



Comparative Evaluation of Activated Sludge and Membrane Bioreactor Systems in Wastewater Management

M. Siva Jagadish Kumar¹, K. Maria Das², Hepsibah Palivela³, M.V. Raju⁴

¹Assistant Professor, Department of Textile Technology, Vignan's Foundation for Science Technology and Research, Deemed to be University, Guntur, Andhra Pradesh, India.

²Assistant Professor, Department of Chemistry, School of ASH, Vignan's Foundation for Science Technology and Research, Deemed to be University, Guntur, Andhra Pradesh, India.

³Project Manager, HVM. India, Vuyyuru, Krishna District, Andhra Pradesh, India.

⁴Assistant Professor, Department of Civil Engineering, Vignan's Foundation for Science Technology and Research, Deemed to be University, Guntur, Andhra Pradesh, India.

(Received: 29 January 2026

Revised: 25 March 2026

Accepted: 30 April 2026)

KEYWORDS

Activated Sludge Process (ASP), Membrane Bioreactor (MBR), Wastewater Treatment, Treatment Efficiency, Sludge Management

ABSTRACT:

Wastewater management is a critical component of environmental engineering and public health, ensuring the safe treatment and disposal of municipal and industrial effluents. Among biological treatment technologies, the Activated Sludge Process (ASP) and Membrane Bioreactor (MBR) systems are widely adopted due to their effectiveness in removing organic pollutants and pathogens. This study presents a comprehensive comparative evaluation of these two systems based on operational principles, treatment efficiency, energy consumption, economic feasibility, and environmental impact. The ASP, a conventional and extensively used method, is valued for its simplicity and cost-effectiveness but is limited by large land requirements, sludge handling issues, and moderate nutrient removal efficiency. In contrast, MBR technology integrates biological treatment with membrane filtration, offering superior effluent quality, reduced footprint, and enhanced operational stability. However, MBR systems are associated with higher energy demand, membrane fouling, and increased capital and operational costs. This study highlights that ASP remains suitable for large-scale, cost-sensitive applications, whereas MBR systems are more appropriate for scenarios requiring high effluent quality and space efficiency. The findings aim to support informed decision-making in selecting appropriate wastewater treatment technologies.

1. Introduction

Water is an essential resource for human survival, economic development, and ecological sustainability. Rapid urbanization, industrialization, and population growth have significantly increased wastewater generation, creating major challenges for effective water quality management. Efficient wastewater treatment is crucial not only for environmental protection but also for enabling water reuse, particularly in water-scarce regions.

Biological treatment processes play a central role in wastewater treatment due to their ability to remove organic matter and nutrients through microbial activity. Among these, the Activated Sludge Process (ASP) has long been the backbone of conventional treatment systems. Developed in the early 20th century, ASP involves aerating wastewater to promote microbial degradation of organic pollutants. Despite its advantages, ASP requires large land areas and is prone to operational issues such as sludge bulking and limited



nutrient removal efficiency. To address these limitations, Membrane Bioreactor (MBR) technology was developed. MBR systems combine biological degradation with membrane filtration, eliminating the need for secondary clarifiers. This integration allows for the production of high-quality effluent suitable for reuse while significantly reducing the treatment plant footprint. However, MBR systems face challenges such as membrane fouling, higher energy consumption, and increased operational complexity. This study aims to compare ASP and MBR systems based on treatment performance, operational parameters, economic aspects, and environmental impacts. The objective is to provide a comprehensive understanding of their advantages and limitations to guide technology selection in modern wastewater management.

2. Literature Review

2.1 Historical Development and Process Design

The Activated Sludge Process has been widely used due to its operational simplicity and cost-effectiveness. It consists of aeration tanks and secondary clarifiers for biological treatment and solid-liquid separation.

MBR technology, introduced in the late 20th century, integrates membrane filtration (microfiltration or ultrafiltration) with biological processes, enabling higher effluent quality and compact system design.

2.2 Treatment Efficiency

MBR systems consistently achieve higher removal efficiencies (>96%) for BOD, COD, and TSS compared to ASP systems (86–90%). Additionally, MBR systems demonstrate superior removal of pathogens and emerging contaminants.

2.3 Land Requirement

MBR systems require significantly less space—up to 50% less—due to the elimination of secondary clarifiers and higher biomass concentration.

2.4 Energy Consumption

MBR systems consume more energy (0.7–1.3 kWh/m³) compared to ASP systems (0.3–0.7 kWh/m³), primarily due to membrane aeration and maintenance.

2.5 Sludge Production

MBR systems produce less sludge due to longer sludge retention times (SRT), reducing disposal costs.

2.6 Operational Challenges

Membrane fouling remains a major issue in MBR systems, requiring periodic cleaning and increasing operational costs. ASP systems, on the other hand, face issues like sludge bulking.

2.7 Application Suitability

ASP is preferred for large-scale municipal applications, while MBR is ideal for urban areas, decentralized systems, and water reuse applications.

3. Discussion

3.1 Treatment Efficiency

Both ASP and MBR systems effectively remove organic pollutants. However, MBR systems demonstrate superior performance:

ASP: BOD removal: 90–94%, COD removal: 86–90%

MBR: BOD removal: >97%, COD removal: 90–96%

MBR systems also achieve lower TSS (<6 mg/L) compared to ASP (15–25 mg/L), producing clearer effluent.

3.2 Nutrient and Contaminant Removal

MBR systems provide better nutrient removal and are more effective in removing micropollutants due to longer SRT and membrane filtration.

3.3 Operational Stability

MBR systems are more resilient to fluctuations in hydraulic and organic loads. ASP systems may experience performance instability under peak loading conditions.

3.4 Energy Consumption

ASP: 0.3–0.7 kWh/m³

MBR: 0.7–1.3 kWh/m³

Despite higher energy use, advancements in membrane technology are improving efficiency.



3.5 Footprint

MBR systems require 35–55% less space, making them suitable for urban areas.

3.6 Sludge Management

MBR systems produce 35–55% less sludge, reducing disposal costs and handling requirements.

3.7 Economic Analysis

CAPEX: MBR is 25–39% higher than ASP

OPEX: Higher for MBR due to energy and maintenance

However, lifecycle costs may favor MBR when water reuse and land costs are considered.

3.8 Environmental Impact

While ASP has a lower direct energy footprint, MBR systems enable water reuse, reducing overall environmental impact.

4. Conclusion

This study highlights the comparative advantages and limitations of ASP and MBR systems. ASP remains a reliable and cost-effective solution for large-scale wastewater treatment with moderate effluent quality requirements. In contrast, MBR systems provide superior effluent quality, reduced footprint, and enhanced operational stability, making them suitable for modern applications requiring water reuse and stringent discharge standards.

Although MBR systems involve higher initial and operational costs, their long-term benefits—especially in water-scarce and urban regions—make them a promising solution for sustainable wastewater management.

The selection between ASP and MBR should be based on site-specific factors such as regulatory requirements, land availability, economic constraints, and sustainability goals.

5. References

1. APHA (1998). *Standard Methods for the Examination of Water and Wastewater*, 20th Edition. American Public Health Association, Washington DC.
2. Asadi, S. S., Rajyalakshmi, K., Kumar, M. S., & Kumar, N. V. (2017). Evaluation of surface water characteristics using remote sensing and GIS-A model study. *International Journal of Civil Engineering and Technology*, 8(9), 1002-1012.
3. Asadi, S. S., Aswitha, K., Hari Chandana, L., & Raju, M. V. (2017). Assessment and evaluation of fluoride concentration in Groundwater of Palnadu Region: A model study. *International Journal of Civil Engineering and Technology*, 8(3), 785-797.
4. Anjaneyulu, Y. (2002). *Environmental Impact Assessment Methodologies*. B.S. Publications.
5. Asadi, S. S., Rao, B. V., Raju, M. V., & Sagar, M. A. (2011). Creation of Information System for Identification of Ground Water Pollution Prevention Zones Using Remote sensing and GIS: A Model Study. *International Journal of Emerging Technology and Advanced Engineering*, 1(2), 145-150.
6. Chanikya P, Raju M (2025) In-Situ Coagulant Generation in Electrocoagulation for Textile Dye Effluent Treatment: Comparative Performance of Fe–Fe, Al–Al, and Cu–Cu Electrode Systems. *J Chem Health Risks* 15(6).
7. Chen, J. et al. (2018). Fouling behavior in MBRs. *Bioresource Technology*, 244, 1152–1160.
8. Charles David, Karpagaraj A, Shobin Loukkose Rosemary, Vallayachari Kommoju, Kuppam Chandrasekhar, Chanikya Pinapala, Raju M. V, Syam Babu Davuluri (2025). Strategy for enhanced treatment of distillery spent wash effluent with aluminum nanoparticle-assisted electrocoagulation. *Chemical Engineering Communications*, 212(11), 1750-1764.
9. Le-Clech, P. et al. (2006). Fouling in MBRs. *Journal of Membrane Science*, 284, 17–53.
10. Kumar, M. S., Raju, M. V., Babu, S. R., & Kumar, M. S. J. (2017). Interpretation and correlative study of water simulation in surface water bodies. *International Journal of Civil Engineering and Technology (IJCIET)*, 8(5), 1206-1211.
11. Raju, M. V., Mariadas, K., Palivela, H., Ramesh Babu, S., & Raja Krishna Prasad, N. (2018). Mitigation plans to overcome environmental issues:



- A model study. *International Journal of Civil Engineering and Technology*, 9(10), 86-94.
12. Raju, M. V., Kumar, M. S., Akram, M. B. W., Vardhan, T. R., & Palivela, H. (2020). Salt Water Intrusion and Delineation of Groundwater Quality at Coastal Aquifers. *International Journal of Engineering and Advanced Technology (IJEAT)*, 9(3), 1746-1750.
 13. Judd, S. (2011). *The MBR Book* (2nd ed.). Elsevier.
 14. MV, R., & K Maria, D. (2020). Green Engineering Strategies on Solid Waste Management to Promote Urban Environmental Sustainability. *International Journal of Advanced Science and Technology*, 29(5), 4638-4648.
 15. MV, R., K Maria, D., & Cyril Lucy, M. (2020). Rapid Environmental Impact Assessment of Lake Water. *International Journal of Advanced Science and Technology*, 29(3), 8468-8478.
 16. Meng, F. et al. (2009). Recent advances in MBRs. *Water Research*, 43(6), 1489–1512.
 17. P. Joshua Reginald, M.V. Raju, D. Satyanarayana, K. Mariadas, M. Satish Kumar. (2021). Kisaan Seva- Aadhaar Linked Smart Farming Application. *Annals of the Romanian Society for Cell Biology*, 5168–5176.
 18. Kumar, M. S., Raju, M. V., & Palivela, H. (2017). An overview of managing municipal Solid waste in urban areas-A model study. *International Journal of Civil Engineering and Technology*, 8(5).
 19. Kumar, T. C. A., Sivaramkrishnan, M., Arshad, H., Raju, M. V., & Kumar, N. B. (2021). Smart river floating garbage cleaning robot using iot and embedded system. *Design Engineering*, 1455-1460.
 20. Kumar, M. S., Raju, M. V., Kumatr, G. V. R., & Palivela, H. (2017). Evaluation of Groundwater Pattern in Black Cotton Soils Using Geo Spatial Technology–A Model Study. *International Journal of Civil Engineering and Technology*, 8(5).
 21. KM Das, M.V. Raju, MS Kumar, AR Rao, (2020), Groundwater Suitability for Drinking at Part of Tenali Municipal Corporation, Guntur District, Andhra Pradesh, India, *Indian Journal of Ecology* 47 (Special Issue (11)), 75-79.
 22. Kumar, M. S., & Raju, M. V. G. Venu Ratna Kumari, Evaluation of groundwater pattern in block cotton soils using geospatial technology–A Model study. *International Journal of Civil Engineering and Technology (IJCIET) Volume*, (8), 851-855.
 23. Kumari, G. V. R., Raju, M. V., Kumar, M. S., Das, K. M., & Satyanarayana, D. (2023,June). Solid waste management: A case study. In 5TH International conference on innovative design, analysis & development practices in aerospace & automotive engineering: I-DAD'22 (Vol. 2766, No. 1, p. 020085). AIP Publishing LLC.
 24. MV, R., & K Maria, D. (2020). Green Engineering Strategies on Solid Waste Management to Promote Urban Environmental Sustainability. *International Journal of Advanced Science and Technology*, 29(5), 4638-4648.
 25. Monica, C. L., Raju, M. V., Kumar, D. V., Babu, S. R., & Asadi, S. S. (2018). Assessment of physiochemical characteristics and suitability study of for domestic purpose: A model study. *International Journal of Civil Engineering and Technology (IJCIET)*, 9(9), 1357-1367.
 26. Monica, C. L., Raju, M. V., Kumar, D. V., Babu, S. R., & Asadi, S. (2018). Assessment of heavy metal concentrations and suitability study of ground water (bore wells) quality for construction purpose: A model study. *Int. J. Civ. Eng. Technol*, 9, 1273-1282.
 27. Moparathi, G. K. S., & Raju, M. V. (2016). Field kits for water quality monitoring–A novel approach. *IJSR-International journal of scientific research*, 5, 835-836.
 28. Pandey, P. K., Raju, M. V., Satyanarayana, D., Kumar, M. S., & Das, K. M. (2024). A Critical Review on Application of Waste Plastic as a Valuable Resource in the Construction Industry. *Naturalista Campano*, 28(1), 1281-1289.
 29. Pandey, P. K., Raju, M. V., Satyanarayana, D., Kumar, M. S., & Das, K. M. (2024). A Critical Review on Application of Waste Plastic as a Valuable Resource in the Construction Industry. *Naturalista Campano*, 28(1), 1281-1289.
 30. Prasadini, T. V., Srinivasu, N., & Raju, M. V. (2019). The future of chlorine disinfectant choice in rural areas. *International Journal of Innovative*



- Technology and Exploring Engineering, 8(8), 1813-1817.
31. Prasadini, T. V., Srinivasu, N., & Raju, M. V. (2019). Evaluation of bacteriological quality characteristics of drinking waters of few village sources in coastal areas of bhimavaram region at West Godavari district, India. *International Journal of Recent Technology and Engineering*, 8(2), 888-892.
32. Raju, M. V., Rao, L. N., Mariadas, K., Kumar, M. S. J., & Babu, S. R. (2019). A study on metals recovery from the waste water effluents in electroplating industry. *International Journal of Civil Engineering and Technology*, 10(02), 1033-1040.
33. Raju, M. V., Asadi, S. S., Satish Kumar, M., & Palivela, H. (2017). Evaluation of cost and time impacts to overruns in construction industry. *International Journal of Civil Engineering and Technology*, 8(4), 1416-1424.
34. Raju, M. V., Das, K. M., Akram, M. B. W., Vardhan, T. R., & Palivela, H. (2019). Water Quality Evaluation of Aquaculture Practices in Coastal Area of Bhimavaram at West Godavari District. *Andhra Pradesh*, 11, 1088-1094.
35. Raju, M. V., Kumari, G. V. R., Mariadas, K., Palivela, H., & Babu, S. R. (2018). Evaluation and remediation of sludge from municipal solid waste dumping sites: A model study. *International Journal of Civil Engineering and Technology (IJCIET) Volume*, 9, 591-599.
36. Raju, M. V., Satish Kumar, M., Venu Ratna Kumari, G., & Ramesh Babu, S. R. (2018). An investigative study on water quality distribution in the zones of municipal corporation using remote sensing and gis applications. *International Journal of Civil Engineering and Technology*, 9(6), 1182-1190.
37. Raju, M. V., Kumar, M. S., Palivela, H., & Kumari, G. V. R. (2017). A Systematic Approach for the Assessment of Environmental Quality at Thermal Power Plants Using Geo Spatial Technology: A Model Study. *International Journal of Civil Engineering and Technology*, 8(5), 224-229.
38. Sai, R. H. N., Madhavi, B., Reginald, P. J., Kumar, P. S., & Raju, M. V. (2025). Tracing The Pathways And Health Risks Of Microplastics In The Food Chain. *Metallurgical and Materials Engineering*, 1448-1454.
39. Sathishkumar, M., Hepibah Palivela MV RAJU, and G. Venu Ratna Kumari. "Water Quality Scenario of Urban Polluted Lakes-A Model Study International Journal of Civil Engineering and Technology." (2017): 8(5), 297-302.
40. Soumya, A., Raju, M. V., Asadi, S. S., Das, K. M., & Kumar, T. C. A. (2019). Interpretation of Glacial lakes and Water Bodies in the Himalayan Region to Control Natural Hazards using Geospatial Technology. *International Journal of Advanced Science and Technology*, 28(16), 1356-1365.
41. SSA, VHR P. Pallavi, M.V.Raju, (2016), Study the Treatment Process in 20 MLD of S.T.P., 3rd National Conference on Water, Environment and Society. ISBN: 978-98-5230.
42. Tchobanoglous, G., Burton, F. L., & Stensel, H. D. (2014). *Wastewater Engineering: Treatment and Resource Recovery* (5th ed.). McGraw-Hill.
43. U.S. EPA (2007). *Membrane Bioreactor Systems Report*.
44. Vutukuru, S. S., Asadi, S. S., Vasantha, R. B. V. T., & Raju, M. V. (2012). Plankton biodiversity as indicators of the ecological status of River Moosi, Hyderabad, India. *International Journal of Earth Science and Engineering*, 5(3), 587-592.
45. Water Environment Federation (2010). *Membrane Systems for Wastewater Treatment*.