

A Comparative Study of Conventional and Advance Wastewater Treatment Options Available: A Systematic Review for Achieving Sustainable Development Goal's

Er Sanwardhan Sangare
KIT's College of Engineering (Empowered
Autonomous), Kolhapur, Maharashtra

Dr. Saurabh Joshi
KIT's College of Engineering (Empowered
Autonomous), Kolhapur, Maharashtra

Abstract - Water resources, public health, and aquatic ecosystems all depend on wastewater treatment, especially in light of the growing complexity of pollutants produced by industrial, agricultural, and residential activities. In order to remove suspended particles, organic matter, nutrients, heavy metals, micropollutants, and new contaminants, this paper gives an overview of both traditional and cutting-edge wastewater treatment technology. While sophisticated techniques like adsorption, membrane filtration, reverse osmosis, advanced oxidation processes, electrochemical treatment, photocatalysis, nanotechnology, microalgae-based treatment, and hybrid systems offer better removal of persistent and complex contaminants, conventional processes like screening, sedimentation, coagulation, flocculation, and biological treatment are still crucial for the efficient removal of basic pollutants. As elements of sustainable wastewater management, the reviewed research also shows growing interest in wastewater reuse, resource recovery, adsorbents produced from agricultural waste, biofertilizer and biofuel generation, and decentralized treatment systems. High energy consumption, capital and operating expenses, electrode and membrane fouling, sludge production, regeneration needs, process complexity, and difficulty with large-scale application continue to be major obstacles. In general, a potential route toward effective, affordable, and sustainable wastewater treatment and water reuse is provided by the combination of traditional and cutting-edge treatment technologies, resource recovery, and circular economy strategies. Future studies should concentrate more on pilot-scale validation and real-world application of energy-efficient, affordable, scalable, and ecologically friendly treatment systems.

Keywords Wastewater Treatment; Conventional Treatment; Advanced Treatment; Adsorption; Membrane Technology; Advanced Oxidation Processes; Hybrid Systems; Sustainable Wastewater Management.

I. INTRODUCTION

Wastewater treatment is an important aspect of environmental protection and sustainable water resource management. Untreated or poorly treated wastewater can introduce organic matter, nutrients, heavy metals, suspended solids, Water resources are becoming more complexly contaminated as a result of the growing discharge of industrial, agricultural, and residential wastewater, necessitating the development of effective and sustainable treatment systems. According to the reviewed research, wastewater should be seen as a possible source of recovered water, nutrients, energy, and other value-added goods in addition to being a waste stream. Pathogens and emerging contaminants into aquatic environments.

Conventional wastewater treatment processes remain fundamental to wastewater management. Suspended particles, organic matter, and other traditional contaminants are frequently removed using physical and chemical methods including screening, sedimentation, coagulation, and flocculation in addition to biological treatment. Although the reviewed literature suggests that conventional treatment alone may have limits in eliminating persistent, complex, and developing pollutants, these methods offer a crucial basis for wastewater treatment. As a result, more focus has been placed on cutting-edge treatment technologies that can produce better effluent quality and greater treatment efficiency.

Advanced wastewater treatment includes a wide range of technologies such as adsorption, membrane filtration, reverse osmosis, advanced oxidation processes, electrochemical treatment, photocatalysis, nanotechnology, microalgae-based treatment, and other innovative systems. These methods have shown promise in eliminating micropollutants, heavy metals, nutrients, hard-to-treat pollutants, and other new contaminants. While adsorption and bio-adsorbents provide possible methods for eliminating certain pollutants, membrane-based systems and sophisticated oxidation processes, for instance, can produce high-quality effluent and aid in water reuse. Wastewater treatment, nutrient recovery, and the creation of valuable biomass and value-added products may all be supported concurrently by microalgal systems.

Despite these benefits, there are a number of difficulties in using cutting-edge technologies. The evaluated research consistently points to high energy consumption, capital and operating expenses, membrane or electrode fouling, adsorbent renewal, sludge and by-product formation, operational complexity, and challenges related to large-scale application. Additionally, wastewater parameters, operational circumstances, desired effluent quality, and economic factors all affect how successful a particular treatment technology is. As a result, no single treatment method can be said to be universally appropriate for all wastewater treatment needs.

Recent research has consequently shifted toward integrated and hybrid treatment systems that combine conventional and advanced processes. Pollutant removal, effluent quality, water reuse, and resource recovery prospects can all be enhanced by such integration. Sustainable methods like using agricultural waste as bio-adsorbents, microalgae for nutrient recovery and value-added products, decentralized treatment systems, processes supported by renewable energy, and turning wastewater treatment residues into valuable resources are also highlighted in the reviewed studies. These methods aid in the creation of wastewater management systems that are resource-efficient and circular.

In this context, the current analysis looks at both traditional and cutting-edge wastewater treatment technologies, their treatment capacities, benefits, drawbacks, and possible uses for sustainable wastewater management. The assessment focuses on how enhanced treatment, water reuse, resource recovery, and integrated treatment technologies are replacing traditional methods of removing pollutants. It also identifies future research needs, such as the creation of low-cost and energy-efficient systems, pilot-scale validation, enhanced resource recovery, and sustainable large-scale applications, and takes into account the main obstacles affecting the practical application of these technologies. Overall, the reviewed literature indicates that a potential strategy for increasing wastewater treatment efficiency while promoting long-term water-resource sustainability is the right mix of traditional and innovative treatment methods.

II. REVIEW OF LITERATURE

A. Innovations and fresh perspectives on recent developments in wastewater treatment technology.

The author states that, the wastewater contains a wide variety of pollutants, including organic compounds, heavy metals, dyes, pharmaceuticals, and other emerging contaminants. Conventional treatment methods are effective for many common pollutants but have limitations in removing persistent and complex contaminants. In this review we describe recent advances in wastewater treatment, including adsorption, membrane processes, advanced oxidation, electrochemical treatment, photocatalysis, nanotechnology, hybrid systems. These technologies have better removal of pollutants and better quality of effluent, but there are still problems like energy consumption, membrane fouling, material regeneration,

sludge generation and cost of treatment. The review also highlights the potential of artificial intelligence and machine learning for process monitoring, optimization, prediction, and predictive maintenance. The combination of the traditional and advanced technologies can provide more efficient, economical and sustainable solutions for the future wastewater treatment.

The research demonstrates that while traditional wastewater treatment is still crucial, it frequently fails to remove complex and newly developing pollutants. Adsorption, membrane filtration, enhanced oxidation, electrochemical treatment, photocatalysis, and nanotechnology are examples of effective alternative technologies. However, energy needs, operating expenses, fouling, regeneration, and by-product creation restrict their widespread use. Better process control, sustainability, and treatment efficiency can result from hybrid treatment systems and the use of artificial intelligence and machine learning. Low-cost materials, renewable energy, resource recovery, and scalable treatment systems should all be the focus of future research. One potential strategy for effective and sustainable wastewater treatment in general is the merging of traditional and cutting-edge technology.

B. Utilizing inexpensive, sustainable biochar to remove harmful heavy metals from aquatic systems: An analysis.

The author explains that the increasing discharge of domestic, agricultural and industrial wastewaters has led to the presence of a wide variety of organic, inorganic and emerging contaminants in water bodies. The review includes conventional and advanced wastewater treatment technologies such as biological treatment, adsorption, membrane processes, advanced oxidation, electrochemical treatment, and photocatalysis. Advantages and limitations of these technologies to remove different types of pollutants are also discussed. Advanced and hybrid treatment methods are found more efficient than the conventional methods. However, high cost of operation, energy consumption, fouling and process complexity still remain major challenges. The review also points to the potential for new technologies and AI based methods to enhance the efficiency and sustainability of the treatment. Finally, a mix of traditional and new treatment methods provides a hopeful strategy for effective and environmentally friendly wastewater treatment.

In order to lower pollution and safeguard water resources, wastewater treatment is essential. This research demonstrates that while traditional treatment techniques are useful for eliminating simple pollutants, they are not as successful at handling complex and newly emergent contaminants. enhanced technologies that might increase the removal efficiency include adsorption, membrane treatment, enhanced oxidation, electrochemical procedures, and photocatalysis. Nevertheless, the use of these is hampered by issues with high energy consumption, operating expenses, fouling, and other technological constraints. Therefore, for effective and sustainable wastewater treatment, a combination of traditional, cutting-edge, and hybrid treatment technologies should be employed. For

large-scale and sustainable wastewater treatment, more research is required to provide affordable materials, energy-efficient procedures, resource recovery, and the use of cutting-edge technology.

C. Quick photocatalytic breakdown of phenol from water with composite nanofibers in the presence of UV light.

The study demonstrates that the significance of creating effective and sustainable solutions for the treatment of wastewater including a variety of organic, inorganic, and emergent pollutants is illustrated by this review. The research examines both traditional and cutting-edge techniques for treating wastewater, such as membrane processes, biological treatment, adsorption, enhanced oxidation, electrochemical treatment, and photocatalysis. The results show that while basic pollutants may be effectively removed using traditional methods, complex and persistent contaminants can be better removed using advanced and hybrid technology. However, their widespread use is constrained by issues such as high energy consumption, operating expenses, membrane fouling, and process complexity. The assessment also emphasizes how new technology and AI-based methods might enhance process optimization and treatment effectiveness. All things considered, combining traditional and cutting-edge treatment techniques can result in wastewater management systems that are more effective, affordable, and sustainable.

Wastewater treatment is essential for controlling water pollution and protecting water resources. Conventional pollutants can be effectively removed using traditional treatment procedures, while complex and developing contaminants are difficult to handle. Adsorption, membrane processes, enhanced oxidation, electrochemical treatment, and photocatalysis are examples of advanced technologies that have demonstrated improved potential for increased pollution removal efficiency. The problems with energy consumption, operational costs, fouling, and process complexity, however, still need to be resolved. Treatment performance and sustainability can be enhanced by combining traditional and cutting-edge methods. Future studies should concentrate on creating environmentally benign, economical, and energy-efficient treatment systems for widespread use. In conclusion, combining the various treatment methods can offer a practical and long-lasting wastewater management solution.

D. Treatment Methods for Microplastics in Water Treatment Facilities: Conventional and Advanced.

The author describes those current advancements in wastewater treatment methods for the efficient removal of different organic, inorganic, and developing pollutants are the main emphasis of this study. Although improved technologies are being developed to address the limits of conventional approaches, conventional methods are still frequently employed to remove common contaminants. The main treatment techniques—biological therapy, adsorption, membrane processes, advanced oxidation, electrochemical treatment, and photocatalysis—are highlighted in this study. These methods shown potential for improving treated water

quality and eliminating contaminants. However, there are still issues with treatment costs, energy usage, fouling, operational complexity, and large-scale application. The significance of combining traditional and cutting-edge treatment techniques to increase overall treatment sustainability and efficiency. The development of economical, energy-efficient, and ecologically friendly technology must continue in order to handle waste waters effectively and sustainably.

In order to handle the growing complexity of wastewater contaminants, wastewater treatment technologies have advanced dramatically. While cutting-edge technologies offer superior treatment for persistent and developing pollutants, conventional treatment methods are still crucial for eliminating fundamental contaminants. Promising outcomes in increasing treatment efficiency have been demonstrated using adsorption, membrane processes, advanced oxidation, electrochemical treatment, and photocatalysis. Cost, energy consumption, fouling, and large-scale application issues still need to be resolved, however. The overall effectiveness and sustainability of therapy can be enhanced by combining traditional and cutting-edge techniques. Developing economical, energy-efficient, and ecologically friendly technology for real-world use should be the main goal of future research. All things considered, there is a great deal of promise for effective and sustainable wastewater management using modern and integrated treatment methods.

E. Modern and Conventional Wastewater Treatment Techniques.

This review focuses on both conventional and cutting-edge wastewater treatment techniques and how they are used in various treatment systems. The evaluation covers traditional primary, secondary, and tertiary treatment procedures in addition to small-scale block-modular therapy systems. The function of a number of techniques in wastewater treatment is investigated, including sedimentation, coagulation, flocculation, biological treatment, adsorption, ion exchange, membrane processes, reverse osmosis, and nutrient removal. The methods under consideration show promise in eliminating organic matter, nutrients, dissolved pollutants, suspended particles, and other impurities from wastewater. The report also emphasizes how crucial it is to choose appropriate treatment methods based on wastewater properties and treatment needs. All things considered, combining conventional and cutting-edge treatment techniques offers a successful strategy for enhancing effluent quality and promoting effective wastewater management.

Wastewater treatment necessitates the appropriate selection and combination of treatment techniques based on the wastewater's properties and the desired effluent quality. For the removal of suspended particles and organic matter, conventional techniques including screening, sedimentation, coagulation, flocculation, and biological treatment are crucial. The quality of treated wastewater can be further enhanced by advanced and tertiary techniques such as adsorption, ion exchange, membrane processes, reverse

osmosis, and nutrient removal. For areas with low and erratic wastewater flows, small-scale block-modular systems are also a practical choice. All things considered, combining conventional and cutting-edge treatment techniques can increase treatment effectiveness and provide higher-quality wastewater for safe discharge and possible reuse.

F. Conventional and sophisticated techniques of treating water: A comparative analysis of Malaysia and a few other nations.

The author focuses on both conventional and cutting-edge wastewater treatment techniques and how they are used in various treatment systems. The evaluation covers traditional primary, secondary, and tertiary treatment procedures in addition to small-scale block-modular therapy systems. The function of a number of techniques in wastewater treatment is investigated, including sedimentation, coagulation, flocculation, biological treatment, adsorption, ion exchange, membrane processes, reverse osmosis, and nutrient removal. The methods under consideration show promise in eliminating organic matter, nutrients, dissolved pollutants, suspended particles, and other impurities from wastewater. The report also emphasizes how crucial it is to choose appropriate treatment methods based on wastewater properties and treatment needs. All things considered, combining conventional and cutting-edge treatment techniques offers a successful strategy for enhancing effluent quality and promoting effective wastewater management.

In conclusion, both conventional and cutting-edge wastewater treatment techniques are crucial for enhancing wastewater quality and safeguarding water supplies. While sophisticated techniques like adsorption, ion exchange, membrane processes, reverse osmosis, and nutrient removal offer extra treatment for dissolved pollutants and nutrients, conventional procedures like sedimentation, coagulation, flocculation, and biological treatment are efficient for removing suspended solids and organic matter. The target effluent quality, treatment needs, and wastewater characteristics all influence the choice of appropriate treatment techniques. All things considered, the right mix of conventional and cutting-edge treatment methods can increase treatment effectiveness and offer a practical strategy for sustainable wastewater management.

G. Using Resource Recovery and Reuse in Advanced Wastewater Treatment Technologies to Address Future Water Scarcity.

This author examined the importance of both conventional and cutting-edge wastewater treatment technologies in enhancing wastewater quality is the main topic of this review. There includes discussion of a number of treatment techniques, including as sedimentation, coagulation, biological treatment, adsorption, ion exchange, membrane filtration, reverse osmosis, primary, secondary, and tertiary treatment, and nutrient removal. The methods under consideration show how well they remove nutrients, dissolved pollutants, suspended particles, organic matter,

and other impurities. The review also emphasizes how crucial it is to choose appropriate treatment methods based on wastewater properties, treatment needs, cost, and operational circumstances. All things considered, combining conventional and cutting-edge treatment techniques offers a successful strategy for raising treatment effectiveness and promoting sustainable wastewater management.

Traditional and advanced wastewater treatment methods are important for the effective removal of different types of pollutants from wastewater. Conventional processes such as sedimentation, coagulation, flocculation, and biological treatment provide effective removal of suspended solids and organic matter, while advanced methods such as adsorption, ion exchange, membrane filtration, reverse osmosis, and nutrient removal can further improve treated water quality. The selection of treatment methods depends on wastewater characteristics, required effluent quality, cost, and operational conditions. The proper combination of different treatment processes can improve treatment efficiency and support wastewater reuse. Overall, integrated traditional and advanced treatment technologies provide a suitable approach for effective and sustainable wastewater management.

H. Traditional and Modern Wastewater Treatment Methods; Sustainable Environment Development and Biofertilizer Production.

This author covers conventional and advanced wastewater treatment technologies focusing on sustainable wastewater management and biofertilizer production. It also discusses limitations of conventional techniques such as thermal treatment, ion exchange, adsorption, electrochemical degradation, coagulation and chemical precipitation such as high energy consumption, undesirable by-products and economic issues. The review focuses on advanced technologies such as nanofibrous membrane filtration, enhanced biological phosphorus removal (EBPR), microbial fuel cells (MFCs) and advanced oxidation processes (AOPs). It also points out the possibilities of using the activated sludge from wastewater treatment for biofertilizer production. To summarize, the abstract points out that novel treatment technologies can improve the efficiency of wastewater treatment, promote environmental sustainability, and minimize the adverse effects of water pollution on humans, animals, and ecosystems.

In conclusion the wastewater treatment is essential to protect public health, to protect ecosystems and to develop sustainable water-resource management. It includes conventional and advanced treatment technologies with advanced methods providing enhanced removal of pollutants and opportunities for resource recovery. In particular, the study emphasizes the importance of advanced methods, such as nanofibrous membrane filtration, advanced oxidation processes, microbial fuel cells and constructed wetlands. It also emphasizes the importance of energy efficiency, biogas production, nutrient recovery and conversion of activated sludge to biofertilizers for sustainable wastewater treatment. Decentralized treatment systems are beneficial and applicable in areas with poor

infrastructure. Finally, the study points to emerging contaminants, treatment efficiency, resource recovery, and the research-practice gap as critical challenges and calls for continued research, technological innovation, collaboration and effective policies for sustainable wastewater management.

I. A Review of Current Developments in Biotechnological Applications for Wastewater Treatment Using Microalgae.

The author explains the significance of wastewater treatment and highlights the main drawbacks of traditional treatment techniques, such as high energy needs, undesirable byproducts, and financial issues. It presents cutting-edge technology such microbial fuel cells, improved biological phosphorus removal, nanofibrous membrane filtration, and sophisticated oxidation processes. The abstract's focus on resource recovery and sustainability, especially the transformation of activated sludge into biofertilizers, is one of its main advantages. Nevertheless, the abstract lacks concrete comparison data and quantitative evidence about the effectiveness of the technologies mentioned, and it is more descriptive than analytical. All things considered, it successfully defines the goal and parameters of the evaluation and draws a link between sustainable environmental management and modern wastewater treatment.

The paper's main themes—conventional and advanced wastewater treatment, energy efficiency, resource recovery, decentralized treatment, and regulatory frameworks—are succinctly summarized in the conclusion. It highlights how sophisticated technologies might offer better treatment and chances for resource recovery, including membrane filtration, enhanced oxidation, electrochemical processes, microbial fuel cells, and artificial wetlands. The potential of activated sludge for producing biofertilizer as well as the significance of biogas and nutrient recovery in creating a circular economy are also highlighted in the conclusion. Its ability to identify future challenges—specifically, new pollutants, treatment efficiency, resource recovery, climate-change resilience, and the gap between research and practical implementation—is one of its main strengths. By explicitly contrasting the benefits and drawbacks of various technologies and determining which strategies are most suited for certain wastewater applications, the conclusion might be more crucial.

J. Utilizing Microalgal Systems to Value-Added Products and Biofuel from Wastewater Resources.

The paper provides function of microalgae in wastewater treatment and resource recovery and views wastewater as a potential resource rather than just a waste stream. It describes how nutrients like phosphorus and nitrogen may promote the growth of microalgae while they also eliminate different metals and pollutants like BOD. highlights several microalgal cultivation systems, such as integrated, closed, and open systems. Its emphasis on the microalgal biorefinery idea, which allows biomass produced

during treatment to be transformed into biofuel, feed, biofertilizer, bioplastic, and other value-added products, is one of its main advantages. It acknowledges the significance of elements including pH, temperature, sunshine, and nutrient availability. The possibility of combining wastewater treatment with microalgal production for nutrient recovery, income generation, and the creation of a sustainable circular bioeconomy is persuasively established in the abstract.

In conclusion, microalgae as a viable method for nutrient recovery and sustainable wastewater treatment. It demonstrates how phytoremediation reduces nitrogen, phosphorus, BOD, and COD while producing relatively less waste. the potential of microalgae for use in the manufacture of biofuel, exopolysaccharides, and bioplastics, both economically and environmentally. However, it acknowledges significant constraints that may impede large-scale commercial applicability, especially the challenges related to microalgal biomass collecting and downstream purification. It also highlights the necessity to maintain ideal operating conditions based on the intended final product, wastewater parameters, and algal strain. Overall, the result highlights sustainable processing and value-added product recovery as crucial areas for future growth and firmly supports the creation of an integrated microalgal biorefinery strategy for full wastewater resource exploitation.

K. Developments in Biological Wastewater Treatment Methods: Emphasis on Resource Recovery and Low-Carbon Energy in the Context of Biorefineries.

The author states that, in contrast to recognizing wastewater as just a waste stream, the abstract portrays it as a useful resource for microbial fermentation and the production of value-added products. It emphasizes how microalgae may be used to clean wastewater and recover nutrients at the same time, especially by removing metals, phosphorus, nitrogen, and BOD. Important growth parameters including sunshine, temperature, pH, and nutrient availability are examined together with various growing techniques, such as open, closed, and integrated systems. Its emphasis on the microalgal biorefinery concept—where recovered biomass may be transformed into biofuel, feed, biofertilizer, bioplastic, and exopolysaccharides—is one of its main advantages. Overall, the abstract successfully presents microalgae as a sustainable method for resource recovery, wastewater treatment, and the growth of the circular bioeconomy.

In conclusion, Microalgae are identified as a viable sustainable technique for nutrient recovery and wastewater treatment in the conclusion. It highlights how well phytoremediation works to recover phosphorus and nitrogen while lowering BOD and COD levels. In Favor of a biorefinery-based strategy, the conclusion also emphasizes the potential of microalgal biomass to produce useful goods including biofuel, exopolysaccharides, and bioplastics. Crucially, it acknowledges practical constraints, including the need for ideal circumstances appropriate for certain algae strains and wastewater types, biomass collection, and downstream purification. These difficulties show that

further study and technical advancement are required for widespread industrial use. In order to accomplish sustainable resource usage, water purification, and the establishment of a circular bioeconomy, the conclusion generally strongly supports the integration of microalgae with wastewater treatment.

L. Update on efficient techniques and procedures for wastewater treatment.

The author introduces the dealing with rising water contamination and the world's need for clean water. With a focus on adsorption, nanotechnology, and membrane technologies, it examines physical, chemical, and biological treatment techniques. The study emphasizes that while a number of cutting-edge techniques might successfully eliminate pollutants, their high cost and poor efficacy may limit their use, especially in low-income nations. Its analysis of the advantages and disadvantages of various treatment methods while highlighting adsorption as a reasonably priced and eco-friendly choice is one of its main strengths. To increase therapy effectiveness, the abstract further suggests comprehending adsorbent processes at the cellular and molecular levels. In general, it highlights the necessity of wastewater treatment systems that are economically viable, efficient, and sustainable.

In conclusion, the necessity for efficient wastewater treatment is highlighted in the conclusion as a result of urbanization, industry, population increase, and developing water shortages. It highlights adsorption and nanotechnology as viable methods for eliminating impurities and enhancing water quality. Although the review acknowledges adsorption as an environmentally favorable treatment technique, it also highlights the significant drawback of regular adsorbent renewal. To enhance therapeutic efficacy, it suggests more research into cellular and molecular adsorption processes. The significance of cost-benefit analysis and pilot and field-scale research prior to large-scale adoption is also emphasized in the conclusion. To increase the efficiency and sustainability of carbon-based adsorbents, more study is advised. In general, the study encourages the creation of affordable, effective, and long-lasting adsorption-based systems for resource management and wastewater treatment in the future.

M. Decentralized wastewater treatment using OT's cutting-edge electrochemical methods.

The author states that the combination of decentralized wastewater treatment systems (DWATS) with sophisticated electrochemical processes as a potential strategy to enhance water reuse and sanitation. It examines hybrid advanced oxidation processes, bio electrochemical systems, electrocoagulation, and electro-oxidation. The study reports prospects for methane generation and nutrient recovery, as well as enhanced removal of organic pollutants, nutrients, micropollutants, and pathogens. Its systematic analysis of over 120 research chosen using the PRISMA approach, which offers a comprehensive evaluation of

current advancements, is one of its main advantages. These systems' sustainability is further reinforced by their compatibility with renewable energy, especially solar electricity. Electrode fouling, energy usage, and community-scale deployment are still issues, too. All things considered, the abstract successfully presents electrochemical-DWATS integration as a viable route for resource recovery, decentralized treatment, and sustainable water reuse.

In conclusion, to obtain better effluent quality, resource recovery, and operational resilience in decentralized sanitation, advanced electrochemical-DWATS integration is identified as a potential strategy. It emphasizes how hybrid systems may improve the removal of new pollutants, offer dependable disinfection, and produce beneficial resources like energy, fertilizer, and clean water. Bio electrochemical and solar-powered devices show promise for distant and off-grid uses. The study does stress that long-term performance, maintenance needs, cost-effectiveness, electrode durability, energy consumption, and environmental effects must be considered for large-scale application. It suggests assessing treatment effectiveness in conjunction with operator workload, disinfection byproducts, and life-cycle costs. While highlighting the need for more pilot-scale and long-term validation before to wider use, the finding generally supports electrochemical integration as a climate-smart and circular method.

N. Comprehensive assessment of traditional and developing methods for enhanced primary wastewater treatment with an insight into future prospects.

The author clarifies that, chemically enhanced primary treatment (CEPT), micro sieving, flotation, electrocoagulation, integrated systems, and traditional sedimentation are all included in this thorough comparison of advanced primary treatment (APT) methods for municipal wastewater. Along with economic and environmental factors, the assessment methodically assesses their efficacy in removing pollutants. The straightforward comparison of treatment efficiency, which demonstrates that sophisticated techniques typically exceed traditional sedimentation, is a key strength. Micro sieving and sedimentation provide reduced costs and carbon footprints, whereas electrocoagulation and integrated systems show greater total removal. However, in a number of technologies, the removal of nutrients, especially total nitrogen, is still restricted or inconsistent. The trade-off between treatment performance and expense is also acknowledged in the abstract. Overall, it successfully illustrates how APT may enable resource-focused, energy-efficient, and climate-neutral wastewater treatment; however, the choice of technology must take into account particular treatment and sustainability needs.

The conclusion confirms that, the comparison to traditional sedimentation, improved primary treatment methods often offer superior pollution removal. It emphasizes that while CEPT and flotation give balanced performance at reasonable costs, electrocoagulation and integrated systems enable extensive multi-parameter removal. Because of their low energy consumption and

operational load, micro sieving and sedimentation continue to be beneficial. Total nitrogen removal, however, continues to be a significant constraint, suggesting challenges in eliminating dissolved nutrients during primary treatment. The study highlights that while performance is dependent on operational conditions and wastewater parameters, no single APT method is always better. Electrocoagulation and integrated systems may be limited by increased energy, capital, and operating expenses. Although further study is required in the areas of nutrient removal, hybrid systems, low-carbon operation, and data-driven optimization, the result generally supports APT as a crucial part of next-generation wastewater treatment.

O. From agricultural waste to water purification: a critical analysis of conventional wastewater treatment methods vs sustainable and scalable alternatives.

The author evaluates the bio adsorbents made from agricultural waste as viable and affordable substitutes for removing heavy metals from wastewater. It draws attention to the drawbacks of traditional treatment techniques, such as their high energy and chemical consumption, high operating costs, and secondary contamination. The thorough evaluation of biosorbent production, characterization, adsorption mechanisms, kinetic and isotherm models, and influencing factors is a significant strength. According to the review, raw biosorbents remove about 60–90% of contaminants, but thermally activated and chemically modified materials can remove up to 99% and 90–97% of contaminants, respectively. Additionally, it links the circular economy and waste valorization with the use of agricultural waste. The abstract highlights hybrid systems, techno-economic evaluation, and pilot-scale validation as future priorities while successfully illustrating the potential of agricultural waste bio adsorbents for sustainable wastewater treatment.

The conclusion identifies that, bio adsorbents made from agricultural waste are a viable, affordable, and eco-friendly way to treat wastewater polluted with heavy metals, especially in areas with limited resources. It highlights how the circular economy, SDGs, and waste-to-wealth idea are all supported by turning agricultural leftovers into bio adsorbents. With removal efficiencies rising from 60–90% for raw biosorbents to 90–97% for modified materials and up to 99% for thermally activated biosorbents, the review shows that chemical and thermal changes can significantly enhance adsorption efficiency. The distance between laboratory research and industry execution is acknowledged in the end, nevertheless. It suggests using life-cycle assessment and techno-economic analysis to improve regeneration, reuse, and safe disposal. To enhance the treatment of complicated wastewater, integration with membrane, oxidation, and biological processes is also recommended.

P. Developments in Advanced Oxidation Processes and Membrane Bioreactors as Advanced Wastewater Treatment Technologies.

The author highlights that the integrated assessment of modern wastewater treatment technologies with a primary focus on advanced oxidation processes (AOPs) and membrane bioreactors (MBRs). It emphasizes how crucial they are to eliminating new pollutants, enhancing effluent quality, and permitting safe water reuse in the face of growing water shortages and climatic challenges. The integration of technological evaluation with EUROSTAT variables, such as sludge production, freshwater availability, water exploitation index, and wastewater-treatment connection, is a significant strength. The statistical study demonstrates that without sophisticated treatment and water reuse, increasing treatment infrastructure by itself does not considerably lessen water stress. The complementing function of MBR–AOP hybrid systems in promoting circular and climate-resilient water management is skillfully highlighted in the abstract. All things considered, it offers a solid basis for assessing advanced therapy from the standpoints of European resource management and technology.

The conclusion identifies MBRs and AOPs as critical technologies for improving circular water management, water reuse, and sustainable wastewater treatment. It emphasizes how AOPs efficiently break down stubborn contaminants and lessen toxicity, while MBRs offer compact treatment and high-quality effluent. The study also highlights the significance of reuse-oriented advanced treatment by showing that resource availability, climate, and water demand have a greater impact on water stress than treatment connections alone. High operational and investment costs, sludge production, data constraints, and public acceptability of water reuse, however, continue to be significant obstacles. Standardized technology comparisons, energy optimization, fouling control, transformation-product evaluation, and enhanced sludge recovery are all suggested in the conclusion. In order to achieve resilient and sustainable wastewater management in Europe, the research recommends combining advanced treatment, water reuse, and resource recovery.

III. CONCLUSION

The analysis of the study shows that in order to achieve efficient wastewater management, both traditional and cutting-edge wastewater treatment methods are crucial. For the removal of suspended particles, organic matter, and other conventional contaminants, traditional methods including screening, sedimentation, coagulation, flocculation, and biological treatment are still crucial. However, the use of cutting-edge technologies like adsorption, membrane processes, advanced oxidation, electrochemical treatment, photocatalysis, nanotechnology, microalgal systems, and hybrid treatment approaches is necessary due to the growing prevalence of heavy metals, nutrients, micropollutants, pharmaceuticals, and other persistent and emerging contaminants. High energy requirements, treatment costs, fouling, sludge and by-

product generation, regeneration requirements, operational complexity, and scale-up challenges limit the wider application of these technologies, which can enhance effluent quality and promote water reuse and resource recovery.

No one treatment technique can offer a perfect answer for every wastewater feature, as the analysed research constantly stress. Therefore, it is crucial to combine traditional and sophisticated procedures in a way that is acceptable for wastewater characteristics, necessary effluent quality, cost, and operating circumstances. Future wastewater treatment should prioritize low-cost, energy-efficient technology, resource recovery, decentralized systems, and circular economy strategies. Techno-economic evaluation, life-cycle analysis, practical implementation, and more extensive pilot-scale and long-term evaluation are also necessary. All things considered, combined conventional-advanced treatment systems present a viable and sustainable strategy for long-term water resource preservation, pollution control, and water reuse.

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