

Design and Fabrication of Mini-Household Water Treatment System

Habu Iyodo Mohammed¹, Umar Adam Musa^{2*}, Ismail Al-Amin Emmah²

Abstract

Access to safe drinking water remains a serious challenge in many developing countries, including Nigeria, due to pollution, poor infrastructure, and ineffective water management. This study presents the design, fabrication, and performance evaluation of a mini household water treatment system that uses charcoal carbon derived from desert date wood. The project aims to provide a low-cost, gravity-driven, and sustainable water purification solution for rural and peri-urban households. The system consists of a two-layer metal frame supporting dual plastic tanks and a charcoal carbon filter housed in a 38.1 mm PVC pipe containing 380 g of media. It operates through gravitational flow, eliminating the need for electrical power. Laboratory tests assessed major parameters Calcium (Ca^{2+}), Lead (Pb^{2+}), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD_5), and Total Dissolved Solids (TDS) and results were compared with World Health Organization (WHO) standards. The results showed clear improvement in water quality: Calcium reduced from 2.41 mg/L to 1.50 mg/L, COD from 2.05 mg/L to 1.10 mg/L, BOD_5 from 3.10 mg/L to 1.13 mg/L, and TDS from 108.96 mg/L to 73.06 mg/L, while lead was undetectable. The system produced 165 litres per day, sufficient for a household of 6–8 people. The study concludes that the developed system is efficient, affordable, and sustainable for household water purification. It demonstrates the potential of using locally available materials and simple gravity-driven design to improve access to potable water in Nigerian communities.

Keywords: Household water treatment system, activated charcoal, desert date (*Balanites aegyptiaca*), gravity filtration, water quality improvement, point-of-use (POU) treatment, sustainable drinking water, rural communities, low-cost filtration, Nigeria

INTRODUCTION

Access to clean and safe drinking water is a fundamental human right and a critical component of public health. However, in many developing countries, including Nigeria, millions of households lack access to potable water due to inadequate infrastructure, pollution, and poor water management practices. According to the World Health Organization (WHO), approximately 60 million Nigerians

rely on unsafe water sources, leading to widespread waterborne diseases such as cholera, typhoid, and diarrhoea. Household water treatment systems (HWTS) have emerged as a practical and cost effective solution to address this challenge, particularly in rural and peri-urban areas where centralized water treatment facilities are often unavailable or unreliable [1-4].

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In Nigeria, the need for sustainable and affordable water treatment solutions is particularly urgent. Studies have shown that traditional methods of water purification, such as boiling and filtration, are often insufficient or impractical due to high

energy costs, lack of access to materials, and inconsistent effectiveness. As a result, there is a growing demand for innovative, low cost, and easy to use water treatment systems that can be fabricated and maintained locally. This project seeks to address this need by designing and fabricating a mini household water treatment system tailored to the specific challenges and requirements of Nigerian households [5-8].

Problem Statement

Despite the abundance of water resources in Nigeria, access to clean and safe drinking water remains a significant challenge for many households. Contaminated water sources, inadequate sanitation infrastructure, and poor water management practices have contributed to the prevalence of waterborne diseases, which disproportionately affect vulnerable populations, including children and the elderly. Existing water treatment solutions, such as centralized treatment plants, are often inaccessible to rural and low income communities due to high costs, logistical challenges, and lack of maintenance [9-14].

Furthermore, many households rely on traditional methods of water purification, such as boiling or cloth filtration, which are often ineffective in removing harmful pathogens and chemical contaminants. There is a critical need for a sustainable, affordable, and efficient household water treatment system that can be easily adopted by Nigerian households to improve water quality and reduce the burden of waterborne diseases [15-18].

Aim & Objectives of the Study

The aim of this study is to design and fabricate a mini household water treatment system that is affordable, efficient, and suitable for use in Nigerian households. The specific objectives of the study are as follows:

- i. Design and fabrication of mini household water treatment system
- ii. Evaluate of the performance of the household water treatment system

Scope of the Study

This study focuses on the design and fabrication of a mini household water treatment system for Nigerian households, with an emphasis on affordability, simplicity, and effectiveness. The system will be designed to treat common contaminants found in Nigerian water sources, including bacteria, viruses, suspended solids, and chemical pollutants. The study will evaluate the system's performance under laboratory conditions and provide recommendations for its implementation in real world settings. While the primary focus is on rural and pri-urban households, the findings of this study may also be applicable to other low resource settings with similar water quality challenges [19-23].

Significance of the Study

The major problems confronting most Nigerian local communities Today is the Non availability portable water for domestic use. Portable water is that which is suitable for drinking and this is a commodity which is very scare to come by in so many communities from cities to villages. A large percentage of communities are blessed with abundant surface and underground waters; but various government and individuals find it difficult to turn the available raw water to suitable ones for the public, because of many factors ranging from economic, technical and management in adequacies. The water available for use in the public today are those procured by the people themselves, through the various unhygienic, which do not satisfy basic requirements of portability. Freedom from pathogenic organism; physical and chemicals qualities and aesthetic qualities [24-27].

Common diseases which can be contacted from drinking bad water include dysentery, gastro entities, typhoid fever and cholera. Other viral diseases include infectious hepatitis, polingeties etc. the best approach to alleviating the highlighted problems is through a system of water treatment which includes, sedimentation, flocculation of impurities, clarification filtration, and disinfection. The major water treatment methods include using coarse filters, coagulation, flocculation, sedimentation or clarification, filtration and chlorination. These conventional methods of treatments are available, for a huge

population in rural areas in developing countries. However, they could be inappropriate or too costly to implement [28-30].

LITERATURE REVIEW

Access to safe drinking water remains a critical public health challenge in many developing countries, particularly in sub-Saharan Africa. In Nigeria, inadequate water infrastructure, pollution, rapid population growth, and socio-economic instability have significantly limited access to potable water, especially in rural and peri-urban communities. Northern Nigeria, including Maiduguri in Borno State, is disproportionately affected due to its semi-arid climate, heavy reliance on groundwater, and prolonged conflict that has disrupted centralized water treatment. Consequently, many households depend on untreated surface and groundwater sources, increasing exposure to waterborne diseases such as cholera, typhoid, and diarrhoea [31-34].

Conventional water treatment processes, including coagulation, sedimentation, filtration, and disinfection, are effective in producing potable water but require high capital investment, skilled operation, and reliable energy supply. These requirements make centralized treatment systems unsuitable for many low-income and conflict-affected communities. As a result, household water treatment systems (HWTs) have emerged as practical alternatives for point-of-use water purification. Several studies have demonstrated that HWTs can significantly improve drinking water quality and reduce the incidence of waterborne diseases in resource-limited and emergency settings.

Groundwater quality assessments in Maiduguri have revealed widespread microbial contamination, elevated turbidity, and the presence of chemical pollutants, largely due to poor sanitation practices, improper waste disposal, and infiltration from pit latrine. Traditional household water treatment practices such as boiling, sedimentation, and cloth filtration are commonly used but are often ineffective or unsustainable. Boiling is energy-intensive, while cloth filtration fails to remove dissolved contaminants and pathogenic microorganisms. This underscores the need for improved household-scale water treatment technologies.

Low-cost HWTs that incorporate filtration and adsorption using locally available materials have been widely investigated. Among these, charcoal carbon has attracted significant attention due to its high porosity, large surface area, and strong adsorption capacity. Charcoal carbon has been shown to effectively remove organic contaminants, improve taste and odor, and reduce Chemical Oxygen Demand (COD) in drinking water. Its application is particularly attractive in Nigeria due to the abundance of biomass resources that support local production and cost reduction. However, charcoal carbon alone is insufficient for microbial removal, necessitating integration with multi-barrier treatment approaches.

Evaluation of HWTs performance commonly relies on key water quality parameters such as Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS), calcium concentration, and heavy metals, particularly lead. BOD and COD indicate organic pollution levels, while TDS and calcium influence aesthetic quality and scaling potential. Lead is of particular public health concern due to its toxicity even at trace concentrations, making its absence in treated water essential.

Gravity-driven packed bed filtration systems are well suited for household applications because of their simplicity, low energy demand, and ease of maintenance. Fluid flow through such systems is commonly described using Darcy's Law and permeability models such as the Kozeny–Carman equation, which are useful for predicting filtration performance under gravity-driven conditions. Overall, existing literature supports the development of affordable, locally fabricated, gravity-driven household water treatment systems as sustainable solutions for improving access to safe drinking water in Nigeria.

MATERIALS AND METHODS

Table 1. Design specification.

i.	21mm × 21mm × 2 square metal pipe
ii.	25.4mm back not (1inch)
iii.	25.4mm union 1 (inch)
iv.	Thread tape
v.	38.1mm socket (1.5 by 1 inch socket)
vi.	25.4mm Ball valve (1inch)
vii.	25.4mm Adapter (1inch)
vii.	38.1mm diameter PVC pipe length 0.6m
viii.	2, 20 liters plastic container

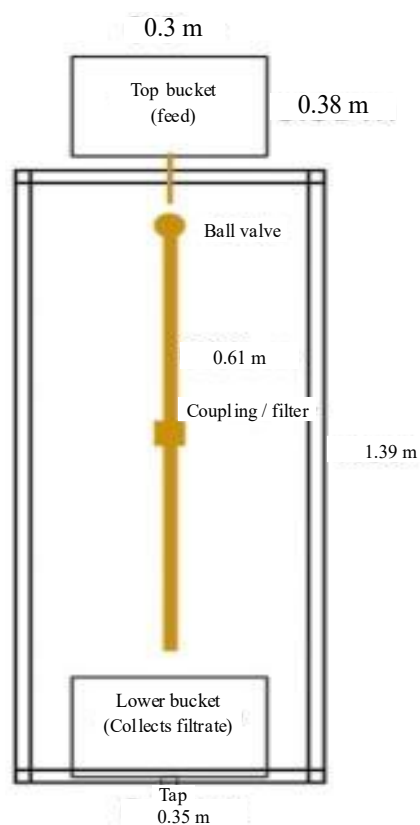


Figure 1. Schematic diagram of the portable water treatment system.



Figure 2. The portable water treatment system.

Fabrication and Assembling

(Figure 1) shows a clear picture of a simple water treatment plant, there are two layers of horizontal frame top and bottom the two layers are of each 0.35 m square. The top layer [shown in Figure 2] which carries the water tank of 20 litre capacity plastic container of 0.3 m Top diameter of the container with height of 0.38 m and 0.36 m bottom diameter, the water tank is supported by 3 (three) 21 mm × 21 mm × 2 Square metal pipe with length of 0.3 metre the top layer frame is 0.35m × 0.35m × 2. (See Figure 3). The total weight of the 20 litre tank is 20 kg and the weight of the container is 0.72 kg making 20.72 kg. The top layer is erected by four 21 mm × 21 mm × 2 square metal pipes of length 1.39 m Welded to the bottom which gives a rectangular frame with 1.39 m in length and 0.35 m in width.

The bottom layer (Figure: 4) was designed with a three 21 mm × 21 mm × 2 square metal pipe with

length 0.30 m which holds the weight of the second tank [Reservoir] which is about 20.72 kg and also provides support to the frame in general. The water tank on the bottom layer has a tap in which drinkable water comes out and is ready for drinking.

The carbon philtre [as shown in Figure 5] was made from 25.4 mm diameter PVC pipe with the length of 0.61 mm and a sieve of 0.2 mm was placed on what ends of the PVC pipe. A 38.1 mm × 25.4 mm socket On both ends of the pipe was installed to reduce the opening of the pipe from 38.1 mm x 25.4 mm, a union of 25.4 mm in diameter was installed again to the ends of the sockets, Which allows the user to screw and unscrew the filter for future use.

Methods

The filter was filled with carbon gotten from the three known as desert date The hardwood was cut into smaller sizes and sun dried to remove moisture.

Wood gotten from dessert date tree was carbonized limited oxygen [pyrolysis], volatile gases escaped through the vents while carbon rich charcoal was left behind.

After completion the drum was sealed and allowed to cool naturally and the resulting blocked charcoal was collected. The charcoal was crushed into smaller granules using motor and pistol.

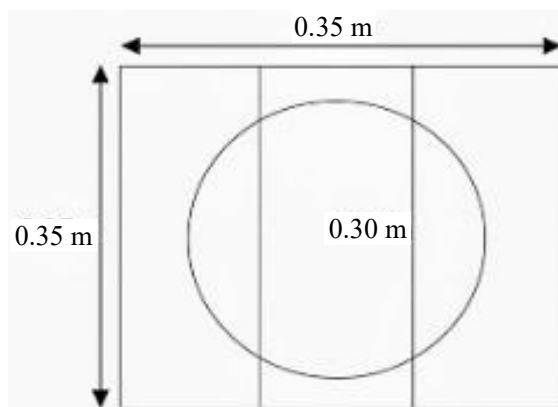


Figure 3. Top layer of the frame.

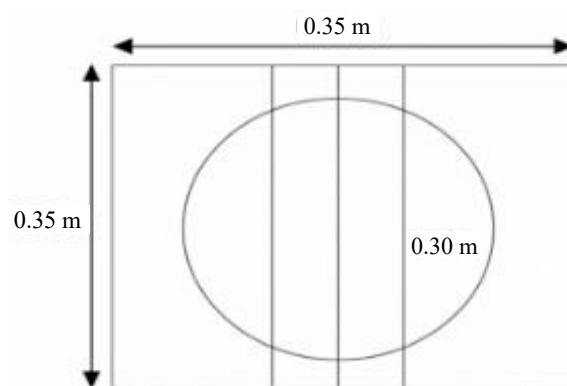


Figure 4. The bottom layer of the frame.



Figure 5. The carbon filter assembly.

The charcoal was repeatedly washed with distilled water until a natural PH was obtained and then

sun dried for four to six hour.

A sieve analysis was conducted with the charcoal carbon and we got our desired size of 1.00mm mesh size and after that our filter is filled with about 380 g [0.38 kg] of the charcoal carbon.

Principles of Operation

This design operates on the process of gravitational flow where water will be directly supplied to the inlet tank from sources like rainwater runoff from a house roof from water addition or from river or pond. The flow of water in the system depends on the height of the bottom storage tank which will be determined by the level of the float the water from the inlet tank will enter the carbon filter and is then stored in the bottom storage tank the frame is designed so as to encourage gravity flow due to its vertical design which also allows for a compact and space reduction process, the frame steel material was painted in order to reduce corrosion and increase aesthetics.

Water Quality Analysis (Lead, Calcium Ion, BOD, COD and TDS Tests)

Calcium Ion (Ca^{2+}) Test Procedure

The calcium content of the water samples was determined using EDTA complex metric titration.

Eriochrome Black T indicator was added.

The sample was titrated with 0.01M EDTA solution until a wine-red to blue end point was reached. Water sample was buffered to pH 10 using ammonium buffer.

Calcium concentration was calculated based on volume of EDTA used.

Lead (Pb^{2+}) Test Procedure

Lead concentration was analyzed using Atomic Absorption Spectrophotometry (AAS).

Samples were first filtered and acidified with nitric acid.

The AAS instrument was calibrated with Pb standards.

The absorbance was measured at the lead-specific wavelength, and the concentration was obtained directly from the instrument.

Chemical Oxygen Demand (COD) Test Procedure

COD was determined using the closed reflux colorimetric method.

Samples were digested with potassium dichromate and concentrated sulphuric acid in COD digestion vials.

The digested samples were placed in a COD reactor at 150°C for 2 hours.

Biochemical Oxygen Demand (BOD_5) Test Procedure

BOD was determined using the standard 5-day incubation method.

Initial dissolved oxygen (DO_1) of the sample was measured using a DO meter.

The sample was incubated in an airtight BOD bottle at 20°C for five (5) days.

Final DO (DO_5) was measured and BOD_5 calculated as: $\text{BOD}_5 = \text{DO}_1 - \text{DO}_5$

Total Dissolved Solids (TDS) Test Procedure

TDS was analyzed using a portable TDS/Conductivity meter.

The meter was calibrated with standard KCl solution.

The electrode was immersed in the water sample.

TDS was recorded directly in mg/L.

RESULTS AND DISCUSSION

This chapter presents the results obtained from the fabrication and testing of the mini household water treatment system. It discusses the changes observed in water quality parameters before and after treatment, compares them with World Health Organization (WHO) guideline standards, and evaluates the effectiveness of the system in relation to existing studies. In addition, the production capacity of the system is presented, demonstrating its potential application for household use table 2-4 and fig 6.

Table 2. Equipment.

Test	Equipment / Materials
Calcium Ion (Ca^{2+}) Test	0.01M EDTA solution, Ammonium buffer (pH 10), Eriochrome Black T indicator, Burette (50 mL), Pipettes and conical flasks, pH meter
Lead (Pb^{2+}) Test	Atomic Absorption Spectrophotometer (AAS), Nitric acid (HNO_3), Distilled water, Volumetric flasks, Whatman filter paper No. 42
COD Test	COD digestion reactor, Potassium dichromate reagent vials, Concentrated H_2SO_4 , Spectrophotometer or colorimeter, Heating block, Pipettes and measuring cylinders
BOD Test	BOD incubator (20°C fixed), DO meter, Airtight BOD bottles, Sodium thiosulphate solution
TDS Test	Digital TDS meter, Standard KCl calibration solution, Clean sample beakers

Table 3. Results of water quality analysis.

1.	Calcium	2.41	1.5	75 (mg/l)
2.	Lead	-0.013	-0.203	0.01 (mg/l)
3.	COD	2.05	1.1	
4.	BOD	3.1	1.13	< 5
5.	TDS	108.96	73.062	500 (mg/l)

Table 4. Result of particle size distribution.

Mesh sizes (mm or μm)	Particle size distribution
2mm	0.08
1mm	2.03
850	2.25
710	2.46
500	6.44
425	2.52
300	2.34
250	0.86
150	0.19
63	0.00
Pan	0.00

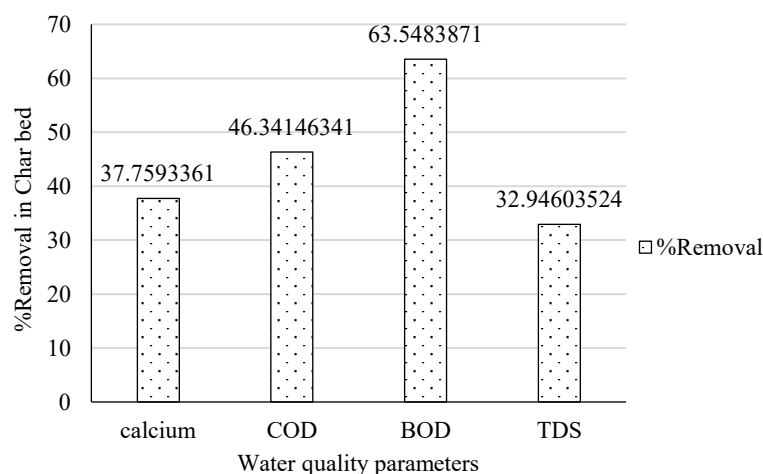


Figure 6. Performance of household water treatment system.

Properties of Minerals

Calcium (Ca^{2+})

The untreated water sample contained 2.41 mg/L of calcium, which decreased to 1.50 mg/L after treatment. This is significantly below the WHO maximum permissible concentration of 75 mg/L for potable water. High calcium levels often contribute to water hardness, which leads to scaling of household appliances such as kettles, pipes, and boilers. Since both untreated and treated values are far below the threshold, the water can be classified as soft water.

The reduction observed reflects the role of charcoal carbon in adsorbing certain dissolved minerals and the partial removal of calcium carbonate particles during filtration. Similar findings were reported by Ekwue & Ramdeen (2004), who observed a reduction in calcium concentration when water passed through a sand–clay filtration system.

Lead (Pb^2)

The concentration of lead in the samples recorded negative values (–0.013 mg/L untreated and –0.203 mg/L treated). Negative readings typically indicate that lead was not detected within the sensitivity range of the analytical equipment. This is highly significant, as lead contamination in drinking water is associated with severe health risks such as neurological damage, kidney impairment, and developmental issues in children.

The WHO guideline value for lead in drinking water is 0.01 mg/L. Since no detectable lead was found, both untreated and treated water samples are safe with respect to heavy metal contamination. This result is consistent with findings by Onyango et al. (2020), who noted that locally sourced charcoal carbon can adsorb trace heavy metals when present, but in this case, the source water was already free from lead contamination.

Chemical Oxygen Demand (COD)

The COD value reduced from 2.05 mg/L in untreated water to 1.10 mg/L after treatment. COD is an indicator of the total oxidizable organic and inorganic matter present in water. Although WHO does not provide a specific standard for COD in drinking water, lower values are always desirable because they indicate fewer pollutants that consume oxidizing agents.

The 46.3% reduction in COD demonstrates the ability of the charcoal carbon filter to adsorb dissolved organic pollutants. This aligns with the work of Dabai et al. (2022), who confirmed that charcoal carbon effectively reduces COD by removing pesticides, hydrocarbons, and other oxidizable compounds.

Biochemical Oxygen Demand (BOD₅)

The BOD level dropped from 3.10 mg/L in untreated water to 1.13 mg/L after treatment. The WHO guideline for safe drinking water is < 5 mg/L, and both untreated and treated samples fall within this limit. However, the 63.5% reduction highlights the system's effectiveness in reducing biodegradable organic matter, which directly affects microbial regrowth.

A lower BOD value means that the treated water is less likely to support bacterial survival, improving its microbiological stability. This finding is consistent with Metcalf & Eddy (2014), who emphasized the importance of BOD reduction in water treatment as a means of reducing pathogenic risks.

Total Dissolved Solids (TDS)

The TDS of the untreated sample was 108.96 mg/L, which reduced to 73.06 mg/L after treatment. The WHO standard for potable water is 500 mg/L, meaning both values are well within safe limits.

Although the untreated water was already acceptable, the 32.9% reduction in TDS improved the palatability and taste of the water. Low TDS values also reduce the risk of scale formation in storage containers and enhance consumer acceptability. These findings are in agreement with WHO (2017), which states that water with TDS below 300 mg/L is generally considered excellent for drinking.

Production Capacity of the System

In addition to improving water quality, the production rate of a household water treatment system is critical in determining its suitability for domestic use. Based on experimental flow-rate measurements, the fabricated system was found to produce 165 litres of treated water per day under continuous operation.

This production capacity is adequate for a typical Nigerian household, where the daily per capita water requirement for drinking and cooking is estimated at 15–20 litres per person. Therefore, the system can comfortably meet the needs of a household of 6–8 individuals.

The reliance on gravity-driven flow rather than electricity or mechanical pumping makes the design both cost-effective and sustainable, especially in rural and peri-urban communities where power supply is unreliable. The observed production rate compares favourably with similar systems reported by Akinbomi & Odika (2023), who developed a prototype household water device with a daily capacity of approximately 120 litres.

Overall Performance of the System

The results demonstrate that the mini household water treatment system is highly effective in improving both the chemical and aesthetic quality of drinking water. While the untreated water was already within WHO limits for most parameters, the system further reduced contaminants to ensure greater safety and acceptability.

The use of locally sourced charcoal carbon not only enhanced contaminant removal but also demonstrated the feasibility of low-cost fabrication in Nigeria. The system's daily production capacity of 165 litres confirms its practicality for household application.

CONCLUSION

The aim was to provide a low-cost, efficient, and sustainable solution to the persistent challenge of potable water scarcity in Nigeria, particularly in rural and peri-urban communities.

The results from the water quality analysis confirmed that the fabricated system significantly improved the safety and acceptability of drinking water. Specifically:

Calcium concentration decreased from 2.41 mg/L to 1.50 mg/L, confirming the system's ability to reduce hardness-related contaminants, though both values were already well below the WHO guideline of 75 mg/L.

Lead was not detected in either untreated or treated samples, confirming the absence of heavy metal contamination within the studied water source.

COD decreased by 46% (from 2.05 mg/L to 1.10 mg/L), reflecting the system's effectiveness in removing oxidizable organic pollutants.

BOD₅ reduced by 64% (from 3.10 mg/L to 1.13 mg/L), indicating enhanced microbial stability of the treated water and reduced risk of bacterial regrowth.

TDS dropped by 32% (from 108.96 mg/L to 73.06 mg/L), improving the taste and palatability of the water.

The production capacity of the system was measured at 165 liters per day, sufficient to meet the daily drinking and cooking needs of a typical household of 6–8 individuals.

These findings confirm that the system is not only effective in improving water quality but is also affordable, sustainable, and practical for household use in Nigeria. The reliance on gravity-driven flow instead of electrical pumps further enhances its suitability for rural areas with limited power supply. Importantly, the project demonstrates that indigenous materials and fabrication techniques can be harnessed to address critical public health challenges.

Overall, the study validates the potential of locally fabricated household water treatment systems as a viable complement to centralized water treatment facilities, thereby contributing to improved access to safe drinking water in underserved communities.

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