Sludge (IFAS) technologies into older STPs that were originally designed with different treatment systems including Upflow Anaerobic Sludge Blanket (UASB), Conventional Activated Sludge Process (CASP), and Moving Bed Biofilm Reactor (MBBR). The paper highlights how these upgraded technologies enhance the operational efficiency and treatment performance of the STPs in Surat, a rapidly growing urban area with increasing sewage loads. Specifically, the study details the deployment of tertiary treatment units following the biological processes, including dual media filtration after SBR to enable safe reuse of treated effluent for gardening purposes, and ultrafiltration (UF) combined with reverse osmosis (RO) units to treat sewage water to industrial-grade standards for reuse in manufacturing and other industrial applications. These tertiary treatment processes ensure compliance with stringent water quality norms, facilitating the sustainable reuse and recycling of wastewater, thereby reducing the dependency on freshwater resources and promoting water conservation. The authors emphasize that the successful adoption of SBR and IFAS technologies allows for better removal of organic and suspended solids, nutrient reduction, and pathogen control compared to conventional processes, while the combination with membrane filtration units further improves effluent quality to meet reuse criteria. The study underlines the importance of technological upgradation for existing STPs to address the challenges posed by urbanization and escalating water demand, positioning Surat as a case study for cities aiming to modernize their wastewater treatment infrastructure for environmental protection and resource recovery. Keywords associated with the study include Sewage, Conventional Activated Sludge Process (CASP), Moving Bed Biofilm Reactor (MBBR), Sequencing Batch Reactor (SBR), Integrated Fixed Film Activated Sludge (IFAS), Ultrafiltration (UF), Reverse Osmosis (RO), Reuse, and Recycle.

III. PROPOSED METHODOLOGY

A. SELECTION OF STPS TECHNOLOGIES

The study involves selecting representative Sewage Treatment Plants (STPs) that use different treatment technologies. The selection criteria include:

- Capacity: Around 1 MLD for uniform comparison.
- Technology diversity: Include conventional and advanced STP technologies.

Table 3.1: Selected STP Technologies for Performance Comparison

Technology	Description
ASP (Activated Sludge Process)	Conventional aerobic treatment using microbial biomass to degrade organic pollutants.
MBBR (Moving Bed Biofilm Reactor)	Uses biofilm carriers suspended in the reactor for attached growth of microbes.
SBR (Sequencing Batch Reactor)	Time-sequenced batch process for aerobic treatment with phases like fill, react, settle, decant.

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UASB + EA (Upflow Anaerobic Sludge Blanket + Extended Aeration)	Anaerobic digestion followed by aerobic polishing for improved effluent quality.
MBR (Membrane Bioreactor)	Combines biological treatment with membrane filtration for high-quality effluent.
BDBR (Bio-Digester & Bio-Remediation) Technology	A newer technology combining bio-digestion with natural remediation for sustainable treatment.

Table 3.2: Performance Comparison Parameters

Parameter	Description
Influent & Effluent Quality	BOD, COD, TSS, TN, TP, Pathogen removal efficiency.
Energy Consumption	kWh per MLD treated.
Sludge Production	Quantity and handling requirements.
Capital and Operating Costs	Installation, operation, and maintenance expenses.
Biogas Production (where applicable)	Amount and usability.
Treatment Time / Hydraulic Retention Time (HRT)	Time taken for wastewater treatment.
Footprint / Land Requirement	Area required for installation.
Operational Complexity	Ease of operation, monitoring, and maintenance.
Environmental Impact	Odor, greenhouse gas emissions, resource recovery.

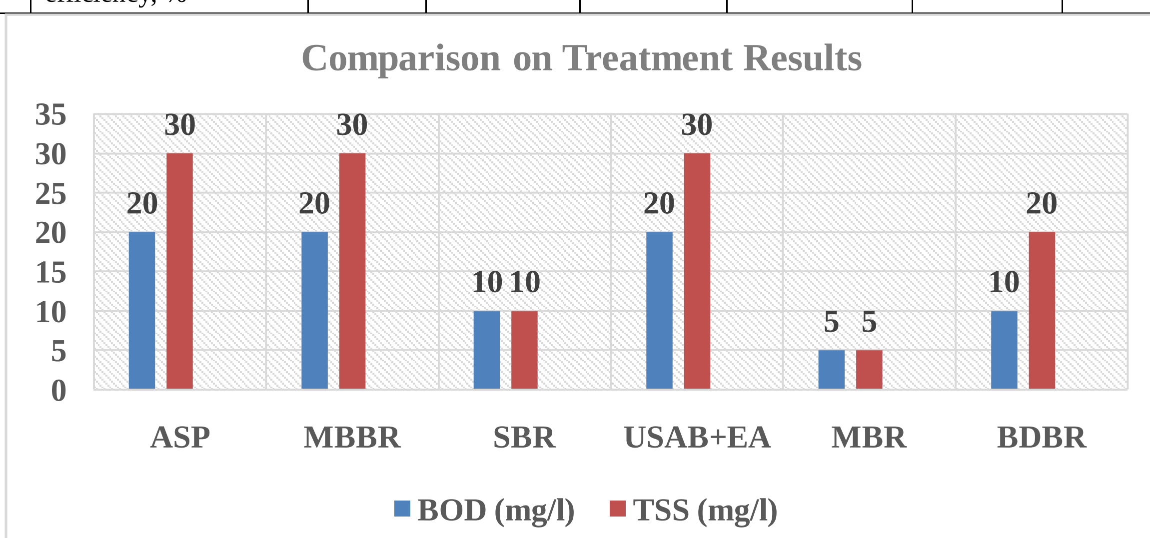
IV. RESULTS AND DISCUSSION

A. PERFORMANCE COMPARISON

A Comparative study of different major technologies for sewage treatment has been made considering key parameters such as performance, efficiency, treatment costs, O&M costs, energy cost and land requirement.

Table 4.1: Comparison on the basis of treatment results

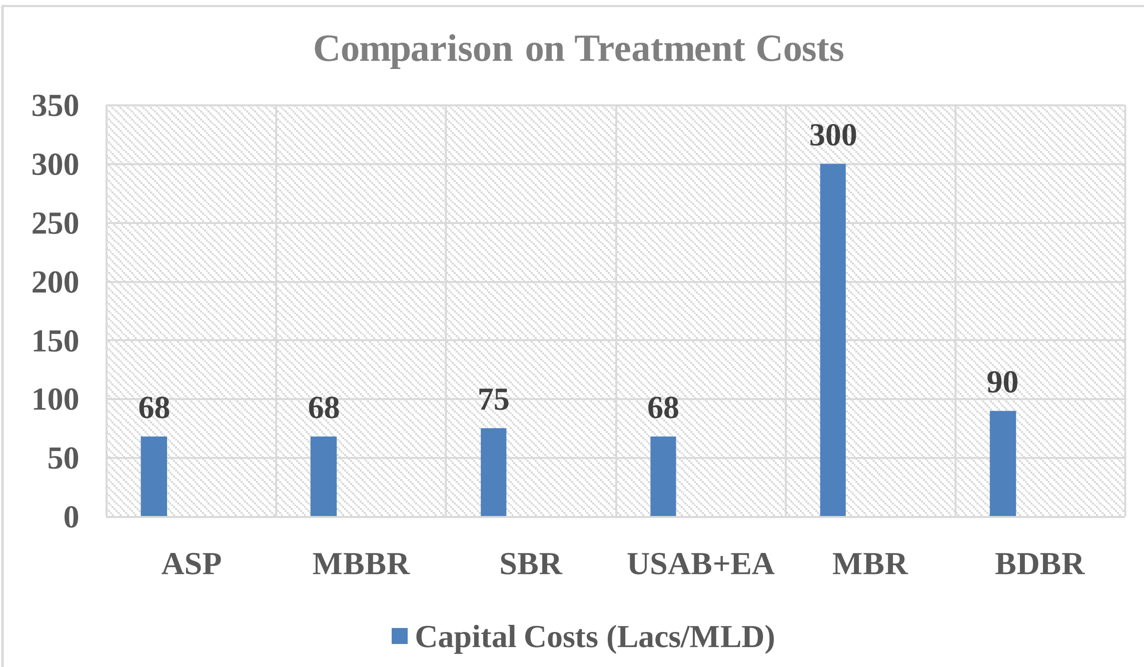
SN	Parameter	ASP	MBBR	SBR	UASB+EA	MBR	BDBR
1.	BOD (mg/l)	<20	<20	<10	<20	<5	<10
2.	TSS (mg/l)	<30	<30	<10	<30	<5	<20
3.	Faecal Coliform, log unit	Upto 2<3	Upto 2<3	Upto 3<4	Upto 2<3	Upto 5<6	Upto 2<3
4.	T-N Removal efficiency, %	10-20	10-20	70-80	10-20	70-80	70-80



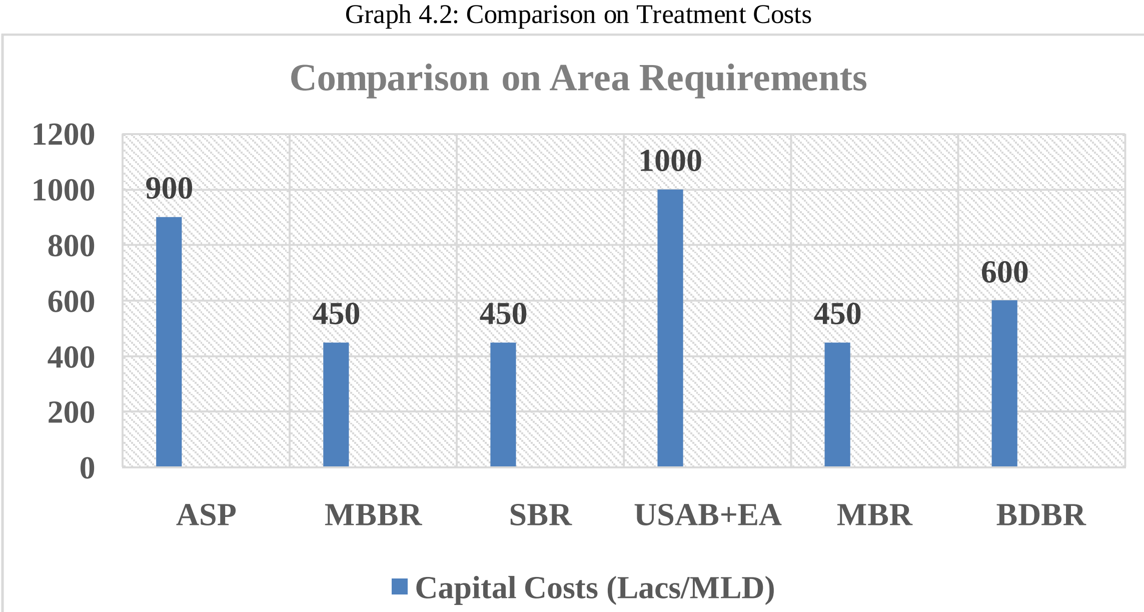
Graph 4.1: Comparison on Treatment Results

Table 4.2: Comparison on the basis of area requirement & treatment costs

SN	Parameter	ASP	MBBR	SBR	UASB+EA	MBR	BDBR
.	Average Area, m^2 per MLD	900	450	450	1000	450	600
.	Average Capital Cost, lacs/MLD	68	68	75	68	300	90
.	Civil Works, % of total capital costs	60	60	30	65	20	60
.	E&M Works, % of total capital costs	40	40	70	35	80	40



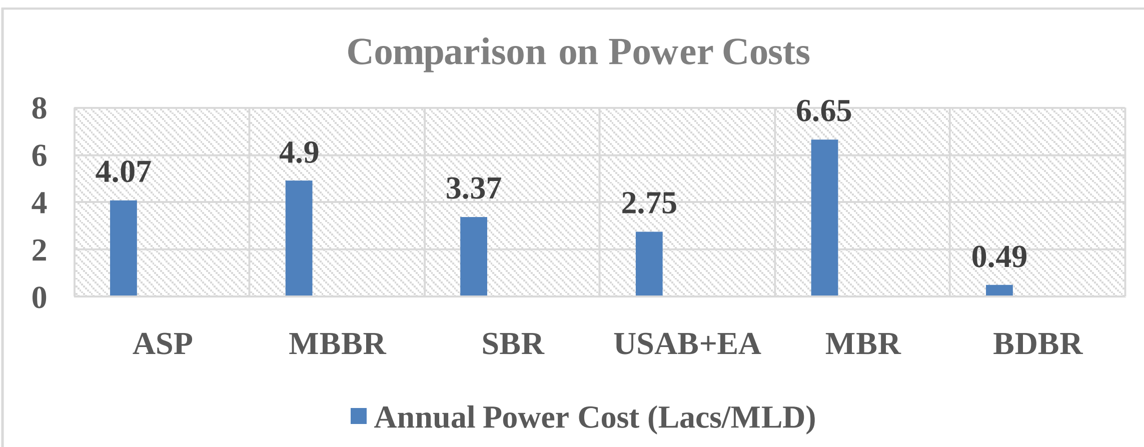
Graph 4.2: Comparison on Treatment Costs



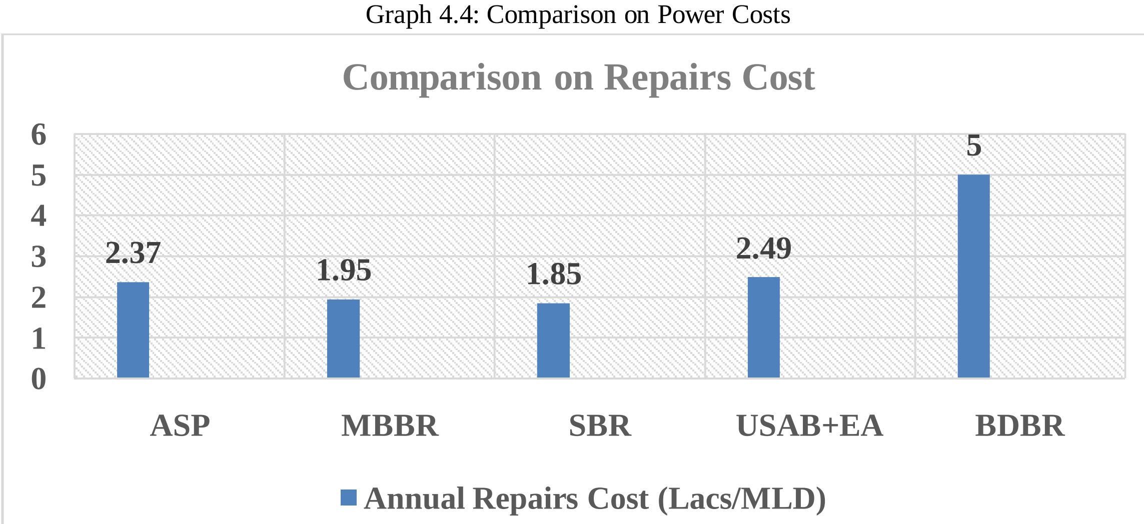
Graph 4.3: Comparison on Area Requirements

Table 4.3: Comparison on the basis of Operation & Maintenance costs

SN	Parameter	ASP	MBBR	SBR	UASB+EA	MBR	BDBR
	Energy cost (Per MLD)						
.	Avg. Technology Power requirement, kWh/d/MLD	180	220	150	120	300	2.00
.	Avg. Technology Power requirement, kWh/d/MLD	4.5	2.50	2.50	4.50	2.50	2.50
.	Total Daily Power Requirement (avg) kWh/d/MLD	184.50	222.50	152.50	124.50	301.50	4.50
.	Daily Power Cost (@6.0 per kWh)/MLD/h (including, standby power cost)	46.43	55.93	38.43	31.43	75.93	1.43
.	Yearly Power cost, lacs pa/MLD	4.07	4.90	3.37	2.75	665	0.49
	Repairs Cost (Per MLD)						
.	Civil works Maintenance, lacs pa/MLD	1.94	1.30	1.04	2.11	-	0.50
.	E&M Works Maintenance, lacs pa/MLD	0.43	0.65	0.81	0.38	-	4.50
.	Annual repair Costs, lacs pa/MLD	2.37	1.95	1.85	2.49	-	5.00



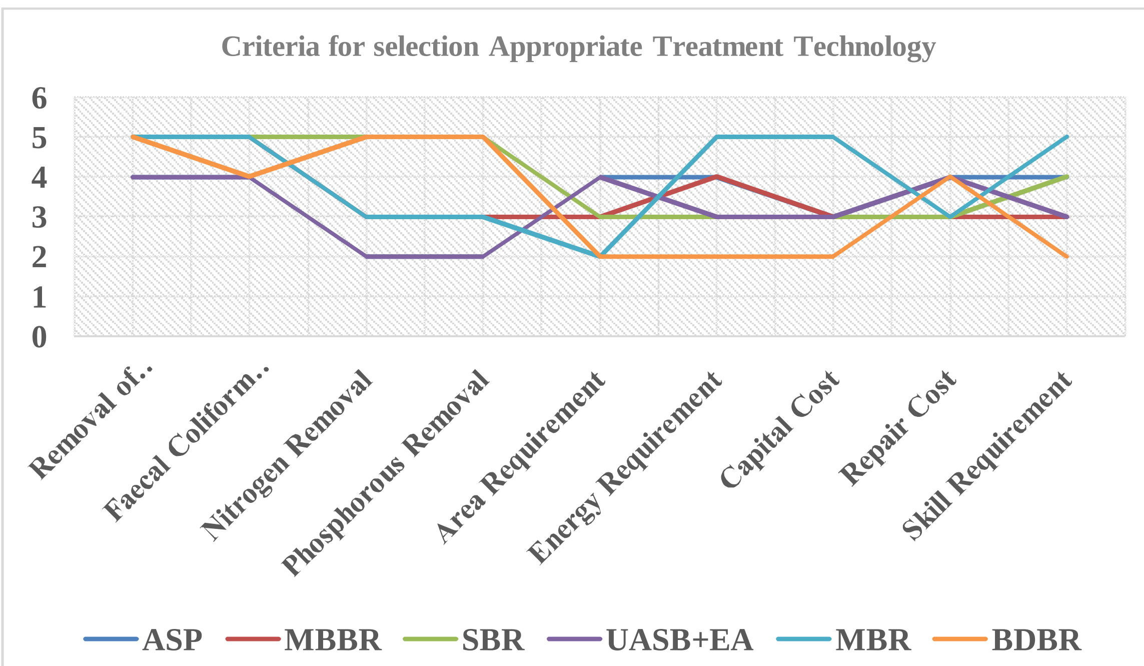
Graph 4.4: Comparison on Power Costs



Graph 4.5: Comparison on Repairs Cost

Table 4.4: Criteria for selection Appropriate Treatment Technology

SN	Parameter	ASP	MBBR	SBR	UASB+EA	MBR	BDBR
.	Removal of BOD, COD, TSS	High	Very High	Very High	High	Very High	Very High
.	Faecal Coliform Removal	High	Very High	Very High	High	Very High	High
.	Nitrogen Removal	Low	Medium	Very High	Low	Medium	Very High
.	Phosphorous Removal	Low	Medium	Very High	Low	Medium	Very High
.	Area Requirement	High	Medium	Medium	High	Low	Low
.	Energy Requirement	High	High	Medium	Medium	Very High	Low
.	Capital Cost	Medium	Medium	Medium	Medium	Very High	Low
.	Repair Cost	High	Medium	Medium	High	Medium	High
.	Skill Requirement	High	Medium	High	Medium	Very High	Low



Graph 4.6: Criteria for selection Appropriate Treatment Technology

The priority in which the options for suggesting the sewage treatment technology is very evident from graph-5.6 it can be concluded that UASB are not applicable because they cannot give the desired treated water quality. Moreover, Activated Sludge process and Moving Bed Bio Reactor process (MBBR) can produce treated water quality but it requires downstream filtration. The overall system becomes expensive from capital and operation point of view. Membrane reactor produces effluent of better quality. However, the running and capital cost for plant based on MBR is extremely high. Thus, on the basis of above study and major factors such as high performance, low area requirement and low capital cost Bio-Digester & Bio-Remediation (BDBR) technology is chosen as the most appropriate technology. BDBR Technology can produce the desired quality of treated water.The most suitable technology for the sewage treatment is the Bio-Digester & Bio-Remediation Technology for following reasons.

- Due to the nature of project, effluent is required for disposal to meet the above standards.

- Modular Approach for provision of Electro – Mechanical units will reduce the initial investment.
- 3-5% Annual operation & maintenance cost.
- Very less power consumption.
- No skilled operator required.
- Low energy demand and environmental impact.

Most suited technology used for municipal plants-

- The method is, therefore, well suited specially for small and medium size communities and zones of a larger city.

Bio-Digester & Bio-Remediation (BDBR) Technology: Maintaining our environment's cleanliness and hygiene depends on sewage treatment facilities.

The ecology and public health are both endangered by the untreated sewage. Sewage treatment is therefore essential to guarantee that it is clean and secure for disposal or reuse. The Bio-Digester Technology for sewage treatment plants was developed by the Defence Research and Development Organisation (DRDO). Sewage treatment facilities that use bio-digester technology offer a ground-breaking approach that is economical, environmentally benign, and requires little upkeep. Anaerobic bacteria are used to break down organic materials in sewage, creating biogas and cleaned water as a byproduct. The cleaned water can either be disposed of in neighbouring bodies of water or recycled for non-potable uses. This technology should be widely used to enhance public health and safeguard the environment because it represents a step towards a more sustainable future.

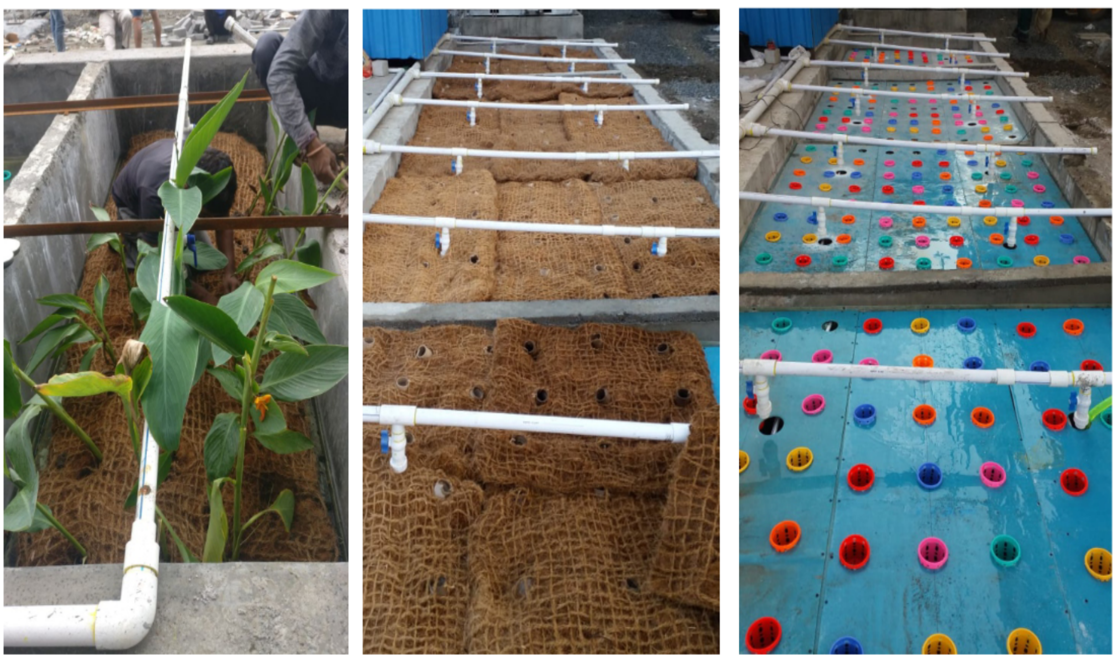


Figure 4.1: Bio-Digester & Bio-Remediation Technology

- *Working Process:*

Anaerobic bacteria are used in sewage treatment facilities as part of the Bio-Digester Technology to break down the organic material in the sewage. Anaerobic bacteria-containing bio-digesters are installed in the anaerobic chamber. These bacteria consume the organic material in the sewage, producing biogas and purified water as a byproduct.Absence of oxygen during the anaerobic digestion process provides the anaerobic bacteria with the perfect conditions for growth. Methane and carbon dioxide are produced when the bacteria in the sewage feed on the organic material. The biogas produced by the anaerobic digestion procedure is collected in a gas holder and can be utilised to create electricity, heat or both.The anaerobic chamber's treated water flows into the tertiary treatment chamber, where it receives additional treatment. The final stage of treatment, known as activated sludge, uses aerobic bacteria to degrade any pathogens and organic materials still present in the water.The treated water must be disinfected in order to get rid of any germs that are still present. Typically, chemicals like chlorine or ultraviolet (UV) radiation are used to do this. Following disinfection, the treated water may be utilised for non-potable tasks like irrigation, flushing, or industrial processes, or it may be released into surrounding bodies of water.Sewage treatment facilities that use Bio-Digester Technology have a number of advantages over those that do not. First off, it is a cost-effective alternative because it uses less electricity and needs little upkeep. Second, it is environmentally benign since it generates biogas, a sustainable energy source, and reuses treated water for non-potable uses, which relieves pressure on freshwater supplies. Thirdly, because it is a decentralised solution, it can be used in tiny towns or far-flung locations where centralised sewage treatment plants are impractical.

- *Bio-Digester & Bio-Remediation Technology Process:*

The raw sewage will be first passed through a Bar Screen Chamber where any extraneous / floating matter would be screened & trapped. The sewage would then be collected in a Raw sewage collection/equalisation tank, where the variations in flow and characteristics are dampened, which otherwise can lead to operational problems and moreover it allows a constant flow rate downstream. Here the sewage will be kept in mixed condition by means of coarse air bubble diffusion.

The sewage water is then taken to Bio-Digester Tank for Treatment of Black water wheredisposal human waste in a 100 % Eco-friendly manner &BOD/COD reduction is achieved by virtue of Anaerobic microbial activities. Then sewage water is taken to an Anoxic tank for reduction in inorganic solids like Total phosphorous and total nitrogen.The sewage will then be pumped to the Bio cord Aeration tank where BOD/COD reduction is achieved by virtue of aerobic microbial activities. The oxygen required will be supplied through fine air bubble diffusers. The excess bio-solids formed in the biological process are separated in the downstream Reed bed Tank where bioremediation of sewage takes place. The clear supernatant after disinfection will be sent to the tertiary polishing section comprising of a Dual Media Filter, Activated Carbon Filter. The treated water may then be used for flushing and irrigation applications. The biological sludge/Silt generated from system will be drained to the Sludge Holding Tank for dewatering.

1) Design basis of 2.0 MLD STP Based on Bio-Digester & Bio-Remediation (BDBR) Technology

Design basis for units of 2.0 MLD Sewage Treatment Plant
Capacity =2000 m^3/day
No of hours of operation =20 hrs/day
Influent sewage water parameters:
pH – 6.5 -9.0
BOD < 300 ppm
COD < 600 ppm
TSS < 300 ppm
Total Nitrogen < 100 ppm
Total Phosphorus < 10 ppm
Faecal Coliform: 10^6 up to 10^8 (MPN)/100ml
Effluent Discharge Standards:
pH – 6.5 -8.5
BOD < 10 ppm
COD < 50 ppm
TSS < 20 ppm
Total Nitrogen < 10 ppm
Total Phosphorus < 1 ppm
Faecal Coliform < 100 MPN/100ml
Peak Factor =3
Peak Flow =3 hours
Flow rate m3/hr = Capacity (m^3/day) / no of hours of operation
= 2000 / 20
Average flow = 100 m^3/hr
Peak Flow = 100 X 3 = 300 m^3/hr

<u>BAR SCREEN CALCULATIONS:</u>
Flow to STP = 2000 m^3/day

Flow to STP on 20 hr Basis = 0.02776 m^3/sec
Peak Factor = 3
Peak flow on hr basis = 3 x 0.02776
Peak flow = 0.08328 m^3/sec
Desired velocity through screen V = 0.3 m/s (At peak flow)
Net area of screen = 0.04166/ 0.3
Area needed = 0.2776 m^2 (Area Needed)
Width provided = 2000 mm
Thus, the size of bar screen provided = 2 X 8 X 0.5 M SWD

RAW SEWAGE/EQUALIZATION TANK CALCULATIONS:
Volume = ((Flow rate x Peak factor)–Flow rate) x Peak flow period
= (100 x 3) – 100.00) x3
Volume required = 600 m^3
Volume provided = 648 m^3
Sizes of Tank provided = 12m x 12m x 4.5 m SWD + free board

BIODIGESTER TANK CALCULATIONS:
Capacity = 2000 m^3/day
Load on Bio-Digester tanks = 300 mg/lit BOD = 300 x 2000/ 2000 = 300 kg/day
No of tanks = 2
Volume per tank = 682.5 m^3
Total Volume of Tanks = 1365 m^3
Sizes of Tank provided = (15m x 13m x 3.5 m SWD + free board) x2
HRT = 13.65 Hrs.

ANOIXIC TANK CALCULATIONS:
Anoxic Reactor Volume = 273 m^3
HRT of the tank =2.73 Hrs
Sizes of Tank provided = (6m x 15m x 3.5 m SWD + free board) x1

BIOCORD AERATION TANK CALCULATIONS:
Capacity = 2000 m^3/day
Load on Biocord tank = 80 mg/lit BOD = 80 x 1000/ 1000 = 800 kg/day
No of tanks = 3
Volume per tank = 260 m^3
Total Volume of Tanks = 780 m^3
HRT = 7.8 Hrs
Sizes of Tank provided = (8m x 13m x 2.5 m SWD + free board) x3

REED BED TANK CALCULATIONS:
Capacity = 2000 m^3/day
Discharge per hour = 100 m^3
No of tanks = 2
Volume per tank = 227.5 m^3
Total Volume of Tanks = 455 m^3
HRT = 4.55 Hrs
Sizes of Tank provided = (14m x 6.5m x 2.5 m SWD + free board) x 2

CHLORINATION TANK CALCULATIONS;

Basis time = 30 Mins
Volume required = (Flow rate x basis time) / 60 = (100 X 30 / 60)
= 50 m^3
Volume provided = 65 m^3
Sizes of Tank provided = (2.5m x 13m x 2 m SWD + free board) x 1

TREATED WATER TANK CALCULATIONS:

Basis time - = 2 Hrs
Volume required = (Flow rate x basis time) = 100 X 2.0 = 200 m^3
Volume provided = 351 m^3
Sizes of Tank provided = (13.5m x 13m x 2 m SWD + free board) x 1

SLUDGE DRYING BED CALCULATIONS:

Total Flow = 2000 m^3/day
Inlet BOD = 300 mg/lit
% BOD converted to sludge = 15%
Total Sludge Generated = 30 kg/day
Consistency = 50 %
Thus, total sludge generated = 15 m^3/day
Sludge Holding Tank volume required 2 days retention = 30 m^3
Volume provided = 36 m^3
Sludge holding tank sizes provided = 8m x 3m x 1.5 m SWD + free board

2) Project Benefits

- Effective technology: The project uses Bio-Digester & Bio-Remediation Technology, which is a space and power saving technology and is a better alternative to conventional wastewater treatment plants. Bio-Digester & Bio-Remediation Technology offers an effective option to the conventional systems made unviable due to scarcity of open space, geographical network of piping, high power and land cost. It has Odourless operations, with a self-regulating system, reduced power consumption, simple to operate, low maintenance requirements and removes pathogenic coli forms.
- Improvement of Environmental Status: The project will contribute to the substantial decrease of pollution caused by the discharge of untreated sewage into the environment. This in turn would improve the quality of water resources such as ground as well as surface water. The contamination of the region's soil is also prevented by the proper collection and disposal of waste water.
- Health Benefits: The proposed project which would ensure the efficient disposal of the waste generation will ultimately bring about social, economic, health and benefits to the community. The allied benefits include reduction in health-care costs related with waterborne and water-related diseases.
- Generation of Employment: The construction phase will have positive effects on employment. During the construction phase, services of local subcontractors will be used which will generate job opportunities for skilled and unskilled workers in addition to professional services of engineers and others.
- Socio-economic Benefits: The Project will promote sustainability of water and wastewater infrastructure to be supported by the Project through high standards of O&M and environmental mitigation and management. The project will enhance the infrastructure of the area with respect to waste water collection and disposal thus enriching the aesthetic appearance of the overall region.
- Reuse of Treated Effluent: The project will promote water conservation measures such as water reuse that will reduce future increases in water demand. The proposed STP project will ensure beneficial reuse of treated sewage for various uses of industry and agricultural activities in and around the project site. The treated sewage sludge which is rich in organic content would serve as low-cost organic manure.

V. CONCLUSION

Upon extensive comparative analysis of key sewage treatment technologies, it is evident that the Bio-Digester & Bio-Remediation (BDBR) system stands out as the most appropriate and efficient solution among the evaluated alternatives. The data indicates that BDBR achieves excellent removal efficiencies for BOD, TSS, and nitrogen, with minimal area requirement and the lowest energy consumption, offering a sustainable advantage over conventional and advanced treatment systems. While technologies like MBR and SBR deliver high effluent quality, they are constrained by significant capital investment and energy demand, which may limit their practical applicability in low-resource settings. ASP and UASB+EA, though economical in terms of setup costs, fail to meet effluent quality standards without supplementary filtration stages, increasing long-term expenses. In contrast, the BDBR system, through its modular and decentralized approach, not only ensures superior treatment performance but also supports energy recovery via biogas production and reduces environmental impact through the reuse of treated water. Its low O&M cost, minimal reliance on skilled manpower, and compatibility with fluctuating influent conditions further strengthen its suitability for widespread adoption in urban and semi-urban regions. Therefore, this study concludes that the BDBR technology, rooted in anaerobic digestion and bioremediation principles, provides a well-balanced and future-ready solution for modern sewage management, aligning with goals of environmental sustainability, economic feasibility, and public health protection.

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