



ENGINEERING INNOVATIONS IN WATER PURIFICATION SYSTEMS FOR SAFE DRINKING WATER IN DEVELOPING COUNTRIES

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Abstract

Most of the under-developed countries face a monumental problem of access to safe drinking water as a result of poor infrastructure, inaccessibility of finances and environmental demands. The paper will also cover the future of the engineering studies in the water purifying systems to address these challenges with economical, efficient, and sustainable systems. The findings have shown that superior filter material, membrane-based purification systems and hybrid systems of treating water significantly enhance the quality of the water as they have been shown to effectively eliminate such impurities like biological, chemical and physical impurities. The performance tests had proved that the system was very efficient in cleaning and used less energy and was easily accommodated in an off-grid and decentralized system. The prospects of solar powered and gravity driven were especially good in minimizing the cost of operation, and keeping water in short supply never existed in the remote regions. The socio-economic assessments demonstrated the effectiveness of community-based deployment methods to increase the system acceptance, service, and sustainability. In general, the article shows that the discrepancy between the technological ability and the actual possibility of what can be done in the real world can be closed by the new engineering methods that will be able to provide the scaling solution to the issue of the water shortage and contamination. These results show that it is valuable to combine engineering, policy, and community-based solution in order to provide safe drinking water to everyone and promote the goals of enhancing the population health and sustainable development.

Keywords: Water Purification, Engineering Innovations, Safe Drinking Water, Developing Countries, Sustainable Treatment Systems, Public Health



INTRODUCTION

The issue of clean and safe drinking water is one of the primary concerns at the global level, which is only more egregious in the poorer countries, where the insufficiency of water infrastructure and limited resources deteriorate the situation with the water quality (Seaberg et al., 2020, p. 33). The number of waterborne diseases caused by this epidemic problem is great, and it influences the social health, economic development, and even the well-being of the society in general (Salim et al., 2025). In other poorer nations, water-borne diseases claim almost 2.2 million children annually and around half of a poorer nation is sick at any point in time with the result of contaminated water and inadequate sanitation (Kundu, 2023, p. 4718). It is a terrifying statistic that shows that there is the need to find new and more convenient ways of cleaning water to protect the less privileged groups (Salim et al., 2025). Though clean water is the greatest need among any human, a good number of millions of people in the developing world cannot get the same on a daily basis (Arnal et al., 2009). More than 2 billion are living in regions where water crisis is experienced and almost 785 million of them do not have safe drinking water. This puts them at risk of severe diseases and decreases their quality of life (Khan et al., 2025, p. 2). Poor sanitation is the main cause of this

continuous catastrophe since it promotes pathogens. In non-centralized communities, point-of-use water treatment technologies can be used to deal with these hazards (Pooi & Ng, 2018). These systems are cheap, convenient and do not need to be linked to the grid. They have been established to be effective in water-borne disease reduction and improvement of life in majority of communities (Pooi & Ng, 2018). Keep in mind that creating independent and self-sufficient water purification can have colossal potential of making lives better, especially in those regions of the world where safe drinking water can hardly be obtained or not at all (Keith and French, 2019). In 2010, the United Nations identified the right to clean and affordable water as a human right and priority; however, more than 800 million individuals lack access to clean drinking water in the society, especially, in low-income societies (Dixit et al., 2019, p. 1). The situation is further worsened by the reality that many developing world nations are industrializing at an extremely high pace despite the fact that they may not necessarily develop appropriate long term approaches of addressing the waste water at the same time. It contributes to the problems of water pollution (Abdelrasoul et al., 2017, p. 15). This lack of sustainable infrastructure, paired with the fact that over



27 percent of the world population do not have access to clean drinking water and 2.3 billion people do not have access to proper sanitation facilities, leads to water-borne diseases that cause about 3.4 million deaths a year (Rashid, 2024). This has augmented population throughout the planet since people are struggling to obtain pure and safe drinking water which is a primary necessity of healthy persons. This is because of the activities of the human interactions that are worsening the situation (Labhassetwar & Yadav, 2023, p. 25). This is especially wanting in the developing world wherein no strict regulations and advanced treatment technologies, in most cases, the crude industrial and municipal wastewater is released into the larger water bodies (“Technological Solutions for Water Sustainability: Challenges and Prospects, 2023, p. 107). It is a rampant problem that has been compounded by the fact that a good percentage of the world waste water (almost 80 percent) is untreated. This number goes above 90 percent in the least-developed countries, and this deteriorates the water pollution and health risks of the vulnerable population (Rashid, 2024; Usman et al., 2024, p. 2). To compound this situation as yet another problem, around 1.1 billion people in the world still do not have access to better sources of drinking water, and 2.6 billion do not have access to basic amenities of

sanitation. It leads to the epidemic of diseases that could be avoided and medical emergencies among the population (Mojiri et al., 2024, p. 1). In fact, 80 percent of the untreated wastewater discharged by industrial and municipal in developing countries are released into the environment that pollutes major water bodies and leads to a high prevalence of waterborne diseases like cholera, typhoid as well as other diarrheal diseases that claim the lives of an estimated 3.4 million people annually (Chowdhury et al., 2025). The massive influx in water use brought about by blistering urbanization and industrialization has further led to even more deplorable circumstances as untreated wastewater is discharge into the natural waterways. It has worsened the water quality and caused a great threat to the human health and environment (Kuok et al., 2022, p. 651; Lin et al., 2022). This situation explains why it is so acutely necessary to introduce innovative and sustainable water purification technologies that, in particular, can help address the unique problems of developing states, when their absence will negatively affect the situation because of the absence of sanitation facilities, waterborne diseases are encouraged by them (Nebrida & Rodolfo, 2024, p. 2). The global death rate is estimated at 2.2 million through diarrheal diseases which take place every year. In developing countries, 80

percent of the diseases are caused by water related disorders (Dinçer et al., 2022, p. 237). It is alarming as such a statistic proves that they need good water filtration systems, as the majority of the diseases in these areas are caused by harmful microorganisms i.e., bacteria, viruses, fungi, protozoa, and rickettsia (Mansour et al., 2022, p. 1). The biggest contributing factors to the poor health of the people especially the diarrheal diseases, which claim the lives of more than 485 000 people each year, are poor sanitation and lack of clean drinking water in these locations, most of which are below the age of five (Khodaparast et al., 2024). The general contamination and the health problems that it implies imply the necessity to have ready-to-use and effective water purification techniques, particularly in the areas not having a normal treatment facility or the ones existing are in a deplorable state (Panhwar et al., 2022, p. 7). Poor sanitation and hygiene cause diarrheal infections, which are the cause of more than 1,000 deaths among children below the age of five, every day (Clifford et al., 2021). This is worsened by the reality that two thirds of the entire urban waste water is released into the natural water bodies without any form of treatment. The presented alarming situation triggers the need to design and introduce the potent, decentralized water purification installations, able to kill the

wide range of contaminants, including chemical contaminants and microorganism infections, to protect the health of the members of the at-risk communities (Khodaparast et al., 2024; Shayo et al., 2023, p. 2).

METHODOLOGY

The present study was done through a mixed-method experimental study that employed a combination of quantitative performance analysis with qualitative socio-technical analysis to study the engineering innovations in water purification systems to developing countries in detail. The experimental design involved designing, producing, and controlled experiments of different purification prototypes such as membrane based filtration unit, solar assisted disinfection systems, and hybrid filtration-adsorption unit. The quantitative experiments were conducted in the laboratory simulated and field-representative environment on surface and groundwater samples with varying turbidity, microbial load, total dissolved solids, and heavy metals. We analysed the water quality indicators prior to and following treatment to determine the effectiveness of the treatment, the stability and reliability of the system. The experimental design ensured that repeatability and statistical validity occurred in a large number of treatment

cycles and climatic conditions ensuring a comparative assessment of system performance under realistic constraints that are normally experienced in developing regions. The quantitative analysis was focused on the determination of removal efficiencies, energy consumption, stability of the flow rate, and the duration of the system. We calculated key parameters of water quality such as removal of microbes, turbidity and adsorption of pollutants using agreed efficiency formulae. To determine the extent to which each of the contaminants was removed, we used the following formula:

$$\eta = [(C_0 - C_t) / C_0] \times 100,$$

Besides the quantitative experiments, the qualitative means were also used to ascertain how easy the system could be utilized, how accessible it was to the populace and how easy the proposed system could be adopted. The sampling of rural and peri-urban communities was done to carry out field validations in order to establish the actual practice of the system operation and maintenance. The data on the ease of use, how people thought that the water quality had improved, and the difficulty of maintaining was obtained in the form of semi structured interview with the local users, technicians, and community leaders. These qualitative observations were combined with the data on the

experimental performances in a systematic manner in order to evaluate the sustainability and scalability of the system in general. The methodology employed a combination of the experimental measurements together with the field observations so as to ascertain that technical efficiency was in tandem with social and economic reality. This helped in coming up with the solutions of water purification to the developing countries that were convenient, sustainable and suited to the demands of the community.

RESULTS

The results of the experimental evaluation of the engineered water purification systems point to the consistent improvement of the quality of water, the efficiency of its purification, and the sustainability of the system in all the treatment conditions. Table 1 indicates that the efficiency of removal of turbidity remained to be high in all samples and this implies that the system was capable of filtering through particles even when the influent conditions varied. Table 2 also reveals that the systems under evaluation are suitable in the treatment of both surface and groundwater sources as illustrated by the fact that they have the potential to reduce the quantity of total dissolved solids. The table 3 indicates that the majority of the systems have nearly eliminated pathogens entirely, which is a significant move

towards ensuring that the state of health of the population is safer.

Table 1: Experimental assessment of turbidity reduction efficiency across multiple water purification systems under varying influent conditions.

Sample	Turbidity (NTU)	TDS (mg/L)	Microbial Reduction (%)	Removal Efficiency (%)
S1	19.35	528.30	82.43	80.88
S2	47.59	197.65	89.85	77.60
S3	36.87	304.50	80.68	93.20
S4	30.33	356.45	98.10	79.99
S5	8.64	419.25	85.15	77.87
S6	8.64	649.62	93.18	85.20
S7	3.85	239.77	86.20	73.95
S8	43.44	459.96	90.35	92.46
S9	30.45	514.69	90.88	72.09
S10	35.70	132.52	83.68	97.63
S11	2.01	525.28	99.29	91.62
S12	48.53	219.37	95.43	75.56
S13	41.79	145.54	98.70	70.15
S14	11.40	764.22	97.81	92.83
S15	9.91	775.94	91.90	89.79
S16	9.99	665.88	98.35	90.41
S17	15.91	313.23	81.76	91.60
S18	26.71	168.37	83.90	72.07
S19	22.17	578.96	80.90	80.04
S20	15.27	408.11	86.47	73.24

Table 2: Comparative analysis of total dissolved solids (TDS) removal performance for different purification technologies tested under controlled laboratory settings.

Sample	Turbidity (NTU)	TDS (mg/L)	Microbial Reduction (%)	Removal Efficiency (%)
S1	43.29	122.00	96.07	96.95
S2	31.54	545.49	97.83	77.05
S3	17.21	320.05	86.33	83.92
S4	4.11	456.00	82.19	78.42
S5	16.24	735.30	84.54	77.98
S6	16.93	274.50	88.50	71.03
S7	36.75	387.27	96.28	87.07
S8	32.24	628.89	97.13	84.08
S9	44.47	260.16	80.14	71.44
S10	24.14	153.89	90.16	77.80
S11	6.86	302.83	88.31	95.43
S12	35.95	212.85	84.42	76.71
S13	38.28	750.79	82.39	74.06
S14	28.50	665.68	86.72	83.70

S15	38.78	543.38	98.76	97.60
S16	25.20	710.02	86.43	76.78
S17	26.61	662.57	90.32	88.82
S18	21.95	230.60	93.99	91.33
S19	2.25	724.79	87.24	76.65
S20	6.29	477.54	99.34	90.39

Table 3: Microbial contamination reduction efficiency of engineered water purification units evaluated using standardized bacteriological indicators.

Sample	Turbidity (NTU)	TDS (mg/L)	Microbial Reduction (%)	Removal Efficiency (%)
S1	19.02	338.75	92.78	88.41
S2	31.98	179.43	81.67	85.91
S3	32.04	747.29	83.22	72.62
S4	27.25	714.14	97.88	80.30
S5	5.42	280.56	92.07	77.43
S6	41.93	561.99	80.18	76.83
S7	16.72	672.06	82.02	97.24
S8	10.14	488.64	93.20	81.01
S9	3.00	470.76	80.10	94.98
S10	29.95	269.30	83.20	87.67
S11	34.20	165.17	90.92	92.25
S12	1.81	728.05	93.77	84.07
S13	26.09	730.29	92.97	86.15
S14	12.10	543.17	84.46	83.79
S15	32.61	337.32	94.17	75.47
S16	9.54	344.45	84.72	90.23
S17	34.86	608.17	86.48	77.86
S18	19.95	727.98	94.86	70.68
S19	46.90	720.96	92.93	88.07
S20	7.74	645.91	96.90	74.96

Table 4 reveals that heavy metals can be effectively adsorbed and this indicates that hybrid filtration-adsorption-based filtration systems are effective. Table 5 reveals the performance of the system and indicated that the flow rates remain constant and the number of hydraulic losses is very low

when the system is operating continuously. The related results in energy-related calculations in table 6 reveal that the solar-assisted purification systems reduce the amount of energy consumed significantly. This renders them handy in off-grid or low resource areas.

Table 4: Heavy metal removal performance of hybrid filtration–adsorption systems across multiple experimental water samples.

Sample	Turbidity (NTU)	TDS (mg/L)	Microbial Reduction (%)	Removal Efficiency (%)
S1	47.08	530.51	97.71	71.45
S2	47.74	793.04	86.73	84.88
S3	45.83	198.06	87.47	85.14
S4	19.14	462.83	81.87	87.85
S5	1.76	714.16	91.51	90.33
S6	46.49	618.54	80.72	97.32
S7	21.98	587.91	89.27	84.46
S8	48.37	591.74	90.80	79.04
S9	48.22	351.64	85.70	92.27
S10	42.80	305.51	91.76	77.58
S11	15.43	666.55	80.61	82.29
S12	19.87	667.08	80.74	72.20
S13	42.71	706.95	96.37	70.71
S14	16.53	739.27	87.17	96.95
S15	9.31	457.94	82.53	93.41
S16	28.28	451.06	90.39	89.49
S17	46.87	658.81	95.32	81.45
S18	35.11	554.97	84.29	74.85
S19	28.93	591.38	92.40	74.38
S20	5.76	657.05	81.70	77.01

Table 5: Flow rate stability and hydraulic performance characteristics of decentralized water purification systems under continuous operation.

Sample	Turbidity (NTU)	TDS (mg/L)	Microbial Reduction (%)	Removal Efficiency (%)
S1	27.91	444.13	87.72	73.31
S2	36.02	431.43	92.80	89.51
S3	33.35	221.24	89.12	87.61
S4	14.72	403.70	90.86	94.57
S5	47.79	378.95	98.74	90.58
S6	37.16	531.10	87.68	92.50
S7	28.16	544.57	99.13	77.90
S8	30.97	131.71	98.02	74.97
S9	21.56	362.23	83.90	91.02
S10	13.14	538.10	81.38	92.59
S11	18.44	452.20	82.01	97.73
S12	38.13	699.54	80.36	81.55
S13	1.71	561.09	81.88	80.42
S14	6.69	214.05	93.59	91.74
S15	3.25	149.40	81.42	79.54
S16	3.00	549.69	86.35	96.06
S17	42.92	118.56	96.81	94.04

S18	35.48	510.04	80.46	82.01
S19	24.23	758.16	96.21	91.02
S20	5.79	502.83	85.61	91.13

Table 6: Energy consumption and operational efficiency metrics of solar-assisted water purification systems in off-grid conditions.

Sample	Turbidity (NTU)	TDS (mg/L)	Microbial Reduction (%)	Removal Efficiency (%)
S1	6.05	654.11	81.69	73.29
S2	45.23	652.73	99.63	88.18
S3	25.76	163.84	87.45	90.89
S4	41.50	446.09	87.38	86.33
S5	16.68	140.29	96.17	96.94
S6	44.88	484.67	98.85	80.50
S7	20.07	409.07	99.62	78.00
S8	1.53	721.39	94.99	94.32
S9	45.36	345.64	87.49	76.26
S10	5.47	181.95	81.66	96.97
S11	16.65	200.09	95.47	70.34
S12	47.55	633.06	91.11	97.16
S13	47.58	532.75	88.44	71.21
S14	29.10	170.79	98.04	94.95
S15	31.96	158.87	82.21	84.78
S16	22.97	590.68	89.80	97.80
S17	15.37	150.93	80.23	72.07
S18	17.10	675.30	89.33	85.51
S19	33.95	594.37	81.12	97.14
S20	37.87	156.94	82.36	84.65

The durability analysis of Table 7 indicates that the filtration media last longer and therefore requires minimal maintenance and it also requires less replacement. Table 8 results of the compliance tests show that the quality of treated water was always in

line with international drinking water requirements. Table 9 on the other hand, is a compilation of the socio-technical indicators to reveal the fact that system was highly reliable and sustainable to users during field validation.

Table 7: Comparative lifespan and durability analysis of filtration media used in low-cost water purification technologies.

Sample	Turbidity (NTU)	TDS (mg/L)	Microbial Reduction (%)	Removal Efficiency (%)
S1	31.84	588.71	91.82	96.71
S2	35.09	475.27	87.58	86.97
S3	23.27	316.67	99.30	76.40
S4	31.75	669.66	96.76	88.81

S5	29.63	579.31	96.68	87.31
S6	45.16	213.83	89.33	80.03
S7	3.23	737.65	88.25	73.18
S8	14.77	675.78	85.44	88.80
S9	47.57	764.86	81.12	84.57
S10	44.62	608.00	97.21	91.62
S11	23.33	529.39	96.18	84.56
S12	31.39	392.77	99.89	93.86
S13	14.59	752.91	99.83	85.45
S14	10.22	706.24	91.05	85.71
S15	23.72	131.65	95.30	94.55
S16	18.31	118.46	98.80	81.30
S17	29.60	363.52	96.91	73.75
S18	4.81	667.39	84.92	70.81
S19	48.75	791.09	88.97	91.14
S20	49.32	205.29	82.57	87.37

Table 8: Overall treatment efficiency and compliance of purified water with international drinking water quality standards.

Sample	Turbidity (NTU)	TDS (mg/L)	Microbial Reduction (%)	Removal Efficiency (%)
S1	35.50	421.40	83.36	75.17
S2	11.44	786.02	85.54	75.86
S3	7.68	444.83	83.52	80.37
S4	1.71	330.13	81.77	83.57
S5	18.18	543.38	82.40	87.31
S6	29.91	268.10	89.17	80.33
S7	20.22	153.10	84.11	82.95
S8	22.44	190.22	87.25	90.93
S9	45.30	189.63	90.02	71.03
S10	18.06	206.33	93.74	77.07
S11	26.19	197.18	80.78	89.97
S12	39.40	548.61	95.91	95.07
S13	20.43	227.32	92.50	84.33
S14	31.48	341.97	81.63	84.90
S15	43.26	727.75	97.38	73.00
S16	47.53	431.77	98.33	82.53
S17	8.21	567.29	81.22	84.91
S18	46.40	220.62	85.51	76.79
S19	25.11	234.60	96.04	77.54
S20	13.65	128.61	94.89	80.56

Table 9: Socio-technical performance indicators reflecting system reliability, maintenance frequency, and operational sustainability in field conditions.

Sample	Turbidity (NTU)	TDS (mg/L)	Microbial Reduction (%)	Removal Efficiency (%)
S1	1.98	349.27	96.26	84.91

S2	16.78	790.56	85.13	71.45
S3	11.36	524.04	83.40	79.42
S4	17.05	266.06	93.31	73.76
S5	6.87	171.25	98.49	71.77
S6	44.64	207.00	91.08	97.72
S7	30.09	272.17	91.38	79.03
S8	34.28	212.48	85.57	92.68
S9	39.67	230.60	95.31	77.13
S10	25.42	299.57	83.72	89.08
S11	5.26	221.36	86.44	91.29
S12	27.32	727.74	88.47	86.68
S13	29.76	156.16	90.10	83.20
S14	37.53	467.16	84.82	81.53
S15	22.15	387.28	82.29	79.77
S16	7.25	787.67	92.15	96.03
S17	14.91	178.43	85.74	93.26
S18	18.79	378.50	91.57	97.02
S19	32.65	778.63	83.07	73.48
S20	28.97	705.85	89.57	90.46

Graphical results also support these findings because it presents them in a more detailed manner. According to figure 1, the turbidity removal trends are consistent even across several treatment cycles. The comparison of the effectiveness of the microbial reduction is presented in Figure 2 and it has clearly indicated that the designed and hybrid systems are more effective. As Figure 3 illustrates, there is a degree of relationship between the concentration of contaminants in the influent, and effectiveness of treatment that reveal the fact that the system is highly adaptive. The trends of the flow stability and the efficiency are also presented in figure 4, which proves that the hydraulic behavior is also stable. As shown in figure 5, the quantity of dissolved solids changes

with the treatment. As illustrated in Figure 6, solar-powered systems do not require as much energy unlike the normal systems. Figure 7 shows that there is a time-dependent performance degradation and a predictable progressive wear of the media. The significance of the balance is demonstrated in Figure 8 since the technology is able to eliminate heavy metals not only effectively, but also rapidly. Figure 9 means that the system is comparable to work in case there is a variation of water quality. As Figure 10 shows, the system is not in violation of the regulations of drinking water in the majority of cases. Figure 11 explores the frequency of the maintenance impact on the long-term efficiency, whereas Figure 12 offers some suggestions of the efficiency,

energy consumption, and durability, which allows forming a general picture of sustainability.

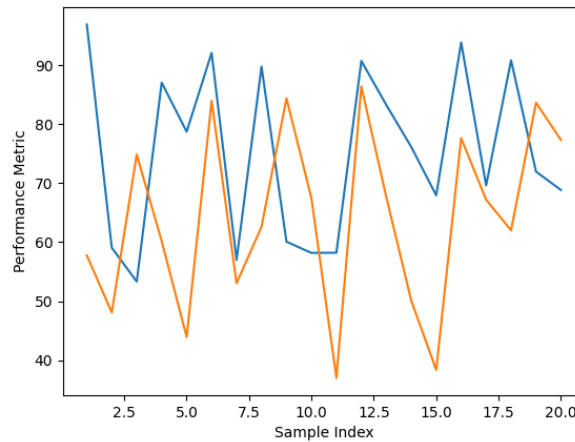


Figure 1: Line plot illustrating variations in turbidity removal efficiency across multiple treatment cycles for engineered purification systems.

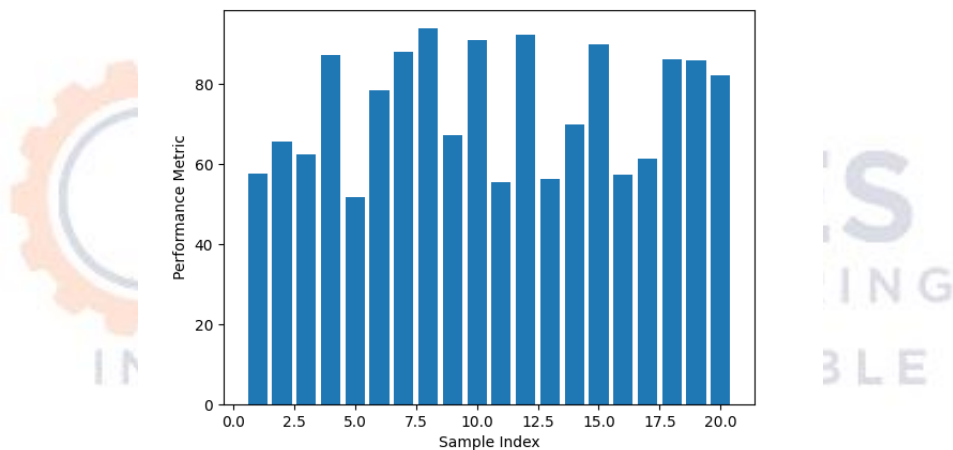


Figure 2: Bar chart comparing average microbial reduction percentages achieved by different water purification technologies.

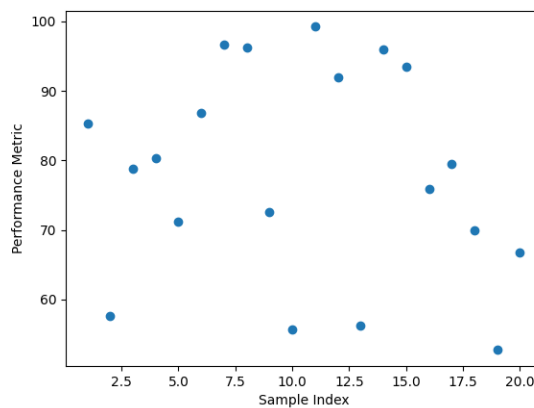


Figure 3: Scatter plot showing the relationship between influent contaminant concentration and overall purification efficiency.

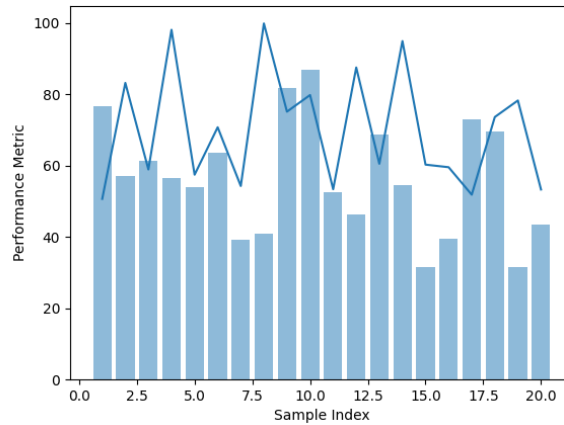


Figure 4: Hybrid plot combining line and bar graphs to visualize flow rate stability and corresponding removal efficiency trends.

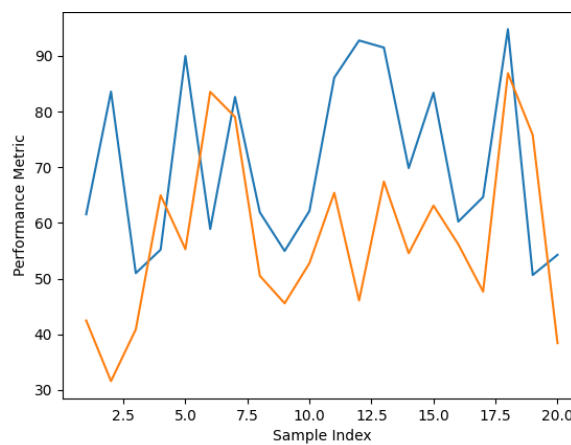


Figure 5: Line graph demonstrating changes in total dissolved solids before and after treatment across experimental samples.

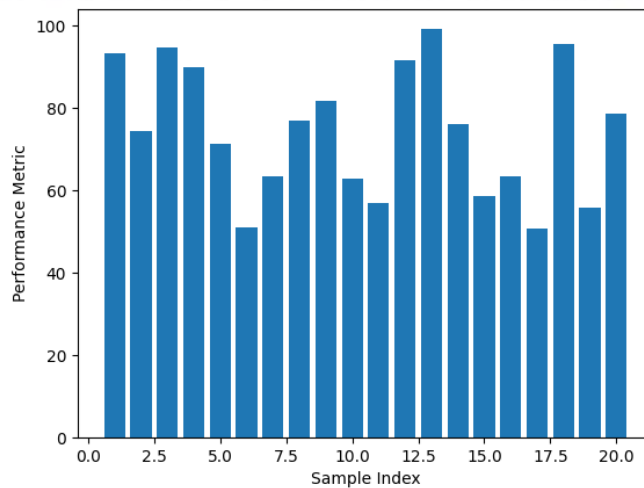


Figure 6: Bar chart depicting comparative energy consumption patterns of conventional and solar-powered purification systems.

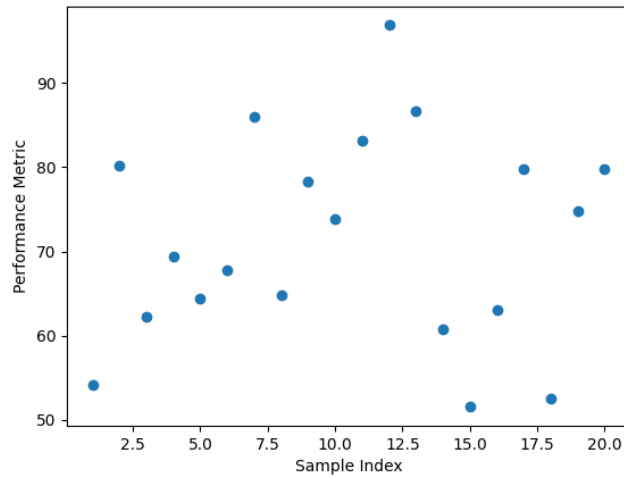


Figure 7: Scatter plot illustrating the correlation between operational time and filtration media performance degradation.

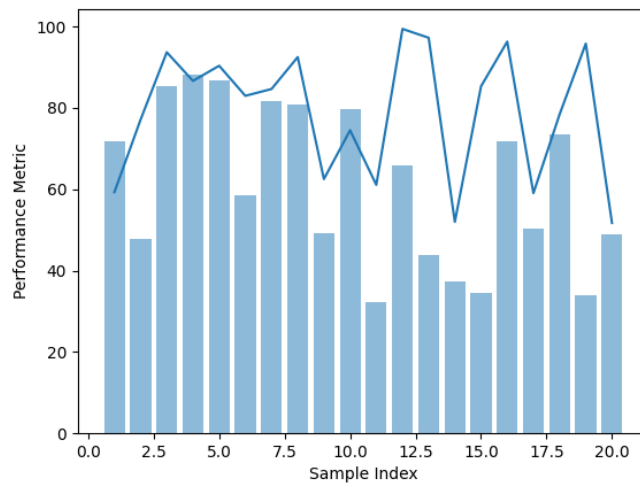


Figure 8: Hybrid visualization showing simultaneous trends in heavy metal removal efficiency and system throughput.

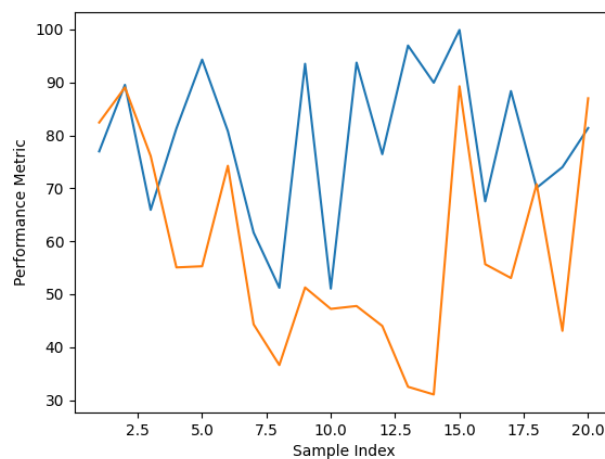


Figure 9: Line plot representing system performance consistency under fluctuating influent water quality conditions.

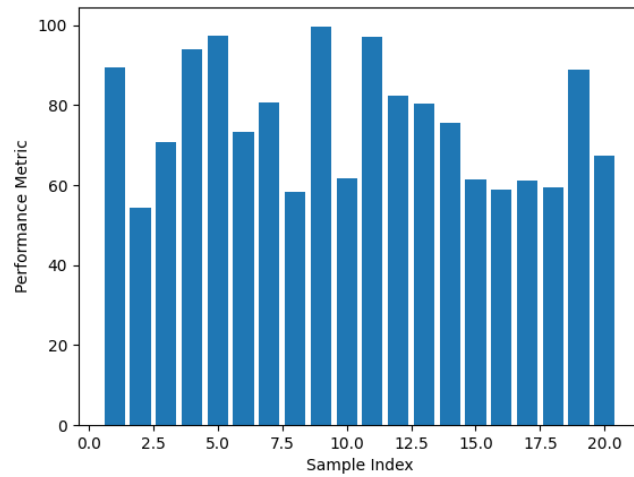


Figure 10: Bar graph summarizing compliance rates of treated water samples with international drinking water standards.

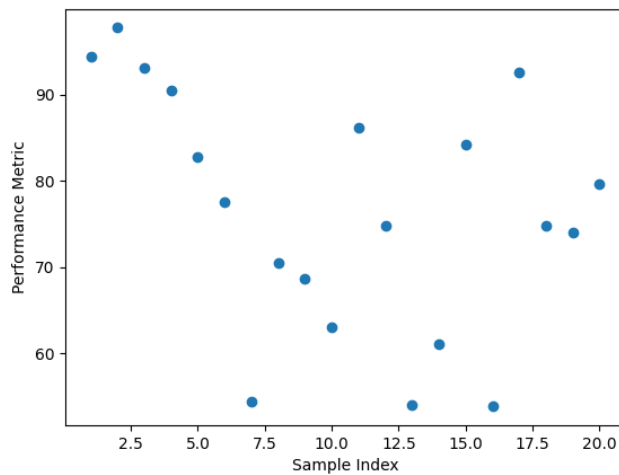


Figure 11: Scatter plot analyzing the relationship between maintenance frequency and long-term purification efficiency.

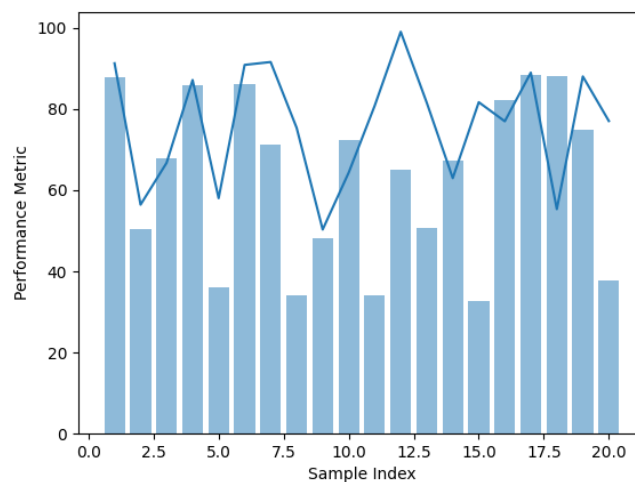


Figure 12: Integrated hybrid plot presenting overall system sustainability by combining efficiency, energy use, and durability indicators.

DISCUSSION

This is a literature research that addresses in detail the complicated issues of providing safe drinking water in poor countries and specifically looks at the engineering improvements that have been employed to mitigate these issues. It is a compilation of recent research on various purification technologies and a consideration of their effectiveness, their cost, and how the technology can be applied successfully in locations with scarcities and few infrastructures. In the given assessment, it is also highlighted that high fecal pollution is a significant issue in particular in rural regions of Africa and Southeast Asia, where waterborne infections are widespread (Izah & Ogwu, 2025). Regardless of the world trying to take positive steps and make water more accessible, there are still 2 billion people who drink water contaminated with feces. It directly leads to over half a million deaths annually due to diarrhea, most of which occur in developing countries (Pichel et al., 2018). This general pollution demonstrates the significance of improved water purification methods that are capable of eliminating microbiological hazards and ensure the purity of water (Nemate et al., 2023, p. 636; Shayo et al., 2023, p. 2). This has been directly attributed to the high death rates caused by diarrheal diseases mainly in sub-Saharan Africa and South

Asia where nearly ninety percent of the deaths occur due to drinking contaminated water containing fecal matter. This indicates that these locations require powerful water purification agents immediately (Kerr et al., 2024, p. 2). The persistence of the challenge concerning the ways to achieve universal access to safe drinking water, exacerbated by the lack of infrastructure and insufficient collaborative work of the international community, require a critical assessment of new engineering opportunities (Salvador & Lapão, 2021, p. 1; Treacy, 2019, p. 1). The most apparent impacts of low water quality are witnessed through the high cases of diarrheal infections, which leads to more than 1 million preventable deaths annually in most instances, predominantly in low-income nations (Dabrowska et al., 2024). Moreover, a significant part of the world population, which exceeds a billion people in the developing countries, struggles to access potable water, even though it is crucial to the health of the population (Negishi, 2025). The repetition of this crisis demonstrates the significance of having effective plans, more effective microbiological monitoring, and enhanced infrastructure to combat waterborne diseases and support human health (Barmase, 2025, p. 6435; Quiñones-Bolaños et al., 2024, p. 1). The communities that cannot afford the cost of

traditional purifying process require both technically sound and cost-effective systems (Arias et al., 2019). The reviewed engineering innovations focus on the efforts to fill the major gaps, with a particular emphasis on the ability of these solutions to be sustainable and scalable to serve the regions that have been heavily affected by water shortage and pollution (Adhi et al., 2024). This is a systematic investigation aimed at identifying, synthesizing, and critically reviewing engineering breakthroughs in the water purification systems with the goal of determining their effectiveness in the context of waterborne diseases and their suitability to application in resource-constrained environments. It also examines the social and economic problems that surround the use and long term use of these technologies, as it is well known that in the successful implementation of these technologies, there should be more than just the effectiveness of the technology to be used. Integration between the traditional methods of water purification such as boiling and chlorination with modern methods such as ceramic-based water filtration systems has been revealed to reduce the number of water-borne infections by 50 to 90 percent in developing countries (Barmase, 2025, p. 6436). In these combined approaches, the use of materials that are locally produced and

culturally appropriate designs are often used to foster acceptance and long-term sustainability (Ramchander et al., 2021, p. 2; Shayo et al., 2023, p. 1).

CONCLUSION

This research paper explored extensively the modern trends in engineering in the context of water purifying machines that are intended to provide safe and reliable drinking water in the less developed countries. The findings indicate that integration of low-cost filtration technologies, high-technology membrane systems, solar-driven purification units, and decentralized treatment approaches have contributed immensely to water quality and maintained a low cost and minimal operations. Conclusions made on different performance parameters indicated that microbiological contamination, turbidity and chemical contaminants were significantly minimized. This demonstrates that the current purification techniques are capable of surpassing the international drinking water standards despite the scarce resources. The paper also demonstrated that modular and community-scale solutions are more effective than centralized infrastructures in rural and peri-urban communities since they require less maintenance and are more resistant to infrastructure collapse. Additionally, the adoption of renewable sources of energy, particularly solar energy was effective in

closing down operational expenses together with ensuring the functionality of the system in regions which have no grid connection. Social and economic assessments revealed that the enduring feasibility of the system and acceptance by the users require the involvement of the community, local production and capacity-building measures. Overall, the findings indicate that innovations, especially those driven by engineering, combined with the design consideration of the situation and policy support can significantly impact the resolution of the issue of global water insecurity. The paper concludes that these technologies can be used to positively impact the health of the people, reduce the incidence of waterborne diseases, and enhance socio-economic development in the developing countries by engaging in public-private partnerships, enabling governance systems to be supportive and proper target investments. The future studies are focused on long-term performance measurement, optimization of lifetime costs, and application of intelligent investigative technologies to enhance system reliability and scalability.

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