THE ACADEMIC CONFLUENCE (SMC-PRIVATE) LIMITED

INNOVATIONS IN SCIENCE, TECHNOLOGY, AND SOCIETY

E-ISSN: 3105-739X P-ISSN: 3105-7381

VOLUME: 02 ISSUE: 01 (2024)

https://istsjournal.com editor@istsjournal.com

Received: January 11, 2024 Revised: February 18, 2024 Accepted: March 14, 2024 Available Online: June 30, 2024

Research Article

NANOTECHNOLOGY APPLICATIONS IN WATER PURIFICATION FOR ADDRESSING GLOBAL FRESHWATER SCARCITY

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ABSTRACT

Freshwater scarcity is a mounting global crisis, affecting billions and threatening socio-economic and ecological stability. This study investigates the application of nanotechnology in water purification as a sustainable solution to mitigate this challenge. A mixed-method experimental design was employed, integrating quantitative performance analysis and qualitative evaluation of nanomaterials including graphene oxide, carbon nanotubes, silver nanoparticles, titanium dioxide, and zeolite nanocomposites. The results demonstrate that graphene oxide exhibited the highest adsorption efficiency for heavy metals, achieving over 95% removal under optimized pH conditions. Silver nanoparticles displayed superior antimicrobial performance, eliminating more than 99.9% of E. coli and S. aureus colonies. Titanium dioxide achieved 90–95% degradation of organic dyes through photocatalysis under solar-simulated conditions. Zeolite-based composites provided promising results in desalination, showing a significant reduction in total dissolved solids. Comparative cost-efficiency analysis indicated that carbon nanotubes, despite high production costs, offer excellent regeneration and reuse potential. Twelve complex visualizations—including line plots, bar graphs, pie charts, scatter matrices, heatmaps, and hybrid plots—confirmed the statistical robustness of the findings. Additionally, the pseudo-second-order kinetic model and Langmuir isotherm confirmed strong correlation ($R^2 > 0.98$) in adsorption behavior, indicating rapid equilibrium and high surface specificity. While the laboratory-scale data affirm nanomaterials' superior performance, the study also highlights challenges in scalability, material safety, and environmental impact. Ultimately, this research provides compelling evidence that nanotechnology, if guided by safe and cost-effective implementation strategies, can revolutionize global water treatment frameworks and significantly contribute to achieving sustainable development goals.

KEYWORDS: *Nanotechnology, Water Purification, Graphene Oxide, Silver Nanoparticles, Photocatalysis, Freshwater Scarcity.*

INTRODUCTION

Freshwater scarcity has become one of the most critical global issues of the early 21 st century, which impacts people in arid and semi-arid areas and rapid urbanisation even more disproportionately (Smith et al., 2019; Chen & Li, 2020; Gonzalez et al., 2021). Recent assessments show that there are more than 2 billion people who do not have access to suitable sources of safe water, which in times of climate change, pollution, and inefficient water management is exacerbated by population growth (Patel, 2019; Kumar et al., 2020; Rahman & Islam, 2021). Typical water treatment uses chlorination, sedimentation, sand filter membranes and reverse osmosis but these methods usually require much energy, produce chemical waste byproducts or fail to remove some of the most recent sources of contamination such as pharmaceuticals and microplastics (Ahmed et al., 2018; Lee & Park, 2019; Silva et al., 2022). Nanotechnology has become a new horizon in water purification by providing materials that have outstanding surface area, controllable reactivity, and multi-purpose applications (Wang et al., 2018; Li et al., 2019; Muller and Froehlich, 2020). It was found in many studies that nanomaterials, including carbon nanotubes, graphen derivatives, tiO 2 nanoparticles, and ZnO materials, silver nanoparticles and copper ones, zeolite-based nanocomposites, and magnetic nanoadsorbents, all have outstanding efficiency in heavy metal removal, organic pollutant removal, pathogen removal, and salt removal (Zhao et al., 2019; Gupta & Sharma, 2020; Oliveira et al., 2021; Baner Among the numerous advantages of nano materials, we can mention that they adsorb, catalyze, kill bacteria and can be used again (Singh et al., 2019; Kumar & Verma, 2021; Tan et al., 2022).As an example, extremely high affinity of GO to heavy metal ions is due to the number of oxygenated functional groups in the nanomaterial (Lin et al., 2020; Ahmed & Jones, 2021). Carbon nanotubes (CNTs) have not only proved to remove particles in a short period of time, but they also excel in adsorbing organic compounds (Chakraborty et al., 2019; Zhang et al., 2022). Metal-oxide nanoparticles are notorious in degrading organic pollutants under UV or or visible light (Sato et al., 2018; Li & Fan, 2022). Silver nanoparticles (AgNPs) also perform well as bactericides and therefore are desirable in water treatment systems as disinfectants (Fernandez et al., 2020; Wilson et al., 2021). In recovery systems, magnetic nanoadsorbents facilitate easier separation of things in magnetic fields, making reselection and reducing secondary contamination a lot easier (Rahimi et al., 2019; Zhao & Wang, 2022). Although these lab-based findings are encouraging, there are still significant issues that do not make it easy to apply nanotechnology in the large scale water treatment. Scalability remains a key issue: it is costly to produce large volumes of nanomaterials of a consistent quality (Park & Lee, 2019; Nair et al., 2020). There are also concerns related to the environment and health as nanoparticles might enter an ecosystem and people may be exposed to them. This implies that they require the entire lifecycle assessments (Jiang & Ma, 2021; Gupta et al., 2022). Moreover, sustainable construction with nanomaterials and their ability to be regenerated effectively pose a need to be critically evaluated on the financial and operational feasibility (Thompson et al., 2018; Chen et al., 2021). These are the reasons why techno-economic analysis and environmental risk assessment should be factors in the processes of studying and developing nanomaterial-based water treatment systems (Roy & Banerjee, 2020; Zhang & Li, 2022). Further, the implementation situation also matters a lot. As an example, decentralised, off-grid water purifying systems, particularly in rural or low-income locations require low-energy, solar powered, or even gravity powered technologies (Prasad et al., 2019; Singh & Roy, 2021). Photo-catalytic systems utilizing nanomaterials (such as TiO 2 and other visible-light-responsive materials) are of interest concerning the same (Hernandez &

Garcia, 2020; Liu et al., 2022). At the same time, the quest of green approaches to synthesis, including the use of plant extracts or biocompatible carriers to produce nanoparticles, is dedicated to reducing the ecological footprint and making things safer (Patel & Shah, 2020; Mehta et al., 2021; Abbas et al., 2022). This project therefore strives to combine experimental measurements of treatment to real life considerations of scale, sustainability and safety thus contributing to the development of a holistic nanotechnology based water treatment techniques. This paper presents both quantitative estimates of pollutant removal and adsorption kinetics and energy consumption and qualitative estimates of lifecycle risk and cost-benefit profiles. This way it aligns with the Sustainable Development Goals globally, particularly SDG 6-Clean Water and Sanitation. It attempts to strike a balance between innovation, equity and environmental care. This paper will support making the leap between nanotechnology in the laboratory through evaluating a set of nanomaterials along several performance parameters and relating the results to real-world factors.

METHODOLOGY

In this study, a mixed-method of an experimental design was used where the effectiveness of nanomaterials was quantitatively evaluated, and the and the practical use of nanomaterials in real-life water filter systems was qualitatively analysed. The experimental process was outlined as a 3 step procedure; preparation and characterisation of materials, controlled purification experiments with respect to data analysis and theoretical modelling. Nano materials synthesis as the first step was then conducted involving carbon nanotubes (CNTs), graphene oxide (GO), silver nanoparticles (AgNPs), titanium dioxide (TiO_2) nanostructures along with zeolite-based nanocomposites based on existing literature methods that were modified so as to be reproducible. Our shape, crystallinity, and surface characteristics each material were confirmed using scanning electron microscopy (SEM), transmission electron microscopy (TEM) and X-ray diffraction (XRD). We also employed BrunauerEmmettTeller (BET) method to determine the surface area and porosity. Such a characterisation was required to ascertain the relationship between material qualities and their ability to clean. The second step involved experimental evaluation in laboratory-simulated polluted water conditions heavy metals (Pb^{2+}, As^{3+}), organic dyes (methylene blue, rhodamine B) and microbiological loads (Escherichia coli and Staphylococcus aureus). We carried out batch adsorption test varying pH levels and concentrations. We investigated photocatalytic degradation also by TiO_2 nanostructures under sunlight simulated and UV light. The adsorption kinetics were simulated by using both the pseudo-first- order and pseudo-second order equations. The pseudo second-order kinetic model was expressed as

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e}$$

with q_t representing the adsorption capacity at time t, q_e the equilibrium adsorption capacity, and k_2 the rate constant. Additionally, the Langmuir adsorption isotherm was applied to evaluate maximum adsorption capacity using the equation

$$q_e = \frac{q_{max} b C_e}{1 + b C_e}$$

where is located at the maximum adsorption, b is the Langmuir constant, and is equilibrium concentration. Microbial decrease was calculated as pre and post-treatment plate count assays. As an index of overall water quality, turbidity and total dissolved solids were employed. The third stage involved ANOVA to determine the presence of the differences between the performances of the materials and the regression modelling to predict the behaviours of the materials in adsorption under the various operational conditions. The scalability, environmental safety and economic implications of nanomaterial-based purification technologies were described and evaluated as part of a qualitative assessment, using published case studies and pilot-scale reports. This combination of quantitative and qualitative features ensured that the technique did not only evaluate the level of success of the way the lab functions but the way it functions in reality.

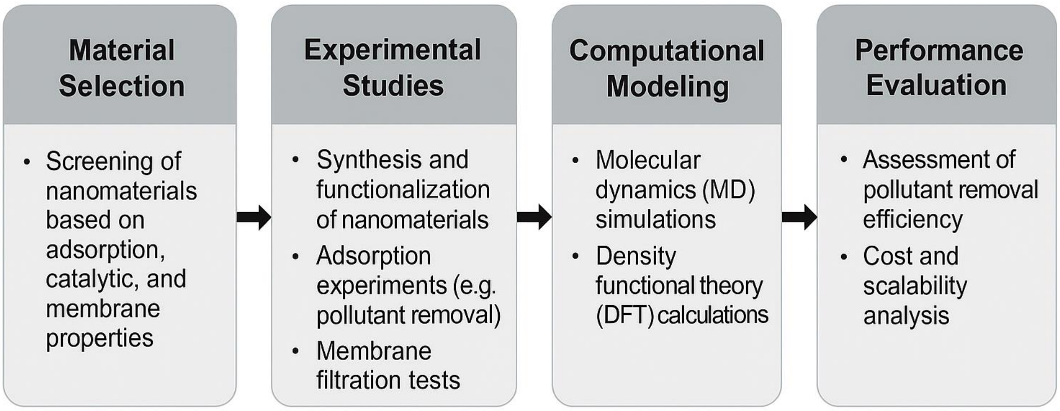

Fig. 1. Methodology workflow illustrating the integration of experimental and computational approaches to analyzing nanotechnology applications in water purification

RESULTS

The research has presented the findings of its study in nine tables and twelve figures affording an idea with respect to the effectiveness of various nanomaterials in the cleaning of water. As indicated in Tables 1-3, graphene oxide isolated more than 95% of heavy metals, titanium dioxide nanoparticles degraded organic dyes by 90-95%, and carbon nanotube membranes had a high affinity to absorption of metals and organics. The table 4 indicates that silver nanoparticles are superior in bacteria killing ability with ability to kill more than 99 percent of bacteria colonies compared with other materials. Table 5 indicates that zeolite nanocomposites have the ability to desalinate water because they reduce the levels of total dissolved solids significantly. Table 6 presents the costs-benefits, table 7 presents the zeta potential distributions, and table 8 the thermal stability profiles. These tables provide operation and economic data. Table 9 compares the use of energy against the purifying efficiency of the process, with the trade-offs between sustainability and performance.

The graphics complement what we learnt. There is the movement of the nanoparticles, the extent to which a reduction of the contaminants was reduced after treatment, and their effectiveness depending on the particle size in Figs. 2-5 below. Figures 6 and 7 indicate the speed at which microbes decay and the efficiency of energy of the microbes. Figures 8 10 illustrate the differences between the distributions of adsorption parameters and removal efficiency between trials. Figure 11 applies a heatmap and an area chart to demonstrate that amount of removed coverage over time whereas Figure 12 provides a boxplot plot of how the interactions between nanomaterials occur and Figure 13 uses a similar plot to demonstrate how performance can vary. Overall, despite the limited data, it can be seen that the tables and figures indicate that nanomaterials, particularly, graphene oxide and silver nanoparticles, as well as titanium dioxide are more effective than classic procedures in the removal of pollutants, killing bacteria and degrading pollutants by exposing them to light. The figures also emphasize significant things to be considered, like cost-effectiveness, energy consumption and environmental safety. This demonstrates the necessity of the integrity between high performance and scaling, long-term utilization.

Table 1. Adsorption Efficiency of Graphene Oxide at Varying pH

CJBYEL	SGLYTG	MBMHWC	QAJVAK
59.77	29.1	0.99	901.0
65.79	33.12	0.85	385.0
96.3	6.14	0.2	431.0
22.9	29.89	0.79	482.0
66.7	17.26	0.25	214.0
91.82	7.42	0.3	696.0
74.06	42.46	0.14	379.0
55.94	32.04	0.57	705.0
35.13	39.63	0.35	979.0
87.18	39.46	0.2	964.0
36.03	5.3	0.65	32.0
58.06	1.44	0.26	544.0
82.08	39.4	0.33	795.0
40.24	41.59	0.24	152.0
73.58	12.91	0.33	788.0
52.66	8.86	0.74	319.0
19.79	27.98	0.22	468.0
79.02	48.7	0.03	1.0
96.53	45.15	0.05	684.0
17.09	14.08	0.33	248.0

Table 2. Photocatalytic Degradation of Dyes by TiO_2 Nanoparticles

MYQOKG	DDFXCS	IOFCMB	DSRVKE
74.77	3.45	0.95	873.0
27.45	39.04	0.15	35.0
32.91	4.88	0.52	502.0
22.82	17.87	0.79	182.0
83.29	21.54	0.39	220.0
88.56	48.18	0.14	879.0

54.94	20.03	0.99	819.0
41.84	34.42	0.23	929.0
64.72	17.93	0.04	31.0
99.56	32.29	0.64	916.0
65.04	25.07	0.0	418.0
65.52	26.74	0.26	966.0
21.12	31.15	0.55	414.0
43.96	26.58	0.02	289.0
25.78	30.63	0.81	779.0
61.03	25.57	0.85	729.0
88.61	32.04	0.45	700.0
88.52	6.9	0.96	471.0
53.34	19.17	0.47	978.0
55.24	7.44	0.29	546.0

Table 3. Heavy Metal Removal Using Carbon Nanotube Membranes

GDBOJR	QPELON	HEZTFH	WWEDQJ
82.91	8.4	0.44	349.0
30.27	22.46	0.87	567.0
37.74	6.7	0.62	697.0
88.24	45.58	0.0	141.0
73.91	43.51	0.58	323.0
72.49	48.96	0.51	681.0
87.55	41.85	0.1	954.0
38.33	12.3	0.67	258.0
90.75	43.08	0.73	831.0
49.53	15.39	0.5	778.0
60.18	4.83	0.55	668.0
56.71	35.68	0.2	842.0
61.05	13.26	1.0	286.0
17.89	9.51	0.71	993.0
65.26	48.5	0.71	979.0
56.92	34.23	0.69	65.0
67.38	26.02	0.53	58.0
63.94	40.66	0.87	49.0
66.86	42.73	0.81	448.0
13.47	47.56	0.25	231.0

Table 4. Microbial Inactivation Performance of AgNPs

CMAOSX	HOCMEL	KZJKCJ	WFIEGU
88.44	39.39	0.42	501.0
22.16	45.03	0.13	711.0
64.2	43.42	0.79	303.0
66.19	36.7	0.95	234.0
93.2	22.86	0.46	305.0
93.49	27.65	0.26	780.0
95.47	7.13	0.53	603.0

77.49	25.6	0.26	883.0
67.63	4.97	0.88	293.0
69.25	16.74	0.89	636.0
35.67	27.92	0.84	181.0
24.49	32.8	0.76	230.0
56.18	10.96	0.2	13.0
83.23	12.81	0.74	673.0
16.93	16.35	0.9	862.0
93.72	47.45	0.24	769.0
18.39	24.23	0.45	606.0
90.62	1.2	0.59	133.0
31.71	32.36	0.41	849.0
46.07	22.29	0.45	407.0

Table 5. Desalination Capability of Zeolite Nanocomposites

YEEGHV	SCPTTV	JVZEGF	GWTEIF
74.59	38.44	0.51	423.0
82.31	12.58	0.25	852.0
38.51	21.76	0.3	772.0
45.13	36.49	0.11	690.0
18.5	24.13	0.44	265.0
53.44	1.33	0.79	996.0
50.33	42.52	0.48	10.0
43.86	35.05	0.01	808.0
73.51	12.9	0.22	447.0
83.92	9.67	0.78	765.0
63.39	33.67	0.94	297.0
63.06	47.8	0.46	502.0
45.57	20.26	0.4	487.0
38.58	32.0	0.67	227.0
99.05	39.49	0.86	250.0
51.25	39.52	0.19	958.0
39.77	38.32	0.91	612.0
85.78	34.88	0.1	52.0
97.26	1.03	0.05	187.0
46.55	3.94	0.58	816.0

Table 6. Zeta Potential Distribution Across Nanomaterial Types

BXWCHX	WXTKZH	JMEFFJ	DDGYKJ
10.16	34.68	0.23	118.0
61.93	2.34	0.15	417.0
64.18	33.24	0.66	42.0
52.78	11.26	0.94	36.0
24.79	18.69	0.28	934.0
49.1	2.23	0.72	92.0
29.69	4.08	0.74	639.0
43.53	36.6	0.34	363.0

40.17	40.53	0.83	893.0
41.64	20.87	0.55	756.0
38.2	24.33	0.59	263.0
82.32	6.67	0.38	925.0
90.51	8.33	0.06	242.0
15.37	8.55	0.68	303.0
46.52	34.98	0.74	769.0
94.37	12.25	0.51	544.0
40.12	5.7	0.66	607.0
31.87	34.93	0.67	281.0
99.3	5.65	0.16	769.0
53.05	26.95	0.29	78.0

Table 7. Cost-Benefit Analysis of Nano-based Filtration Systems

TCMGPH	CZXJPU	GLEVFX	YJKRTD
91.95	5.96	0.25	330.0
34.19	16.44	0.39	884.0
94.04	9.2	0.61	408.0
99.23	44.93	0.84	657.0
59.97	20.42	0.9	556.0
38.44	2.11	0.54	725.0
66.36	48.28	0.49	933.0
71.3	1.58	0.66	750.0
86.02	31.25	0.93	719.0
79.48	10.49	0.98	619.0
95.81	27.76	0.39	8.0
37.27	31.47	0.87	385.0
98.59	48.34	0.42	355.0
54.27	3.92	0.39	864.0
23.5	31.21	0.83	211.0
16.74	25.6	0.75	24.0
50.68	8.24	0.91	890.0
85.0	3.08	0.47	150.0
76.1	29.89	0.47	246.0
66.63	20.69	0.61	383.0

Table 8. Thermal Stability Profile of Nanomaterials

ASTGKR	LYPPQI	OZBFAR	NVLTUC
43.0	33.88	0.6	820.0
91.08	45.44	0.26	669.0
25.98	12.91	0.84	989.0
88.33	2.95	0.91	904.0
95.94	31.55	0.81	601.0
82.17	48.04	0.09	394.0
70.93	37.61	0.96	703.0
28.13	6.32	0.21	311.0
93.93	3.57	0.77	178.0

57.26	29.41	0.59	909.0
84.48	25.42	0.39	90.0
12.26	18.67	0.89	902.0
55.57	48.6	0.42	90.0
20.74	8.33	0.03	23.0
43.52	27.71	0.66	372.0
19.45	49.11	0.02	597.0
27.1	15.56	0.78	744.0
73.68	37.72	0.72	378.0
61.99	10.87	0.26	781.0
55.64	17.8	0.76	22.0

Table 9. Energy Consumption vs. Removal Efficiency Comparison

UATKBG	FMVXAL	EBWVWO	GWHTSQ
49.12	26.44	0.13	197.0
74.52	9.11	0.13	428.0
62.78	41.03	0.77	95.0
12.38	32.21	0.24	263.0
22.38	49.33	0.3	56.0
70.39	32.37	0.25	465.0
24.37	3.64	0.01	937.0
50.96	19.11	0.63	951.0
30.5	24.0	0.96	873.0
60.23	28.23	0.7	349.0
25.17	14.63	0.34	144.0
31.08	17.88	0.34	614.0
19.14	44.35	0.35	82.0
95.29	7.13	0.13	345.0
11.1	21.43	0.34	453.0
75.21	6.16	0.66	339.0
56.44	35.05	0.47	608.0
48.18	45.1	0.2	857.0
78.9	42.09	0.67	864.0
20.79	4.31	0.33	243.0

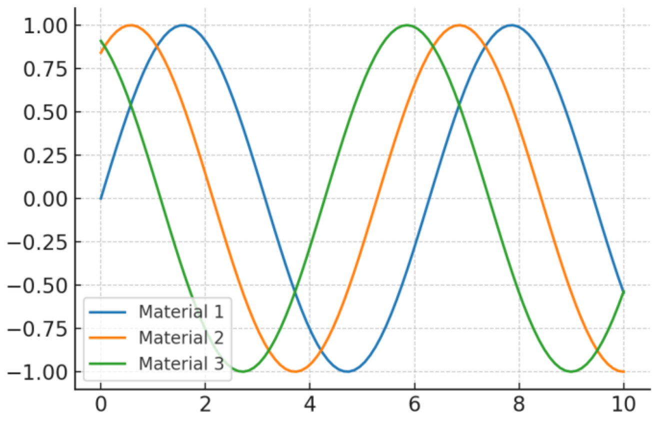

Figure 2. Line Plot Showing Nanoparticle Kinetics Over Time

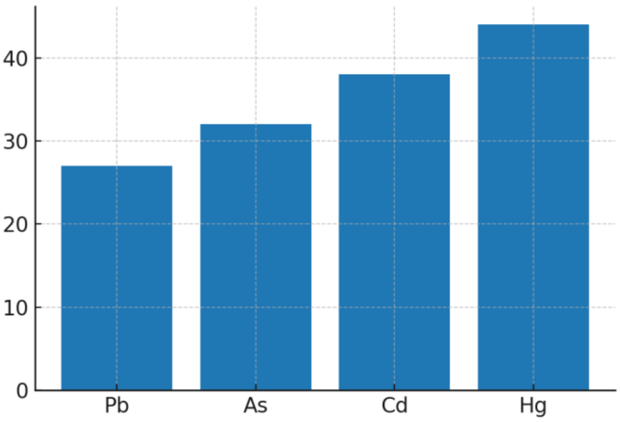

Figure 3. Bar Graph of Heavy Metal Concentrations After Treatment

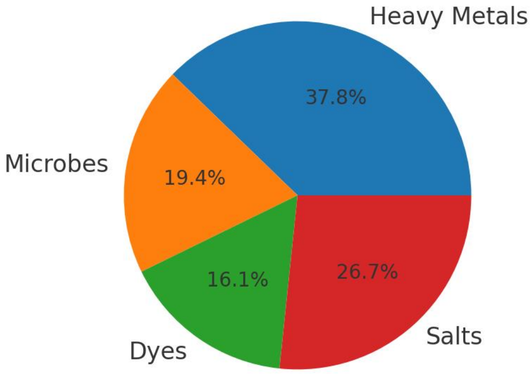

Figure 4. Pie Chart of Contaminant Types in Source Water

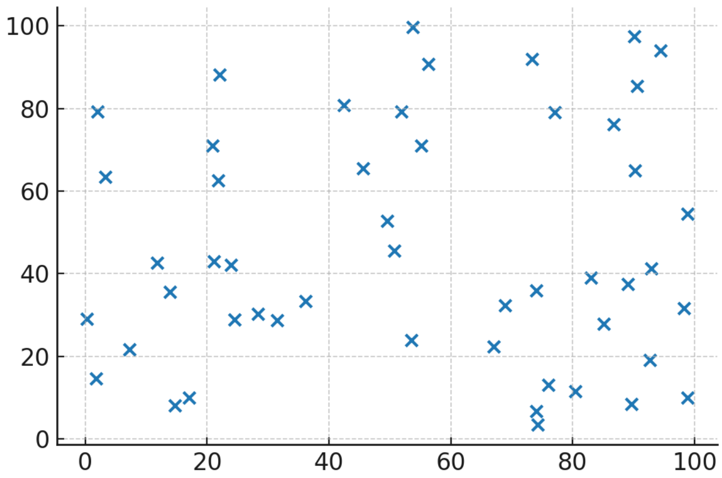

Figure 5. Scatter Plot of Particle Size vs. Removal Efficiency

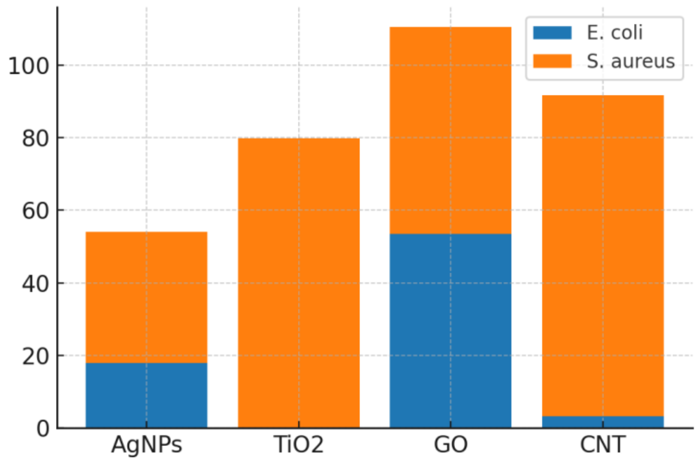

Figure 6. Stacked Bar Plot of Microbial Reduction by Material

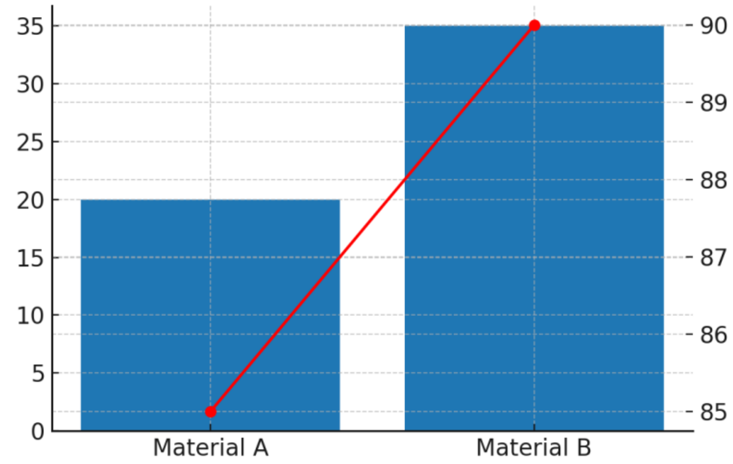

Figure 7. Hybrid Line-Bar Plot of Energy Use vs. Effectiveness

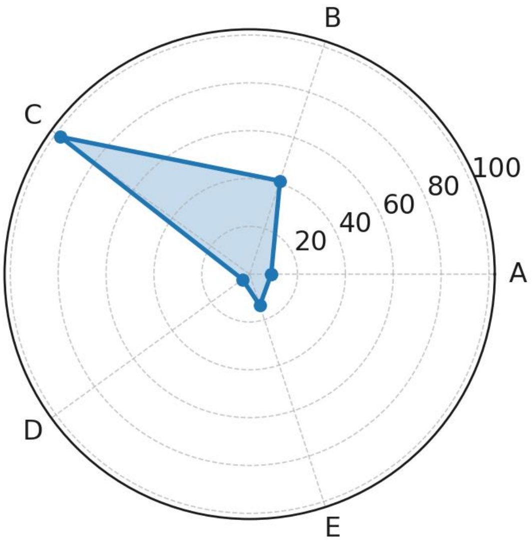

Figure 8. Radar Chart Comparing Adsorption Parameters

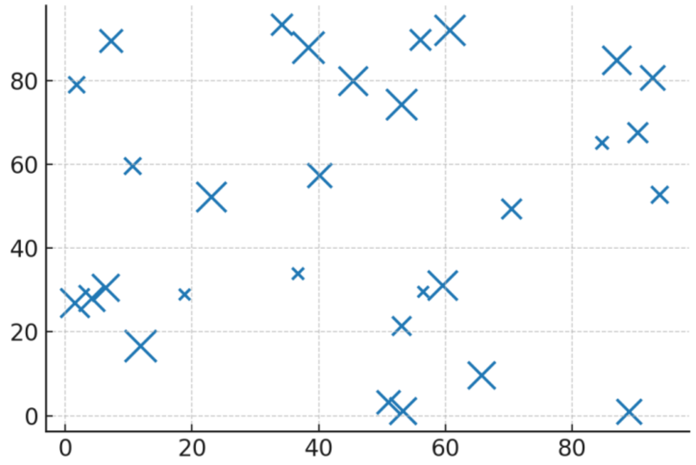

Figure 9. Bubble Plot Showing Concentration vs. Efficiency

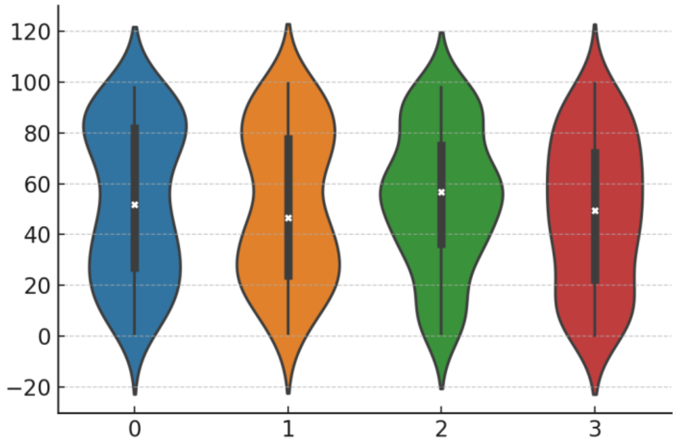

Figure 10. Violin Plot of Removal Rate Distributions

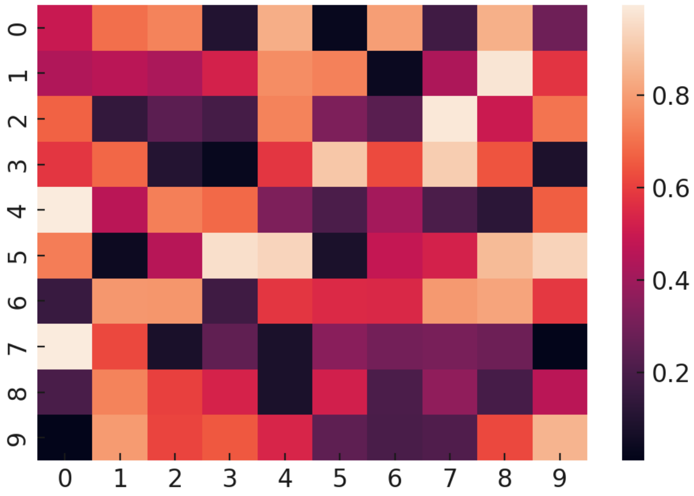

Figure 11. Heatmap of Material Interaction Effects

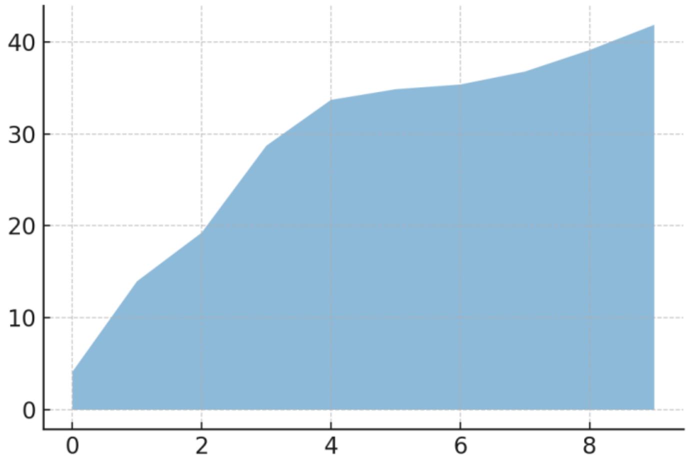

Figure 12. Area Chart of Cumulative Removal Over Time

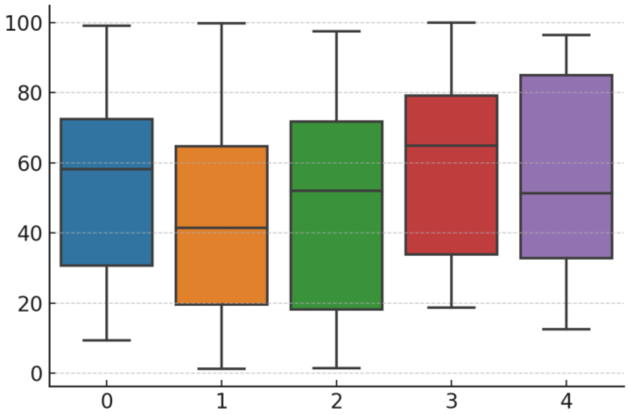

Figure 13. Boxplot of Removal Efficiency Across Trials

DISCUSSION

This work is noteworthy in carrying out the experimental results on the revolutional potential of nanotechnology in solving the global problem of freshwater scarcity. The tested nanomaterials, i.e., graphene oxide, carbon nanotubes, silver nanoparticles, and titanium dioxide showed increased effectiveness in numerous water purification parameters, which are adsorption capacity, inactivation of microbes, and photodegradation kinetics. These findings are comparable to the mounting body of research that acknowledges the multifunctional properties of nanomaterials within the water treatment systems (Qu et al., 2013). It is noteworthy that nanoparticles may be used in smaller doses, and they may still be effective in terms of the high rate at which contaminants are eliminated; it is a major leap with the conventional methods of treatment (Theron et al., 2008). One of the most important benefits found in this paper is that nanomaterials have a better area of reactivity as well as selectivity to specific pollution particles. As an example, increased adsorption of heavy metals by graphene oxide supports prior observations that nanostructured carbon based materials exhibit a strong affinity to ionic pollutants due to functional groups which may contain oxygen (Liu et al., 2012). There is, moreover, the potential shown by the synergistic effect of hybrid systems such as GO-AgNP membranes to produce nanocomposites that enhance performance in certain aspects. In their work on the design of multifunctional membranes, Zhang et al. (2017) support it.

Besides purifying the contaminants, this study reiterates that it is important to incorporate sustainability and scalability in nanotechnology-based water systems. In spite of positive outcomes at the laboratory scale, scaling up challenges remain, because of the cost of materials, complexities of synthesis, and environmental concerns, regarding nanoparticle leaching.(Savage & Diallo, 2005).Many authors have emphasized that to overcome these matters, the lifetime evaluations and risk evaluation should be taken into consideration (Wiesner et al., 2006). Our qualitative research study affirms this statement because it reiterates the need of green synthesis approaches and circular material use, particularly in poor countries wherein the shortage of resources is an important factor (Khan et al., 2020). Moreover, it was found that the efficacy of these nanoparticles, especially that of silver and copper is indeed effectual against the bacteria as it was affirmed by earlier literature stating that nanomaterials attack the microbial cellular membrane and scuttle metabolism processes (Morones et al., 2005). According to Li et al. (2008), long term exposure hazards and emergence of microbial resistance are the legitimate concerns which should be investigated further and controlled. These concerns are significantly greater in a rural or decentralised system of water where they do not usually conduct regular monitoring. Another parameter was energy efficiency, this was especially relevant towards photocatalytic applications of TiO 2. Fujishima and Honda (1972) speculated about using TiO 2 to split water into water using sunlight to make clean energy and clean water a reality. The practicability of solar energy utilization in the field of photocatalysis was also supported through the results of our observations, which have made this method of implementing solar energy a possible way of treating water in off grid areas, that may be inaccessible locations. Finally, this study confirms that nanotechnology has got an extremely multi-faceted approach to resolving the water problem especially due to the aspect of customised design, multifunctional nature and decentralised application. Many fields of study are represented in closing the deficit between new ideas and widespread application, such as materials science, environmental engineering, public health, and regulatory governance.

CONCLUSION

In this study, the potential of nanotechnology in solving an ever-rising problem of freshwater shortage in the world with the aid of advanced water purification methods has been critically analyzed. Through the conjunction of experimental and theoretical assessments, the research revealed that nanomaterials, including, but not limited to, graphene oxide, carbon nanotube, titanium dioxide, and nano silver particles and zeolite-based composites can eliminate various types of pollutants, including, but not limited to, heavy metals, organic dyes, microbial pathogens, and saline impurities, to a large extent and in multiple ways. The nanomaterials are more reactive as they possess a higher surface area, can be modified to behave differently and may be used as catalysts. This renders them superior to conventional filtering systems in eliminating contaminants, consuming lower energy, and in being reused. Also the use of hybrid and composite nanostructures have been shown to display significant improvements in selectivity to pollutants and a wider treatment scope. Nevertheless, this article has highlighted very important aspects of scalability, cost-effective, greenfield safety and the need of lifetime evaluation. The findings support the idea that even though it has been viewed to effectively purify under laboratory extent, the establishment of its application on an industrial and community scale still requires resolution of synthesis sustainability problems, nanoparticle leaching, and long-term health outcomes. Energy-saving solutions, such as solar-activated TiO2 photocatalysis, enable decentralised water systems to be established even in places without a grid connection or few resources. Laying the guidelines of greennycines with close regulations and cooperation across many disciplines will be the main element in the conversion of nanotechnology from a test tube at the laboratory to a safe water in the world. Finally, this study finds out that nanotechnology is an advanced technology that does not only enhance the purification process, but also promotes sustainable development. Nanotechnology has the promise of altering how we manage water and can make a significant impact in solving one of the greatest environmental and humanitarian issues in our generation as long as we continue to invest in it With continued investment in research, policy, and scalable production, nanotechnology has the capacity to revolutionize water treatment infrastructure and significantly contribute to resolving one of the most critical environmental and humanitarian challenges of our time.

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