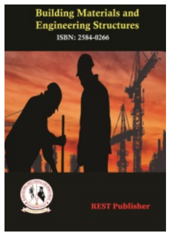
REST Publisher; ISSN No: 2584-0266 (Online)

Building Materials and Engineering Structures

journal homepage: https://restpublisher.com/journals/bmes/



Advances in Water Purification Technologies Innovations and Challenges Using TOPSIS Method

Vidhya Prasanth*, Chandrasekar Raja, M. Ramachandran, Sathishkumar Mani

REST Labs, Kaveripattinam, Krishnagiri, Tamil Nadu, India

ARTICLE INFO

Article history:
Received: 13 March 2026
Accepted: 25 March 2026
Available online: 31 March 2026

Keywords:
TOPSIS
Water Purification
Contaminant Removal Efficiency

ABSTRACT

In recent years, tremendous improvements have been made in water filtration technology to meet both the increasing complexity of water contaminants and the increasing demand for clean water. Technological advances in this field include a wide range of approaches and materials, from innovative oxidation methods and filtration techniques to the combination of nanotechnology and biomimetic membranes. These technologies have increased the effectiveness and efficiency of removing various contaminants such as organisms, heavy metals, microplastics and pharmaceuticals. The discovery of new materials such as graphene oxide and carbon nanotubes has improved membrane technologies such as reverse osmosis and nanofiltration. In addition, the development of electrochemical techniques such as capacitive deionization and electrocoagulation enabled energy-efficient solutions for desalination and heavy metal removal. Photocatalytic purification, which uses minerals such as titanium dioxide, has emerged as a strong technology for breaking down organic contaminants by creating reactive oxygen species when exposed to light. Despite these advances, the profession still faces significant challenges. One key barrier to broad acceptance of new technologies was their economic feasibility, particularly in poor countries with limited infrastructure and financial resources. Furthermore, the sustainability of these technologies is being called into question due to their high energy requirements and the risk of releasing secondary pollutants. To address these challenges and ensure that water purification technology can meet future requirements in a sustainable and fair way, sophisticated monitoring systems must be included, as well as a comprehensive approach to water management. In conclusion, even though water filtration technologies have advanced significantly, more research and development are needed to solve the operational, financial, and environmental issues that arise with these advancements. Synergistic integration of many technologies optimized for performance, economy, and low environmental impacts the key to the future of water purification.

1. INTRODUCTION

Access to safe drinking water is a fundamental human right that is necessary for good health. Despite the fact that lakes, rivers, seas, subterranean streams, and oceans account for around 70% of global water supplies, approximately 1.5 billion people worldwide continue to lack adequate drinking water, with almost half suffering from health problems as a result. Water is essential for the existence of all living beings and for everyday life. However, increased development has harmed natural water supplies. According to the World Health Organization (WHO) and UNICEF's 2014 progress report on drinking water and sanitation, around 748 million people still lack access to safe drinking water. Furthermore, 3,900 children die every day from illnesses caused by drinking polluted water or inadequate hygiene habits. Ion exchange is a well-established technology for reducing water hardness that is currently being studied for its efficacy in eliminating heavy

*Corresponding author: prasanthvidhya69@gmail.com
DOI: http://doi.org/10.46632/bmes/4/1/3

metal ions. This method employs porous ion exchange microbeads to release pre-saturated, non-toxic ions, which are subsequently caught during filtration. The major goal of supplying clean water is to disinfect it efficiently and effectively against both known and developing ailments while preserving the water supply.Waterborne diseases have a significant impact on public health, particularly in impoverished regions of Southeast Asia and Sub-Saharan Africa. These diseases are caused by various aquatic pathogens, including prions, bacteria, rickettsiae, viruses, fungi, and helminths. Heterogeneous catalytic ozonation has recently become more popular because of its potential for effectively breaking down and mineralizing refractory organic pollutants while having a minimal negative impact on water quality.There are around 40 zeolites in nature, the most accessible of which is clinoptilolite. These zeolites are three-dimensional, negatively charged structures created by replacing Si4+ with Al3+. The structures are often made up of oxygen, silicon, and aluminum. Column filters employ zeolites as adsorbents, which are manufactured from silicon-aluminum solutions or coal fly ash. Bacterial agents are among the numerous dangerous species that cause a variety of illnesses. Campylobacter jejuni is responsible for a considerable number of bacterial gastroenteritis cases, which frequently originate from inappropriate handling of chicken products. While several Escherichia coli strains may generate Shiga toxin, the O157 strain has received the most attention due to its link with deaths. The O157 strain has a plasmid encoding Shiga toxin synthesis. Consuming contaminated beef products can result in infections, and research suggests that dirty drinking water can also cause similar ailments. Recent advances in nanotechnology, such as nanoparticles and nanofiltration, show promise for solving a variety of water quality challenges. One of the most fascinating areas of research is the development of sophisticated water desalination technology. Contaminant instability:Electrochemical methods such as electrocoagulation and electrodialysis are effective in removing pollutants by inducing instability and aggregation. Electrodialysis selectively transfers ions through membranes, enabling the extraction of particular ions from water. Advanced Oxidation Technologies (AOTs) are recognized for their distinct oxidation processes. These operations often produce extremely reactive hydroxyl radicals via reactions started by AOT chemicals or equipment. While some AOTs use sulfate radicals as powerful oxidizing agents, this chapter will mostly focus on the more regularly used hydroxyl radical-based AOTs, with just a brief discussion of sulfate radicals.Carey et al. were the first to demonstrate that UV light could remove polychlorinated biphenyls (PCBs) in aqueous TiO2 solutions, enabling chloride ions to form, in 1976. In 1983, Ollis et al. revealed that by exposing aqueous TiO2 solutions to light, chloroalkanes and chloroalkenes may be totally mineralized into CO2 and HCl. Since then, multiple research have demonstrated that the TiO2 photomineralization process can cure a wide spectrum of organic contaminants in water streams, with the majority of these investigations using TiO2 suspensions. Pelizzetti, Serpone, and Matthews enhanced TiO2 on glass substrates. For practical applications, a technique that removes the necessity for filtering and resuspending the photocatalyst is preferred. Another important reason to keep water clean is the capacity to remove nanoparticles (NPs) used to detect heavy metals or other contaminants after they have fulfilled their purpose. A number of studies looked into the possibility of locating gold nanoparticles (AuNPs) in environmental materials using fluorescence or absorption techniques. Additive manufacturing (AM), often known as 3D printing, has become an attractive and efficient approach for producing membranes with precise features. In 3D printing, a computer directs the layer-by-layer deposition of materials to create a specific pattern. In contrast, conventional manufacturing often uses traditional methods and molds to make identical objects. Water is the most important element for the existence of Earth, and getting safe drinking water in the twenty-first century will be a major worldwide concern. Every living being need clean, water that is clear to exist. Despite knowing that water covers over 71 percent of the earth's surface, international standards classify just under one percent of it as safe to drink. Water contamination is mostly caused by industrial wastewater discharge, agricultural operations, municipal wastewater, ecological changes, and warming temperatures. Even tiny levels of heavy metals, dyes, and microbes can pose major risks to the environment, aquatic environments, and the health of people. Anisotropic membranes are classified into two types: phase-separation membrane (also known as Loeb-Sourirajan membranes) and composite membranes, which comprise thin-film, coated films, and self-assembled structures. Loeb-Sourirajan membranes, like isotropic microporous the membranes, have a constant chemical make-up, but their porosity and pore size change with thickness. The creation of these anisotropy membrane in the early 1960s marked a significant milestone in membrane technology. Thin-film and other composite membranes, on the other hand, have diverse structural and material compositions.Water is a vital element of the cosmos and is necessary for all ecosystems on Earth to function properly. Regardless, certain parts of humanity lack access to safe drinking water. Pollution of water sources is causing fast degradation in purity. Our water resources have been polluted by a variety of non-point sources as a result of rapid human population expansion, modern industry, civilization, residential and agricultural practices, and other geological, environmental, and worldwide changes. Adsorption, a phenomenon on the surface is the rise in concentration of a certain component at the interface or contact of two phases. An adsorbate is a substance (pollutant) that attaches or sticks to a solid surface, whereas a substance called an adsorbent is a solid layer itself. Adsorption is influenced by temperature, the kind of adsorbent and adsorbate used, the presence of additional pollutants, and ambient and laboratory conditions (pollutant concentration, pH, contact time, and adsorbent particle size) [16]. The stage inversion process is employed to manufacture a substantial amount of porous polymeric membranes (MF to UF) for water filtration, including hollow fibers. The ensuing structure has fundamental constraints, wether utilized directly in the separation layer or indirectly in the supporting layer (NF and RO). These disadvantages includes low flux (high energy expenditure) and a high foul propensity due to the asymmetry pore shape and distribution throughout the membrane thickness. Currently, several purification devices, some of utilizing membranes, have been developed and demonstrated to improve access to safe drinking water for off-grid people or remote areas without water systems [17].Water has become the greatest cause of mortality among children worldwide, with around 5500-6200 fatal crashes per day.Increased population, climate change, increased demand for food and energy, pollution of surface groundwater resources, soil erosion, sanitation issues, fertilizers, pesticides, heavy metals, industrial effluents, oils, and various toxic chemicals are the primary sources of water contamination for the world's 0.8 million people. Contaminants in water sources remain an issue to human health. As a result, contaminants in water must be eliminated before to consumption. Wastewater treatment preserves a balance both freshwater and sewage.As a result, the effectiveness of wastewater treatment operations has a substantial effect on water neutralization and preservation of critical water resources. As a result, technical developments in the wastewater treatment industry are among today's top priorities. Water filtering processes, both simple and complex, are thoroughly explained [18].Technological and science directions provide a route to the future. They raise awareness of future technical development demands, give a framework for organizing technology forecasts and plans, and convey technological needs, targets, and expectations to end users and the research and development community. Water purification technology is an important 'tool' for addressing future water supply issues. Technologies initially meant to desalinate water are exceptionally successful at eliminating contaminants (varying from naturally occurring salts to artificial compounds) from contaminated streams.. This distinctive capacity allows such technologies to 'create' new water from underutilized impaired sources (e.g., salty groundwater, impaired rivers, and post-consumer reclaimed waters) in addition to producing safe water by eliminating a broader range of substances than traditional avenues of investigation for today's researchers [19].Nanoparticles includes a vast range of methods, instruments, and applications, and it is widely regarded as one of the most significant technologies of the modern era. Designed nanoparticles are materials with sizes ranging from 1 to 100 nm. Their distinct physicochemical (e.g., size, form) and surface (e.g., reactivity, conductivity) features aid in the creation of novel materials and technical solutions to challenges that have proved difficult to tackle using traditional methods. Though nanotechnology is employed in a variety of businesses, including medical, energy, and agriculture, purification of water remains the primary barrier for human growth. Water treatment techniques, including nanoscale materials, are currently available, and customer demand for clean water is growing [20]. These chemical molecules build in both the air and water. This feature permits VOCs to get inside and remain in water used for drinking sources. These compounds can be especially hazardous since they can pollute both surface and groundwater sources. These pollutants have been related to a variety of negative human health consequences, including harm to the circulatory, digestive, and brain systems [21]. Metal meshes, particularly copper and stainless steel (SS), are widely employed as filtration substrates for oil-water separation. Clearly, the mesh surface must be altered to obtain one of the three unique wettability qualities discussed in this section. One typical method is to use low surface energy polymers, hydrocarbon derivatives, or nanostructures to produce them superhydrophobic and superlyophilic. An early research of this technology, published in 2004, used a polytetrafluoroethylene (PTFE) coating on stainless steel mesh. - and nanostructures for oil-water separation. These technological challenges can be solved by designing tiny photocatalyst structures or dispersion nanotechnology photocatalyst particles on a highly porous substrate. Several design strategies have been developed for preparing permeable photographic catalysts with a large surface area, clearly defined constituents at nano and mesoscales, and measurable morphologies at various length scales, laying the groundwork for a rational design and synthesis of efficient porous photographic catalysts [23]. Photocatalytic oxidation can be either heterogeneous (the catalyst exists in a different phase than the catalysts) or homogeneous. Both methods may be used to filter water. Homogeneously photocatalysis depends mainly on the photofentan process, which uses ultraviolet (UV)/visible radiation to produce radicals composed of hydroxyl (the HO•) and other reactive oxygen species, which are capable of interacting with and oxidizing contaminants. However, this method is not economically practical due to the difficulties of extracting or collecting the suspended catalyst from water [24]. They are extremely costly and ineffectual at treating dangerous compounds, particularly in high quantities. Some treatments remove toxic substances, while others reduce nitrogen and phosphorus.There are quite a few ways of handling bulk chemicals in one step. It frequently involves numerous procedures, including cleaning, settling, and filtering. Chloride and ozone frequently serve as disinfectants to clean drinking water and wastewater, reducing the spread of waterborne illnesses. [25] More than 71% of the Earth's surface is covered by water, however the total amount of fresh water accessible for direct usage is quite restricted. Oceans account for over 97% of the water on the earth, hence they cannot be used directly for human purposes. The remaining 3% is clean and practical water. Of this 3%, around 68.7% is locked in ice sheets or glaciers.. Groundwater constitutes more than 30% of the total water supply and contains a variety of organic and inorganic impurities from industrial, agricultural, and residential garbage disposal. Traditional water distribution systems include purifying huge quantities of water at a single treatment center and then distributing the filtered water across long distances.Housing and other locations [26]

2. TOPSIS METHOD

The multi-criteria TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) approach is a popular choice in many areas, including the selection of materials, such as celluer polymers. Several factors, including mechanical qualities, thermal stability, cost-effectiveness, and environmental impact, are usually taken into account while using TOPSIS for celluer polymer selection. In order to ascertain each alternate celluer polymer's proximity to the ideal solution and distance from the negative solution in a multidimensional space, the approach compares them to ideal and negative reference solutions. Decision-makers may choose the best material for their needs by using TOPSIS, which offers a systematic method to rank celluer polymers according to their overall appropriateness for certain applications through the normalization and weighing of variables. The TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) approach, one of the most popular multi-criteria decision-making techniques, has drawn the interest of researchers, leading to the proposal of several enhanced iterations of the technique. Among MCDM techniques, the TOPSIS method is the second most often used strategy. Numerous academics have utilized TOPSIS to address straightforward or intricate issues in various fields, and have adjusted or expanded the TOPSIS approach to address unique situations.

(1) Calculate the normalized decision matrix. The normalized value nij is calculated as

(2)Calculate the weighted normalized decision matrix. The weighted normalized value vij is calculated as

(3) Determine the positive ideal and negative ideal solution

(4) Calculate the separation measures, using the n-dimensional Euclidean distance. The separation of each alternative from the ideal solution

(5) Calculate the relative closeness to the ideal solution.

(6) Rank the preference order. For ranking alternatives using this index, we can rank alternatives in decreasing order.

Nevertheless, there are certain shortcomings with the TOPSIS approach. Rank reversal is a phenomena that TOPSIS has been linked to, which is one of its issues. When an option is added to or withdrawn from the decision issue, the alternatives' order of preference changes in this phenomena. The authors 57 suggested a novel approach for solving this problem inside the TOPSIS method's 58 framework. However, as noted in 59 Garca-Cascales and Lamata (2012), "the two techniques; the modern" and "the 60 classical" do not always have to provide the same order." "How can a reliable method for solving the RRP in the traditional TOPSIS approach be created?" We anticipate that the TOPSIS technique will only need minor modifications, maintaining the original features that Hwang and Yoon (1981) suggested. Since the weight and attribute values are all ambiguous, a TOPSIS strategy is suggested to tackle the multiattribute decision-making problem. First, the interval ambiguous attribute value has performed a weighted calculation in accordance with the interval value's operation criteria. One crucial MCDM tool is the TOPSIS technique. It is straightforward but thorough when used to assess an MCDM problem. Furthermore, the integrated program takes the goal weight into account (Boran, Genc, Kurt, & Akay, 2009; Deng, Yeh, & Willis, 2000).

Alternatives

- Reverse Osmosis (RO)
- Nanofiltration (NF)
- Capacitive Deionization (CDI)
- Electrocoagulation (EC)
- Photocatalytic Purification (PCP)
- GrapheneOxideMembranes(GOM)

Water purification technology advancements have resulted in a number of unique solutions, each with its own set of advantages and drawbacks. Reverse Osmosis (RO) remains a prominent technique because of its 99% pollutant removal effectiveness, making it suitable for desalination and wastewater treatment. However, its energy consumption is rather high (3.5 kWh/m^3), with moderate operating complexity and environmental impact.

Nanofiltration (NF) has a slightly lower contaminant removal efficiency (95%), but benefits from increased energy efficiency (2.8 kWh/m^3) and lower cost. It is useful for softening hard water and eliminating specific pollutants such as organic compounds and multivalent ions.

Capacitive Deionization (CDI), an energy-efficient option, requires only 1.2 kWh/m^3. It is highly effective for brackish water desalination and selective ion removal, although its scalability is limited compared to RO and NF.

Electrocoagulation (EC) is a simple and cost-effective method for removing suspended particles, heavy metals, and oils from water, with an operating cost of $0.25/$m^3$. However, it faces scaling issues and increased operational complexity.

Photocatalytic Purification (PCP) is a cutting-edge technique that uses light to activate catalysts such as titanium dioxide, effectively removing organic pollutants. Its energy efficiency is high at 1.0 kWh/m^3, and it has minimal environmental impact. Despite these advantages, its scalability is limited, and it requires significant operational complexity.

Graphene Oxide Membranes (GOM) are a promising innovation, with a 97% pollutant removal efficiency and strong scalability. Their low energy usage (2.5 kWh/m^3) and manageable operating complexity provide a balance of efficiency and environmental benefits.

In summary, while these modern water purification technologies offer promising solutions to global water challenges, each has its own advantages and limitations. The choice of technology depends on factors such as energy efficiency, cost, scalability, and environmental impact, highlighting the importance of a tailored approach based on specific application requirements.

Evaluation Parameters

Benefit Criteria:

- Contaminant Removal Efficiency (%)
- Energy Efficiency (kWh/m^3)
- Scalability (1-10 scale)

Non-Benefit Criteria:

- Cost ($/$m^3$)

- Operational Complexity (1-10 scale)
- Environmental Impact (1-10 scale)

Water purification technologies have advanced significantly, introducing a variety of approaches evaluated based on pollutant removal efficiency, energy consumption, scalability, cost, operational complexity, and environmental impact. Reverse Osmosis (RO) is a widely used method for desalination and wastewater treatment due to its high pollutant removal efficiency of 99%. However, its energy consumption is relatively high at 3.5 kWh/m^3. It has an operational complexity rating of 6 and an environmental impact rating of 5, indicating moderate challenges in both aspects.

Nanofiltration (NF) exhibits a slightly lower pollutant removal efficiency of 95%, but offers improved energy efficiency at 2.8 kWh/m^3. With a lower operational cost of \$0.45/m^3, it is effective for softening hard water and removing contaminants such as organic compounds and multivalent ions. Its scalability rating of 7 reflects a good balance between efficiency and practical implementation, although it still presents moderate complexity and environmental impact.

Capacitive Deionization (CDI) is an energy-efficient technique, requiring only 1.2 kWh/m^3. It is particularly suitable for brackish water desalination and selective ion removal. With a cost of \$0.30/m^3 and an operational complexity rating of 4, it is relatively simple to operate. However, its scalability rating of 6 indicates certain limitations in large-scale applications.

Electrocoagulation (EC) is a cost-effective method for removing suspended particles, heavy metals, and oils from water, with an operating cost of \$0.25/m^3 and energy consumption of 2.0 kWh/m^3. Despite its advantages, its scalability (rated 5) and higher operational complexity (rated 7) may restrict its widespread adoption.

Photocatalytic Purification (PCP) utilizes light-activated catalysts, such as titanium dioxide, to effectively degrade organic pollutants. It demonstrates excellent energy efficiency at 1.0 kWh/m^3 and has minimal environmental impact (rated 2). However, its scalability is limited (rated 4), and it requires relatively high operational complexity (rated 6).

Graphene Oxide Membranes (GOM) represent an emerging technology with a pollutant removal efficiency of 97% and strong scalability (rated 9). Their moderate energy consumption (2.5 kWh/m^3) and operational complexity (rated 5) make them a balanced option for various applications. Additionally, they exhibit low environmental impact (rated 3).

3. RESULTS AND DISCUSSION

TABLE 1. Water Purification Technologies

Technology	Contaminant Removal Efficiency (%)	Energy Efficiency (kWh/m^3)	Scalability (1–10)	Cost (\$/m^3)
Reverse Osmosis (RO)	99.00	3.50	8.00	0.50
Nanofiltration (NF)	95.00	2.80	7.00	0.45
Capacitive Deionization (CDI)	85.00	1.20	6.00	0.30
Electrocoagulation (EC)	80.00	2.00	5.00	0.25
Photocatalytic Purification (PCP)	90.00	1.00	4.00	0.35
Graphene Oxide Membranes (GOM)	97.00	2.50	9.00	0.55

Table 1 presents a comparison of advanced water purification technologies based on key parameters such as pollutant removal efficiency, energy consumption, scalability, and cost. Reverse Osmosis (RO) achieves the highest removal efficiency (99%) but requires high energy (3.5 kWh/m^3) and cost (\$0.50/m^3). Nanofiltration (NF) offers slightly lower efficiency (95%) with better energy performance and moderate cost.

Capacitive Deionization (CDI) and Electrocoagulation (EC) are more energy-efficient and economical but face scalability limitations. Photocatalytic Purification (PCP) shows good efficiency with low energy use, though scalability is limited. Graphene Oxide Membranes (GOM) provide high efficiency (97%) and excellent scalability, but at the highest cost, requiring careful selection based on application needs.

Figure 1 compares advanced water filtration systems based on their performance characteristics. Reverse Osmosis (RO) exhibits the highest pollutant removal efficiency at 99%, but it consumes 3.5 kWh/m^3 of energy and costs \$0.50/m^3.

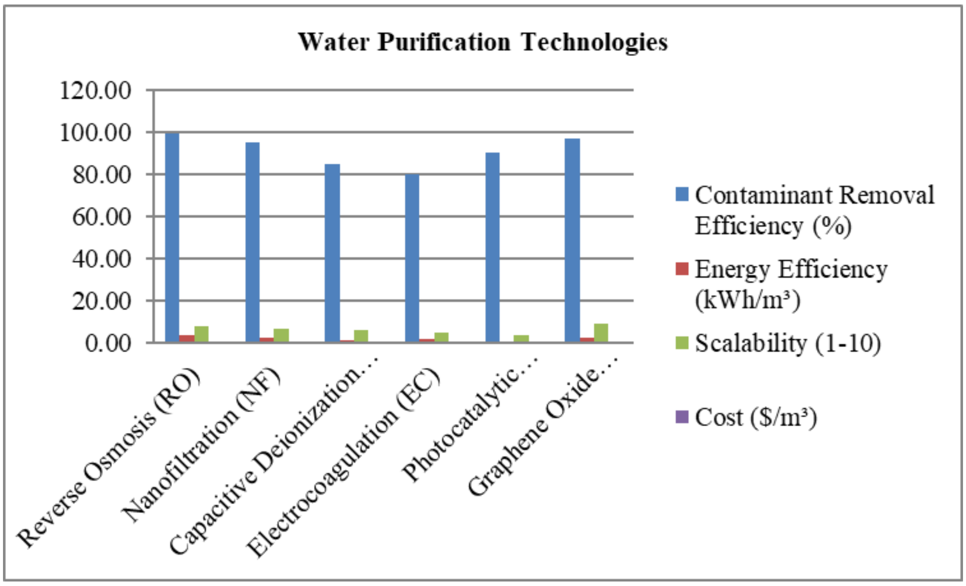


FIGURE 1. Water Purification Technologies

Nanofiltration (NF) achieves 95% efficiency with improved energy performance (2.8 kWh/m^3) and a slightly lower cost of \$0.45/m^3.

Capacitive Deionization (CDI) is highly energy-efficient (1.2 kWh/m^3) and cost-effective (\$0.30/m^3), with an 85% removal efficiency. Electrocoagulation (EC) provides a low-cost solution (\$0.25/m^3) with energy usage of 2.0 kWh/m^3 and 80% efficiency. Photocatalytic Purification (PCP) demonstrates low energy consumption (1.0 kWh/m^3) and 90% efficiency but has limited scalability. Graphene Oxide Membranes (GOM) offer high efficiency (97%) and excellent scalability, although at the highest cost of \$0.55/m^3. Each technology balances these factors differently to meet specific application requirements.

TABLE 2. Normalized Data

Technology	Contaminant Removal Efficiency (%)	Energy Efficiency (kWh/m^3)	Scalability (1–10)	Cost (\$/m^3)
Reverse Osmosis (RO)	0.4429	0.611	0.4860	0.4927
Nanofiltration (NF)	0.4250	0.489	0.4252	0.4434
Capacitive Deionization (CDI)	0.3803	0.210	0.3645	0.2956
Electrocoagulation (EC)	0.3579	0.349	0.3037	0.2463
Photocatalytic Purification (PCP)	0.4027	0.175	0.2430	0.3449
Graphene Oxide Membranes (GOM)	0.4340	0.437	0.5467	0.5419

Table 2 presents normalized data for evaluating innovative water filtration systems based on four major performance indicators. Reverse Osmosis (RO) shows a balanced profile, with a normalized pollutant removal efficiency of 0.4429, energy efficiency of 0.611, scalability of 0.4860, and cost of \$0.4927. Nanofiltration (NF) exhibits slightly lower values, particularly in energy efficiency (0.489) and scalability (0.4252).

Capacitive Deionization (CDI), despite its lower pollutant removal efficiency (0.3803), performs well in terms of energy efficiency (0.210) and cost (0.2956). Electrocoagulation (EC) has comparatively lower values overall, including 0.3579 for removal efficiency, 0.349 for energy efficiency, and 0.2463 for cost. Photocatalytic Purification (PCP) demonstrates better energy efficiency (0.175) but limited scalability (0.2430).

Graphene Oxide Membranes (GOM) stand out with the highest scalability score (0.5467) and strong overall performance, including a normalized cost of 0.5419. These normalized values enable effective comparison and support decision-making based on specific performance criteria.

Figure 2 shows normalized data for several water purifying processes. Reverse osmosis (RO) provides balanced performance,

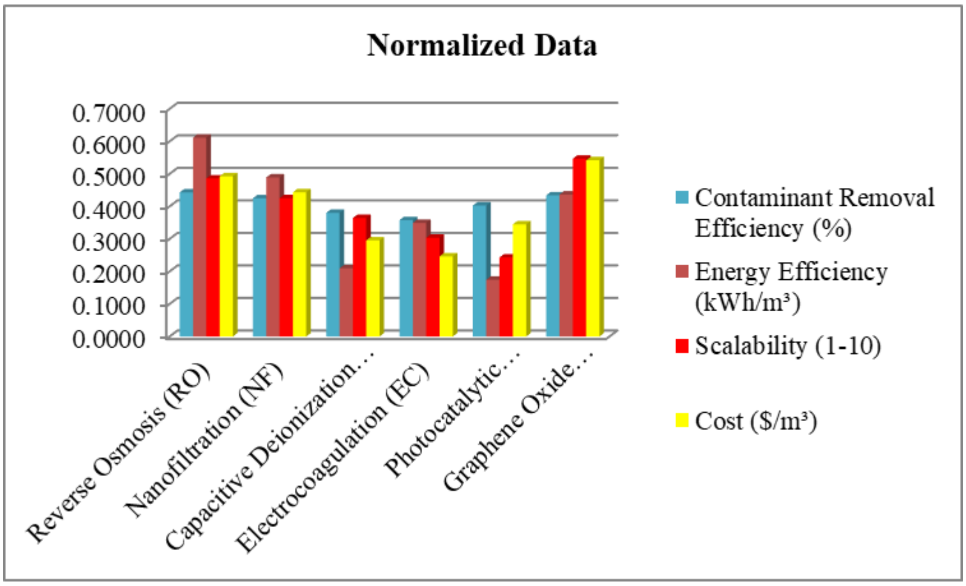


FIGURE 2. Normalized Data

with normalized ratings of 0.4429 for pollution removal efficiency and 0.611 for energy efficiency. Nanofiltration (NF) has somewhat lower metrics. Capacitive Deionization (CDI) is more cost effective (0.2956) and energy efficient (0.21), but has a lower removal efficiency (0.3803). Electrocoagulation (EC) has the lowest overall ratings. Photocatalytic Purification (PCP) is extremely energy-efficient (0.175), but less scalable (0.2430). Graphene Oxide Membranes (GOM) are renowned for their great scalability (0.5467) and overall performance, particularly in terms of cost (0.5419).

TABLE 3. Weightages

C1	C2	C3	C4
0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25

Table 3 depicts the weightages attributed to the assessment factors for each water purification technique, suggesting that all metrics are equally important. Each parameter—contaminant removal efficiency, energy efficiency, scalability, and cost—has been given a weight of 0.25. This equal weighting implies a balanced approach to evaluate the performance of each technology, with no single factor unduly influencing the total rating. By using equal weightages, the evaluation gives a full perspective of each technology's strengths and flaws, allowing for a more thorough comparison. This method aids in the selection of the most appropriate technology based on a balanced examination of all key aspects.

Figure 3 depicts a weighted normalized decision matrix for assessing water purification systems, stressing a balanced assessment of pollutant removal efficiency, energy efficiency, scalability, and cost. Reverse Osmosis (RO) has the greatest ratings across all parameters, showing good overall performance, with weighted values of 0.1528 for pollutant removal and energy efficiency, 0.1215 for scalability, and 0.1232 for cost. Nanofiltration (NF) follows, with a high energy efficiency (0.1223) and balanced performance in other metrics. Capacitive Deionization (CDI) offers high energy efficiency (0.0524), but poor removal efficiency (0.0951) and scalability (0.0911). Electrocoagulation (EC) performs moderately across all categories, with the lowest score in cost (0.0616).Photocatalytic Purification (PCP) has good energy efficiency (0.0437) but low scalability (0.0607) and average overall scores. Graphene Oxide Membranes (GOM) exhibit balanced performance, with a significant scalability score (0.1367) and high scores in other metrics, indicating its promise as an effective purifying technique. This matrix allows for the comparison and selection of the best technology based on a thorough, equally

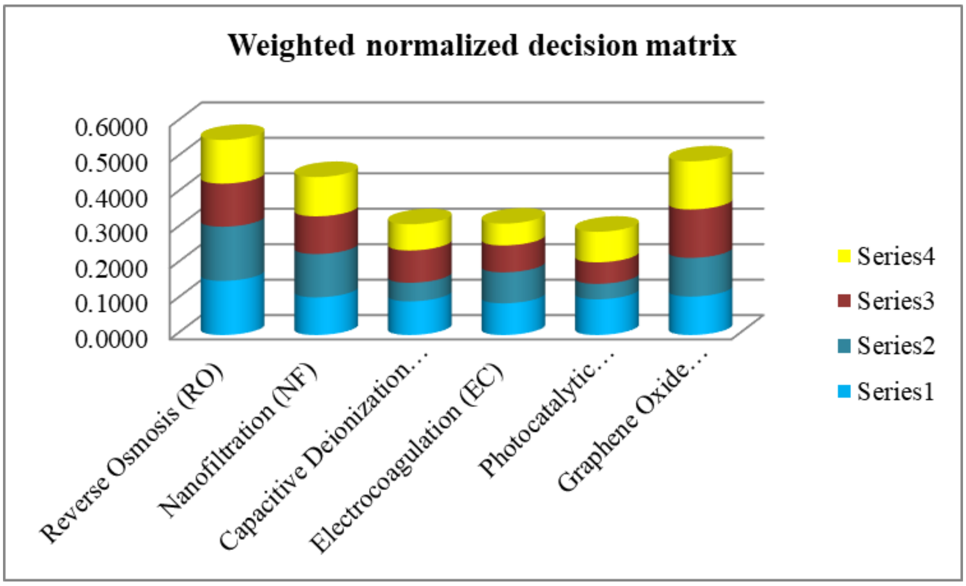


FIGURE 3. Weighted normalized decision matrix

weighted evaluation of all essential variables.

TABLE 4. Positive and Negative Matrix

Positive Matrix				Negative Matrix			
C1	**C2**	**C3**	**C4**	**C1**	**C2**	**C3**	**C4**
0.1528	0.1528	0.0607	0.0616	0.0895	0.0437	0.1367	0.1355
0.1528	0.1528	0.0607	0.0616	0.0895	0.0437	0.1367	0.1355
0.1528	0.1528	0.0607	0.0616	0.0895	0.0437	0.1367	0.1355
0.1528	0.1528	0.0607	0.0616	0.0895	0.0437	0.1367	0.1355
0.1528	0.1528	0.0607	0.0616	0.0895	0.0437	0.1367	0.1355
0.1528	0.1528	0.0607	0.0616	0.0895	0.0437	0.1367	0.1355

Table 4 shows the positive and negative matrices used to assess water filtration technology. The positive matrix emphasizes the greatest possible performance numbers for each criterion, whereas the negative matrix displays the least acceptable performance values. For all methods, the ideal pollutant removal efficiency and energy efficiency are 0.1528. The optimal scalability value is 0.1367, whereas the most beneficial cost value is 0.1355. These values serve as the standards for optimal performance across all criteria. In contrast, the negative matrix records the least desired values for each parameter. The lowest values for scalability and cost are 0.0607 and 0.0616. The least favorable results for pollutant removal efficiency and energy efficiency are 0.0437 and 0.0895, respectively. These benchmarks serve as references for the evaluation's worst-case situations. By comparing each technology's actual performance to these matrices, stakeholders may decide how well it corresponds with the desired results and find areas for improvement. This study helps you make more educated judgments about which water filtration technology provides the best mix of efficiency, scalability, and cost-effectiveness.

TABLE 5. Final Result of Water Purification Technologies

Technology	S_i^+	S_i^-	C_i	**Rank**
Reverse Osmosis (RO)	0.0865	0.1277	0.5962	1
Nanofiltration (NF)	0.0872	0.0894	0.5061	3
Capacitive Deionization (CDI)	0.1204	0.0773	0.3910	5
Electrocoagulation (EC)	0.0924	0.1052	0.5323	2
Photocatalytic Purification (PCP)	0.1235	0.0912	0.4248	4
Graphene Oxide Membranes (GOM)	0.1229	0.0682	0.3569	6

Table 5 shows the final results of the water filtration methods, ranked by their performance ratings (Ci). Reverse Osmosis

(RO) is the highest-ranked technique, with a Si Plus score of 0.0865, a Si Negative score of 0.1277, and a Ci value of 0.5962. This shows that among the investigated technologies, RO provides the highest mix of efficiency, scalability, and affordability. Electrocoagulation (EC) is ranked second, with a Ci score of 0.5323, indicating outstanding overall performance. Nanofiltration (NF) ranks third with a Ci value of 0.5061, suggesting high performance but somewhat lower than EC. Photocatalytic Purification (PCP) and Capacitive Deionization (CDI) rank fourth and fifth, respectively, with Ci values of 0.4248 and 0.3910. These technologies perform moderately throughout the assessment criteria, but do not compare to the top-ranked approaches. Graphene oxide membranes (GOM) are placed sixth, with a Ci value of 0.3569. GOM has potential, however it is surpassed by other technologies in this review. Overall, this rating establishes a clear hierarchy of water filtration methods based on their overall performance, assisting in selecting the best approach for certain applications.

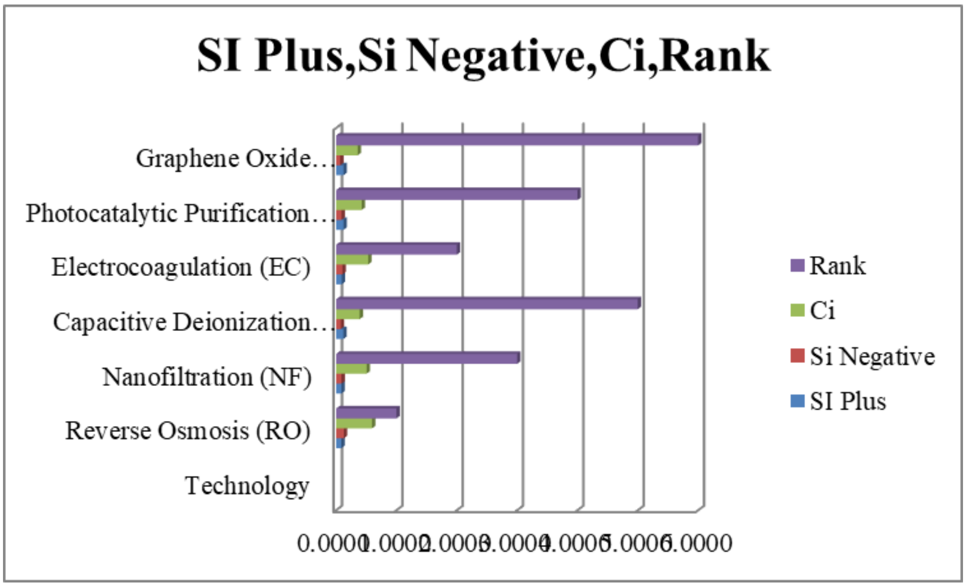
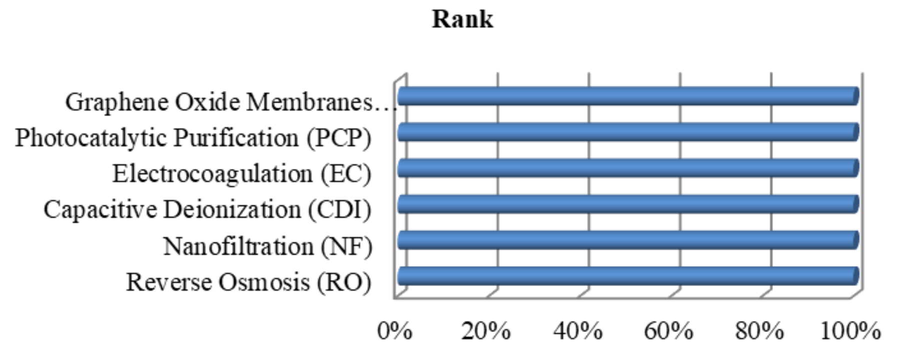


FIGURE 4. Result of Water Purification Technologies

Figure 4 depicts the final results of the water filtering technologies, ordered by their performance ratings (Ci). Reverse Osmosis (RO) is the top-ranked method, with a Si Plus score of 0.0865, a Si Negative score of 0.1277, and a Ci value of 0.5962. GOM has potential, however it is outperformed by the other technologies in this assessment.Overall, this grade offers a clear hierarchy of water filtering systems based on overall performance, which aids in picking the optimal strategy for certain applications.

Figure 5 Reverse osmosis (RO) is the most widely used and successful method for eliminating a wide range of pollutants from water. Electrocoagulation (EC) is ranked second, regarded for its capacity to effectively remove suspended particles, heavy metals, and other contaminants via electrochemical processes. Ranked third, nanofiltration (NF) is known for its ability to selectively remove certain ions and tiny organic compounds, making it ideal for tailored filtration procedures. Photocatalytic purification (PCP), ranked fourth, uses light-activated catalysts to breakdown organic contaminants and is recognized for its potential use in improved oxidation processes. Capacitive deionization (CDI), ranked sixth, is valued for its energy efficiency and capacity to desalinate water by electrostatic adsorption of ions on porous electrodes. Finally, graphene oxide membranes (GOM) rank sixth, having been recognized for their unique approach to water filtration, which provides great permeability and selectivity, despite the fact that they are still in the research phases when compared to more established technologies.



	Reverse Osmosis (RO)	Nanofiltration (NF)	Capacitive Deionization (CDI)	Electrocoagulation (EC)	Photocatalytic Purification (PCP)	Graphene Oxide Membranes (GOM)
Rank	1	3	5	2	4	6

FIGURE 5. Rank

4. CONCLUSION

Advances in water filtration technology have considerably improved our capacity to supply clean and safe water, tackling both emergent toxins and conventional pollutants. Key developments such as reverse osmosis (RO), electrocoagulation (EC), nanofiltration (NF), photocatalytic purification (PCP), capacitive deionization (CDI), and graphene oxide membranes (GOM) have all made distinct contributions to improving water quality. RO remains the most extensively used owing to its broad-spectrum effectiveness, although EC and NF provide focused treatments for specific pollutants. Innovations like PCP and GOM represent the cutting edge of purification, pushing the limits of efficiency and selectivity. However, these improvements are not without difficulties. High operational expenses, energy requirements, and the necessity for frequent maintenance and membrane replacement all provide considerable challenges. Furthermore, the management of byproducts and the environmental impact of large-scale application must be carefully considered. It is critical to strike a balance between the efficacy of these technologies and their environmental and economic viability. The future of water purification rests in combining these technologies to optimize their strengths while mitigating their shortcomings, enabling cross-disciplinary cooperation to drive further innovation. As we work to address the worldwide water issue, these developments provide a viable route to guaranteeing access to safe drinking water for all, underscoring the importance of continuous research, development, and investment in this critical area.

REFERENCES

[1]. Ahmad, A., & Azam, T. (2019). Water purification technologies. In Bottled and Packaged Water (pp. 83-120). Woodhead Publishing.

[2]. Chandrasekar Raja, Ramya sharma, M. Ramachandran, Vidhya Prasanth, "A Review on Selecting material suitable for a statically loaded thermal conductor using the TOPSIS Method", Journal on Applied and Chemical Physics, 3(4), December 2024, 1-12.

[3]. Senusi, Faraziehan, Mohammad Shahadat, Suzylawati Ismail, and Shazlina Abd Hamid. "Recent advancement in membrane technology for water purification." Modern Age Environmental Problems and their Remediation (2018): 147-167.

[4]. SELVARAJ, K., SS MAKKAPATI, SR RAYARAO, PH NAVATH, and S. RAYARAO. "COMPUTATIONAL MOLECULAR BIOLOGY IN DATA SCIENCE APPLICATIONS ON BIOINFORMATICS IN GENETIC SEQUENCING OF COVID MUTATIONS." JOURNAL OF DATA SCIENCE 1, no. 1 (2024): 5-9.

[5]. Bolisetty, Sreenath, Mohammad Peydayesh, and Raffaele Mezzenga. "Sustainable technologies for water purification from heavy metals: review and analysis." Chemical Society Reviews 48, no. 2 (2019): 463-487.

[6]. Divya Soundarapandian, “Artificial Intelligence Applications in Education and Disaster Management Using Weighted Sum Method”, Journal of Computer Science Applications and Information Technology, 9(2), 2024, 1-5.

[7]. Perikala, Karthik. "Cloud-Native NoSQL Foundations for Large-Scale Generative AI Platforms." International Journal of Cloud Computing and Supply Chain Management 1 (3), (2025), 1-6.

[8]. Shannon, Mark A., Paul W. Bohn, Menachem Elimelech, John G. Georgiadis, Benito J. Marinas, and Anne M. Mayes. "Science and technology for water purification in the coming decades." Nature 452, no. 7185 (2008): 301-310.
[9]. Dapeng, L.I. and Jiuhui, Q.U., 2009. The progress of catalytic technologies in water purification: A review. Journal of Environmental Sciences, 21(6), pp.713-719.
[10]. Rajender Radharam, "AI-Enabled High-Performance Data Analytics Framework: Using Adaboost Regression For Healthcare&Automobile Domains" Journal of Artificial Intelligence and Machine Learning, 1(4), 2023, 1-9.
[11]. Jedla, Maheshwara Reddy, Bhargavi Koneru, A. Franco, Dinesh Rangappa, and Prasun Banerjee. "Recent developments in nanomaterials based adsorbents for water purification techniques." Biointerface Res. Appl. Chem 12 (2022): 5821-5835.
[12]. Cahoon, Lawrence B. "Water purification: treatment of microbial contamination." In Advances in water purification techniques, pp. 385-395. Elsevier, 2019.
[13]. Savage, N., & Diallo, M. S. (2005). Nanomaterials and water purification: opportunities and challenges. Journal of Nanoparticle research, 7, 331-342.
[14]. Tembekar, O. V. Advancements in Water Purification Technologies.
[15]. Rajendra Kattunga, "Evaluating Manual vs Automated Warehouse Processes Using SAP EWM in Enterprise Environments", International Journal for Research Trends and Innovation, 10(7), 2025.
[16]. Choi, H., Al-Abed, S. R., Dionysiou, D. D., Stathatos, E., & Lianos, P. (2010). TiO2-based advanced oxidation nanotechnologies for water purification and reuse. Sustainability science and engineering, 2, 229-254.
[17]. Al–Ekabi, Hussain, Ali Safarzadeh–Amiri, Wendy Sifton, and Joan Story. "Advanced technology for water purification by heterogeneous photocatalysis." International Journal of Environment and Pollution 1, no. 1-2 (1991): 125-136.
[18]. Pantapasis, Kostantinos, and Alexandru Mihai Grumezescu. "Gold nanoparticles: advances in water purification approaches." In Water purification, pp. 447-477. Academic Press, 2017.
[19]. Singh, N. B., Garima Nagpal, and Sonal Agrawal. "Water purification by using adsorbents: a review." Environmental technology & innovation 11 (2018): 187-240.
[20]. Naidu Paila, "AI-Based Analysis of Post-Surgical Patient Data for Risk Stratification After Total Knee Arthroplasty", Journal of Artificial Intelligence and Machine Learning, 3(4), 2025, 1-8.
[21]. Scriven, N., Thoburn, G., Tanbouza, N., Darby, C., Carlisle, E., Hamilton, H., Otumudia, E., Santos, I.S.M., Spencelayh, M., Woof, C. and Yarrow-Wright, L., Environmental Science Water Research & Technology.
[22]. Mohiyaden, Hairun Aishah, Lariyah Mohd Sidek, Gasim Hayder Ahmed Salih, Ahmad Hussein Birima, Hidayah Basri, Ahmad Fauzan Mohd Sabri, and M. D. Noh. "Conventional methods and emerging technologies for urban river water purification plant: a short review." ARPN J Eng Appl Sci 11, no. 4 (2016): 2547-2556.
[23]. BOUKHALFA, Nadia, Nassima DJEBRI, and Mokhtar BOUTAHALA. "ADVANCES IN WATER TREATMENT BY ADSORPTION TECHNOLOGY: APPLICATION TO THE REMEDIATION OF POLLUTED WATER BY ANIONIC DRUG."
[24]. Perikala, Karthik. "International Journal of Cloud Computing." Management 1, no. 3 (2025): 1-6.
[25]. Sharma, Priyanka R., Sunil K. Sharma, Tom Lindström, and Benjamin S. Hsiao. "Nanocellulose-enabled membranes for water purification: perspectives." Advanced Sustainable Systems 4, no. 5 (2020): 1900114.
[26]. Uddin, Z., F. Ahmad, T. Ullan, Y. Nawab, S. Ahmad, F. Azam, A. Rasheed, and M. S. Zafar. "Recent trends in water purification using electrospun nanofibrous membranes." International Journal of Environmental Science and Technology 19, no. 9 (2022): 9149-9176.
[27]. Sathishkumar Mani, Libiya Saravanan, M. Ramachandran, Muniyammal Sakthivel, "Evaluating the Impact of Antibiotics on Childhood Immunity: A WASPAS Analysis of Immune System Development and Long-Term Health Effects" Computer Science, Engineering and Technology, 3(4), 2025, 37-47.
[28]. Rajender Radharam, "Operational Analytics Platform for Healthcare Encounter Resolution Using Machine Learning", Journal of Data Science and Information Technology, 1(4), 2024, 1-7.
[29]. Hinkebein, Thomas E., and M. K. Price. "Progress with the desalination and water purification technologies US roadmap." Desalination 182, no. 1-3 (2005): 19-28.
[30]. Seetaram Rao Rayarao Navath, Suryakiran, Surya Rao Rayarao, Krishnamoorthy Selvaraj,Satya Sukumar Makkapati, "Leveraging Data Analytics to Explore the Impact of CMS Medicare Measures on Health Screens and Stars Supplemental Provider Rating in Enhancing Preventive Care Approaches", Journal of Business Intelligence and Data Analytics, 1, 2024, 6-10.
[31]. Kunduru, Konda Reddy, Michael Nazarkovsky, Shady Farah, Rajendra P. Pawar, Arijit Basu, and Abraham J. Domb. "Nanotechnology for water purification: applications of nanotechnology methods in wastewater treatment." Water purification (2017): 33-74.
[32]. Foster, John, Bradley S. Sommers, Sarah Nowak Gucker, Isaiah M. Blankson, and Grigory Adamovsky. "Perspectives on the interaction of plasmas with liquid water for water purification." IEEE Transactions on Plasma Science 40, no. 5 (2012): 1311-1323.
[33]. Divya Soundarapandian, "Predictive Analytics For Customer Loyalty: A Machine Learning Approach To Loyalty Engineering In Digital Banking", International Journal of Information Technology and Management Information Systems (IJITMIS), 15(1), 2024, 54-71.
[34]. Lee, Chee Huei, Bishnu Tiwari, Dongyan Zhang, and Yoke Khin Yap. "Water purification: oil–water separation by nanotechnology and environmental concerns." Environmental Science: Nano 4, no. 3 (2017): 514-525.
[35]. Pan, Jia Hong, Haiqing Dou, Zhigang Xiong, Chen Xu, Jizhen Ma, and X. S. Zhao. "Porous photocatalysts for advanced water

purifications." Journal of Materials Chemistry 20, no. 22 (2010): 4512-4528.

[36]. Foteinis, S., & Chatzisymeon, E. (2020). Heterogeneous photocatalysis for water purification. In Nanostructured Photocatalysts (pp. 75-97). Elsevier.

[37]. Bilquis Ali and Prabha Patil Rajendra Kattunga, “Comparative Evaluation of Artificial Intelligence Prototypes for Human-Centered Enhanced Intelligence Systems”, International Journal of Research in Computer Applications and Information Technology, 7(2), 2940–2955.

[38]. Singh, Baljinder, Nutan Shukla, Chan-Hyun Cho, Byung Sun Kim, Myoung-Hwan Park, and Kibeom Kim. "Effect and application of micro-and nanobubbles in water purification." Toxicology and Environmental Health Sciences 13 (2021): 9-16.

[39]. Paila, Naidu. "Reducing Manual Workload in SAP IBP Time-Series Supply Planning: A Practical Approach to Automation." International Journal of Cloud Computing and Supply Chain Management 1, no. 3 (2025): 1-7.

[40]. Dhakras, Prathamesh A. "Nanotechnology applications in water purification and waste water treatment: a review." In International conference on nanoscience, engineering and technology (ICONSET 2011), pp. 285-291. IEEE, 2011.