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COMPREHENSIVE REVIEW OF POINT-OF-USE (POU) WATER FILTRATION METHODS: PERFORMANCE, LIMITATIONS, AND THE FUTURE OF HYBRID SYSTEMS

Rahul Chakrabarty *[1], Quazi Hamidul Bari[2] and Abhishek Sarkar[3]

[1] *Postgraduate Student, Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh, e-mail: ck.rahul18@gmail.com*
[2] *Professor, Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh, e-mail: qhbari@ce.kuet.ac.bd*
[3] *Postgraduate Student, Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh, e-mail: sarkar1701019@gmail.com*

***Corresponding Author**

ABSTRACT

More than 2 billion people don't have access to safely managed drinking water, and about 1.7 billion people depend on water that is contaminated with fecal organisms. Biosand filters, ceramic pot filters, granular activated carbon (GAC) filters, membrane (gravity-driven) systems, and cloth filters are all examples of point-of-use (POU) filtration methods. They are all good options for treating household water in places with few resources. This systematic review adheres to PRISMA guidelines and evaluates the efficacy and constraints of these point-of-use (POU) technologies. A search was conducted through major databases such as Web of Science, PubMed, and Scopus for peer-reviewed studies on the effectiveness of POU filters. The main results show that biosand and ceramic filters remove a lot of bacteria and protozoa (usually 2-7 $\log_{10}$ for *E. coli*), but untreated filters don't remove many viruses or chemicals. GAC filters are great at getting rid of taste, smell, and organic micropollutants, but they aren't made to kill microbes. Gravity-driven membrane (GDM) technology may eliminate a small number of bacteria (about 1-3 $\log_{10}$) and operate effectively at low pressures by using gravity to transport water. Large particles and copepods (70–99% of *V. cholerae* carriers) may be removed by sari cloth and other multi-layer fabric filters, but germs cannot be killed properly by them. New "hybrid" POU systems that combine adsorption, membranes, biological filtration, UV, or electrochemical processes show promise for multi-barrier treatment that works effectively on mixed contamination (pathogens, metals, organics). In general, not all water quality issues can be resolved by a single POU technique. The optimum approach is to mix and match (hybrid) techniques according to the types of pollutants. This review indicates where further research is needed (for example, on long-term virus removal and user adoption) and also emphasizes the need for integrated POU solutions to keep people healthy at the community level, which doesn't have enough health care.

Keywords: *Point-of-Use (POU) Water Treatment; Ceramic Filters; Biosand Filters; Activated Carbon; Membrane Filtration.*

1. INTRODUCTION

Getting safe drinking water is still a big problem around the world. Even though there has been significant progress toward Sustainable Development Goal 6, almost 2 billion people still drink water contaminated with fecal coliforms or harmful metals (WHO & UNICEF, 2023). Water shortages are a threat to global health, the economy, and society due to the increasing water demand and, in parallel, the scarcity of fresh water (Chakrabarty & Mohiuddin, 2024). Rural and peri-urban areas in developing countries are hit the hardest because centralized water treatment systems are not always available or long-lasting. Point-of-use (POU) or household-level water treatment technologies are effective ways to improve water quality and lower the risk of waterborne diseases in these contexts (Sobsey et al., 2008; Clasen et al., 2015). The primary purpose of these systems is to help communities that don't have centralized systems obtain safe water through effective treatment and secure household storage.

Centralized water treatment systems work well in city areas where there are sufficient resources (Shemer et al., 2023); however, they are frequently impractical in rural or resource-limited regions due to high installation and maintenance costs, the necessity for trained operators, and the requirement for stable energy supplies (Peter-Varbanets et al., 2009). Inadequate distribution infrastructure also makes it hard for marginalized groups to get clean water and forces them to rely on water sources that are polluted. Contaminated water is still a major source of pathogens, and unsafe water can spread more than 80 diseases (Omarova et al., 2018). Surface water is contaminated by waste from both industrial and residential sources; however, these effects can be minimized through the treatment of wastewater before it is released as effluent (Chakrabarty & Bari, 2025). Improving water, sanitation, and hygiene could prevent over 2 million deaths annually among children under five (Ben Ayed et al., 2020). Low-cost POU systems do not require electricity or advanced infrastructure and typically operate through mechanical straining, adsorption, ion exchange, and biological processes.

People all over the world have used a variety of low-cost POU filters to solve problems with cost and durability. These include biosand filters, ceramic filters, activated carbon filters, and hybrid sand-charcoal-gravel filters (Chaukura et al., 2023; Murphy et al., 2010). Each design works better at removing contaminants and is better for certain water sources. Among these, locally produced systems remain the most viable for long-term rural use. The biosand filter (BSF) is a cheap version of the slow sand filter that uses layers of sand and gravel to create a biologically active layer (schmutzdecke) that helps eliminate pathogens by consuming and adhering to them (Stauber et al., 2006). BSFs reduce turbidity and microbial contamination, including bacteria, protozoa, and viruses, making them suitable for households (CAWST, 2012; Wang et al., 2014). However, if filters aren't properly maintained or if influent water contains high iron or arsenic, they don't work as well, and performance decreases.

Ceramic pot filters (CPFs) are another big group of cheap filters. Made from clay and organic burn-out materials such as rice husk or sawdust, they effectively remove turbidity and microbes by size exclusion and adsorption (Yang et al., 2020). Incorporating colloidal silver improves disinfection by limiting bacterial regrowth (Oyanedel-Craver & Smith, 2008). CPFs are affordable, socially acceptable, and can provide 1 to 3 liters of safe water per hour. However, they are fragile, and their flow rates drop over time because they get clogged. Activated carbon and biochar-based filters are widely used for removing organic contaminants, odors, and taste. Activated carbon, typically derived from coconut shells or wood, adsorbs organic compounds, chlorine, and some metals (Babel & Kurniawan, 2003). Biochar, made by burning biomass, is another cheap option with a lot of surface area. When mixed with sand or ceramics, it also helps get rid of pollutants like arsenic, fluoride, and nitrates. Boiling is also the most commonly used household treatment method, and it is considered to work effectively against bacteria, viruses, protozoa, and fecal coliforms (Juran & MacDonald, 2014; Pagsuyoin et al., 2015). Some modern technologies, such as ultraviolet (UV) or solar disinfection (SODIS), are now used to kill more germs. Furthermore, low-cost POU filters still have problems, such as being hard to keep up with, not being well-known by users, and not performing well consistently. For long-term use, social acceptance and proper utilization are very important.

Low-cost POU filtration systems, such as biosand, ceramic, activated carbon, biochar, and hybrid designs, show a lot of promise for making safe water available to everyone in places where centralized safe water distribution is not working. For long-term sustainability, there needs to be more innovative ideas, ensuring accurate testing in the field, and community engagement. This review paper emphasizes ceramic, biosand, activated carbon, membrane, and cloth filtration systems. It looks at how effectively they function, what issues they raise, their limits, and how to incorporate them for better performances. The review seeks to enhance engineering practice and direct research in sustainable household water treatment by utilizing peer-reviewed studies from 2000 to 2025.

2. METHODOLOGY

This review adhered to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standards, including identification, screening, eligibility, and inclusion, to guarantee transparency and reproducibility (Page et al., 2021). Extensive searches were performed in Web of Science, Scopus, PubMed, and Google Scholar for literature published between 2000 and 2025. The inclusion criteria comprised peer-reviewed journal articles and reviews assessing POU filtration performance (laboratory or field), published in English. Studies on centralized or community-scale systems, non-filter POU methods (e.g., chlorination alone), non-English publications, and non-peer-reviewed sources were not included (Figure 1).

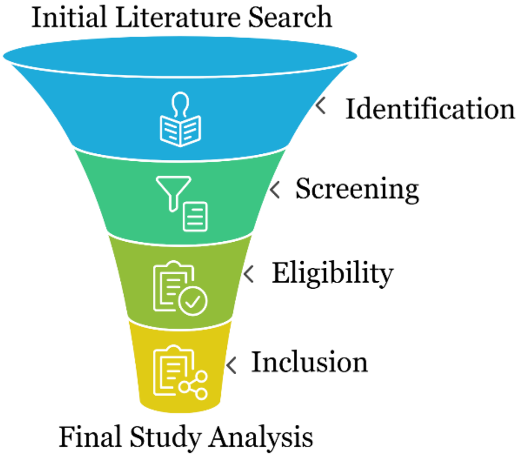

Figure 1: Systematic Review Process.

Data were extracted from full texts regarding filter type, treatment mechanism, materials, target contaminants, removal efficiency (log-reduction or percentage), operational conditions, and statistical analyses. A qualitative synthesis was performed on selected studies, and quantitative metrics were compiled, with standard performance ranges indicated when multiple values were reported. Due to methodological heterogeneity, a formal meta-analysis was not performed; instead, comparative summaries were utilized. The quality of the evidence was considered, with randomized trials and well-controlled experiments being given the most weight.

3. EXISTING LARGE-SCALE TECHNOLOGIES AND THEIR LIMITATIONS

3.1 Overview of Centralized Water Treatment Processes

Large-scale water treatment systems are necessary for supplying safe drinkable water to densely populated urban areas with well-established distribution networks. Although highly efficient, these systems present limitations in resource-constrained conditions. A centralised water treatment system generally involves screening, coagulation-flocculation, sedimentation/clarification, advanced treatment processes (e.g., reverse osmosis, ultrafiltration, adsorption), disinfection, safe storage, and proper distribution. Table 1 presents the main pros and cons of these technologies.

Table 1. Advantages and limitations of large-scale water treatment technologies

Technology	Operation	Advantages	Limitations	References
Coagulation, Flocculation, Sedimentation	Chemicals (e.g., alum) form flocs that settle out, clarifying the water	Effective for turbidity and suspended solids; widely used	Chemical dependency; sludge generation; reduced efficiency at low temperatures; moderate energy requirement	Tahraoui et al., 2024; Aragaw & Bogale, 2023
Reverse Osmosis (RO)	Pressurized water passes through semi-permeable membranes to remove salts and dissolved contaminants.	High removal of dissolved solids and heavy metals; high-quality output	Membrane fouling; brine disposal issues; costly maintenance; high installation cost; and limited removal of some chemicals	Matin et al., 2021; Park et al., 2020

Ultrafiltration (UF)	Water passes through fine membranes to remove particulates, bacteria, and viruses.	Chemical-free pathogen removal; effective for suspended matter	Membrane fouling; limited toxic-element removal; possible bacterial regrowth; requires reliable power	Shoshaa et al., 2023
Disinfection (UV, ozone, chlorine)	Pathogens inactivated using UV light, ozone, or chlorine	Rapid disinfection; simple operation; widely available	Risk of dosing errors; harmful by-products; limited residual protection; risk of recontamination	Hossen et al., 2023

3.2 Rationale for Point-of-Use (POU) Water Treatment Systems

Point-of-Use (POU) water treatment technologies are becoming more popular in developing areas where centralized infrastructure is not reliable or doesn't exist (Odwori, 2019). These systems for homes are cheap, don't need large infrastructure, and can be tailored to the needs of the local environment and water quality. They effectively decrease microbial contamination and limit recontamination during storage. POU interventions have been shown to cut down on waterborne diseases by as much as 35% (Verhougstraete et al., 2020). Furthermore, they offer a sustainable approach, requiring minimal energy, and empower local communities to manage their own water quality and quantity.

4. POINT-OF-USE FILTRATION TECHNOLOGIES

4.1 Bio-Sand Filters (BSF)

The Bio-Sand Filter (BSF), derived from traditional slow sand filtration, was first developed by Dr. David Manz at the University of Calgary during the 1990s and distributed globally through the Centre for Affordable Water and Sanitation Technology (CAWST, 2012). BSFs are cheap, easy to maintain, and can be made ready with locally available materials. It aims to provide safe drinking water to homes without access to centralized treatment (Janjaroen, 2016). Differents types of BSF used, as-

- **Conventional Bio-Sand Filter Design:** The conventional BSFs use gravity to move water through fine sand and gravel to clean it physically and biologically. A biologically active layer (*schmutzdecke*) develops at the sand surface and is crucial for the elimination of microbes (Bradley et al., 2011; Wang et al., 2014). The charge volumes of CAWST's most popular models, Versions 9 and 10, are 20 L and 12 L, respectively. Version 10 has a 55 cm sand layer and a smaller charge volume to make contact time longer and improve filtration efficiency (Janjaroen, 2016).
- **Kanchan Arsenic Filter (KAF) Modification:** Modified BSFs deal with both chemical and microbial contamination. Heavy metals like arsenic and iron are common pollutants in groundwater, and previous research has shown that iron (Fe) can get rid of them (Chiew et al., 2009; Mehta & Chaudhari, 2015). The Kanchan Arsenic Filter uses corroding iron nails over sand to form ferric hydroxides that adsorb arsenic and other metals. Iron addition enhances metal removal but can reduce oxygen availability and hinder pathogen removal (Janjaroen, 2016).
- **Iron-Amended Bio-Sand Filters:** Iron-amended BSFs combine fine sand with steel nails, steel wool, or zero-valent iron. This allows them to remove both microbial and inorganic contaminants at the same time (Bradley et al., 2011). A bio-layer forms in the same way as a normal BSF, with intermittent use (usually 20 L every 24 hours) helping it along. These systems can reduce more than 4 logs of viruses and up to 95% of dissolved iron and arsenic (Janjaroen, 2016; Wang et al., 2014).

4.2 Ceramic Water Filters (CWF)

Ceramic water filters (CWFs) are low-cost purification devices that are used at the point of use. They are made from local clay mixed with organic burn-out materials like sawdust or rice husk, which burn away during firing at 800-900 °C to make a porous structure (Yang et al., 2020). They work by letting gravity pull water through them and getting rid of pollutants through physical straining, adsorption, and, when coated, silver-based disinfection (Farrow et al., 2018; Oyanedel-Craver & Smith, 2008). There are pot, candle, disk, and tubular forms of CWFs. Pot filters are the most common for home use, while candle, disk, and tubular designs are more common in community or portable systems.

- **Filter Media Composition and Additives:** The main part of the filter medium is a mix of clay and organic matter. The clay gives the structure strength, and the organic material controls the perfect size of the pores after firing. The type and amount of burn-out material have a big effect on the flow rate and how well microbes are removed. Adding more rice husk or recycled paper fibers can make hydraulic conductivity better while still getting rid of bacteria (Yang et al., 2020). To get rid of arsenic, fluoride, and other metalloids more effectively, additives like Fe_2O_3, La_2O_3, MgO, and TiO_2 have been added (Yang et al., 2020; Schaefer et al., 2018).
- **Treatment Performance and Efficiency:** CWFs effectively remove microbes, demonstrating 2-7 log reductions of E. coli (99-99.9999% removal) and more than 99% removal of protozoan cysts in both laboratory and field studies (Brown & Sobsey, 2010; Farrow et al., 2018). However, unmodified ceramic filters don't work very well for removing viruses or chemical contaminants that are already in the water. Metal oxide coatings like La_2O_3 and Fe_2O_3 can help to get rid of more than 90% of arsenic(V). They keep the effluent concentrations below the WHO limit of 10 $\mu g\ L^{-1}$ for thousands of pore volumes (Schaefer et al., 2018; Yang et al., 2020).
- **Socioeconomic Acceptance and Adoption:** Because they are cheap, easy to use, and work with local production, CWFs are used in more than 20 developing countries, including Cambodia, Guatemala, and China (Yang et al., 2020). According to cost analyses, a CWF used for ten years costs about $63 per household, while centralized systems cost about $221 (Rayner et al., 2013). Users also say that the taste, smell, and clarity are better than chlorination, which is often turned down because of taste issues.

4.3 Gravity-Driven Membrane (GDM) Systems

Gravity-driven membrane (GDM) systems use hydrostatic pressure instead of pumps to achieve the low transmembrane pressures (approximately 20-70 mbar) that are required for microfiltration and ultrafiltration. A key operational feature of these systems is the intentional creation of a biofilm, or "cake layer," on the membrane surface. This layer stabilizes water flow (flux) and improves the removal of biological contaminants, such as organic matter and bacteria. GDM systems suit low-resource settings due to pump-free operation, minimal chemical use, and low maintenance.

- **Membrane Composition and Biofilm Function:** GDM systems use low-pressure MF/UF membranes such as polymeric PES and PVDF hollow fibers (Pronk et al., 2019). Using second-life membrane modules lowers the capital costs even more and makes things more environmentally friendly (Stoffel et al., 2023). An active cake layer improves pathogen removal and organic matter degradation, reducing pretreatment to simple screening or sedimentation and avoiding continuous chemical cleaning (Pronk et al., 2019; Wang et al., 2022).
- **Filtration Performance and Long-Term Stability:** GDM systems maintain stable operation at steady flows of 3-10 $L \cdot m^{-2} \cdot h^{-1}$ (Pronk et al., 2019; Wang et al., 2022). They effectively eliminate turbidity and suspended solids, lower bacteria levels by 1 to 3 logs, and accelerate the decomposition of dissolved organic carbon (DOC) through biofilm activity (Truttmann et al., 2020). Long-term studies show that using gravity-driven backwashing to control fouling works well for more than three years (Stoffel et al., 2023; Wei et al., 2025).
- **Community Adoption and Operational Feasibility:** With low energy requirements, minimal maintenance, and inexpensive operation, GDM systems are appropriate for low-income communities (Pronk et al., 2019). Their operation simplicity without pumps or chemicals makes them more acceptable to the consumers, and communities say that the treated water tastes and looks good (Wei et al., 2025). Some problems still need to be solved, such as the cost of membranes, supply chain problems, and the need for basic operator training (Stoffel et al., 2023).

4.4 Granular Activated Carbon (GAC) Filters

A lot of people use granular activated carbon (GAC) filters to get rid of organic pollutants, smells, and tastes. The carbon granules in them are very porous and usually come from wood, coal, or coconut shells. They have a lot of surface area for adsorption. As biofilms grow, biodegradation and adsorption work together to improve overall performance. GAC filters are effective, simple to use, and work well in both small and large systems. Another reason for being well-liked by the public is that GAC doesn't require numerous chemicals. When the media becomes too full, it can be replaced or regenerated.

- **Composition and Adsorptive Media Characteristics:** To make GAC, materials like coal or coconut shells are burned and then activated. This creates a large-surface-area adsorbent (Jjagwe et al., 2021). Coconut-shell GAC has a surface area of about 941 m^2/g and is very microporous, which makes it great for getting rid of organic pollutants. Granules (0.2-5 mm) help biofilm grow and lower pressure loss, which lets both adsorption and biodegradation happen (Betsholtz et al., 2024; Ho & Newcombe, 2007). GAC can be regenerated or replaced, and the appropriate number of media is important for the best performance (Petrović et al., 2025).
- **Removal Efficiency and Operational Constraints:** GAC removes natural organic matter (NOM), which compounds are responsible for taste and odor, as well as micropollutants, and precursors to disinfection by-products (Betsholtz et al., 2024; Petrović et al., 2025). Water chemistry affects how things stick to each other, and this behaviour usually follows the Freundlich isotherm and pseudo-second-order kinetics (Ogbeh et al., 2025). Microbial biofilms improve biodegradation progressively, particularly for contaminants such as microcystins (Ho & Newcombe, 2007; Wang et al., 2007). Operational constraints encompass turbidity interference, fines release, and media saturation, which require regeneration or replacement.
- **Public Acceptance and Cost Considerations:** GAC is a good treatment option that doesn't cost too much. The cost depends on the quality of the influent, the empty bed contact time (EBCT), and how often the media needs to be replaced (Ogbeh et al., 2025). People generally like it because it works well, is easy to use, and doesn't use any chemicals. In low-resource settings, adoption of GAC may be limited by frequent media replacements and supply-chain challenges, while Social Life Cycle Assessment (SLCA) can quantify broader social and health benefits to inform implementation (Stoffel et al., 2023).

4.5 Cloth Filtration

Using cotton, muslin, or nylon fabric, cloth filtration helps to remove turbidity, particles, and zooplankton from surface water (Clasen & Bastable, 2003). Not a disinfectant, but it does kill a lot of copepods that carry Vibrio cholerae, which lowers the risk of cholera spreading (Colwell et al., 2003). It is a cost-effective first-line treatment familiar to resource-limited communities.

- **Filter Media and Composition:** Multilayered cotton sari, cloth, muslin, or other woven fabrics are often used in cloth filters. According to Colwell et al. (2003), older cotton fabric is superior because repeated washing reduces the weave size to between 20 and 50 μm. In fishing communities, nylon and polyester meshes are more durable and have pore sizes that stay the same. The tightness of the weave and the number of threads affect how well the filter works. They can be washed and reused, but prolonged use may cause the fibers to loosen, reducing their effectiveness.
- **Performance and Removal Efficiency:** Although cloth filtration effectively removes significant particles, turbidity, and pathogens linked to plankton, it is not as effective in eliminating bacteria, viruses, or chemicals (Clasen & Bastable, 2003). Four to eight layers of sari cloth can cut the number of helminth eggs and protozoan cysts by up to 50%, and get rid of 70-99% of V. cholerae carriers, and lower turbidity by 20-60% (Colwell et al., 2003). It works best as a pre-treatment and works even better when used with SODIS, boiling, chlorination, or ceramic filters. According to Colwell et al. (2003), field research conducted in Bangladesh showed that sari filtration reduced the incidence of cholera by about 48%.
- **Public Acceptance and Socioeconomic Factors:** People like cloth filtration because it doesn't require any technical training and uses cheap, common materials (Clasen & Cairncross, 2004). Bangladesh has a long tradition of filtering water with a sari cloth, commonly used by women who collect water for their households. While this method is most accepted within a multi-barrier treatment framework, its use may decline if viewed as outdated or burdensome.

5. SUMMARISED COMPARISON

The Bio-Sand Filter (BSF), Ceramic Water Filter (CWF), Gravity-Driven Membrane (GDM) System, Granular Activated Carbon (GAC) Filter, and Cloth Filtration are compared in Table 2 and Figure 2.

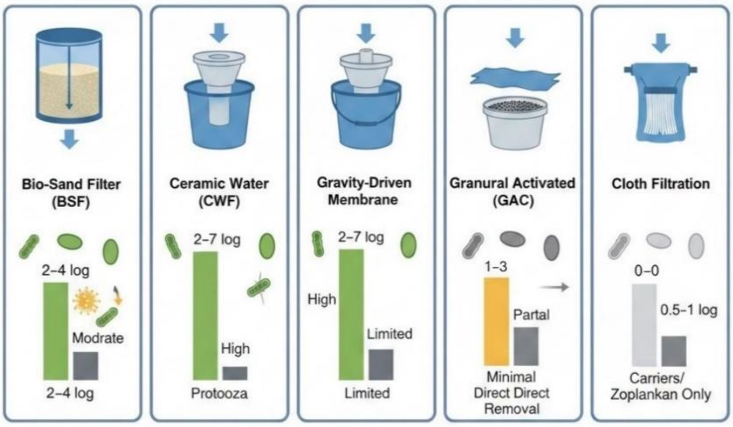

Figure 2: Comparative Microbial Removal Efficiency of POU water treatment technologies.

Table 2. Comparison of five Point-of-Use (POU) water treatment technologies

Feature	Bio-Sand Filter (BSF)	Ceramic Filter (CWF)	Gravity-Driven Membrane (GDM)	Granular Activated Carbon (GAC)	Cloth Filtration
Primary Mechanism	Physical straining; biological purification via schmutzdecke; adsorption	Physical straining; adsorption; silver-based disinfection	MF/UF via hydrostatic head; biofilm (cake layer) for biological removal	Adsorption on high-surface-area carbon; biofilm-supported biodegradation	Physical removal of particulates, turbidity, and zooplankton; not a disinfectant
Filter Media / Composition	Fine sand and gravel; KAF/iron-amended versions include iron nails or ZVI	Clay + organic burn-out materials (e.g., rice husk); fired at high temperatures; oxide additives	Low-pressure MF/UF PES or PVDF membranes (hollow fibers)	Porous carbon granules from wood, coal, or coconut shells	Multilayered sari cloth, muslin, nylon, or polyester; 20-50 µm pores (tighter in older cloth)
Target Contaminants	Microbes, turbidity, arsenic/iron in modified designs	Bacteria, protozoan cysts; arsenic/fluoride in coated versions	Turbidity, suspended solids, bacteria, and DOC	Organic pollutants, taste/odor compounds, micropollutants, DBP precursors	Turbidity, large particles, zooplankton, V. cholerae carriers; partial helminth/protozoa removal
Microbial Removal Efficiency	High; iron-amended designs achieve >4-log virus removal	2-7 log E. coli; >99% protozoan removal	1-3 log bacteria; enhanced by the cake layer	Secondary microbial removal via biodegradation	70-99% removal of V. cholerae carriers; limited bacterial/viral removal
Operation / Maintenance	Gravity-driven; low maintenance; intermittent dosing (≈20 L/day)	Gravity-driven; easy to use; clogging possible over time	Gravity-driven (20-70 mbar); minimal chemicals; periodic backwashing	Gravity or pressure-driven; media regeneration or replacement required	Very low cost; washable and reusable; performance decreases as fabric loosens; best as pre-treatment

6. FUTURE HYBRID FILTRATION SYSTEMS

Hybrid filtration systems use more than one treatment method to get around the problems with single-technology POU systems. These designs offer multi-barrier protection that meets WHO standards by combining adsorption, membrane separation, biological filtration, and disinfection. Research shows that hybrid systems perform better in complex contamination scenarios involving metals, pathogens, organic micropollutants, and high turbidity (Peter-Varbanets et al., 2009; Sima & Elimelech, 2013).

6.1 Sand-Biochar-Ceramic Hybrid Systems

These systems combine sand filtration, biochar adsorption, and the ceramic micropores. They have higher flow rates than ceramic filters alone and display better performance in removing microbes from the schmutzdecke and ceramic layer (Brown & Sobsey, 2010; Stauber et al., 2006). Biochar contributes removal of organic pollutants and heavy metals (Babel & Kurniawan, 2003; Mohan et al., 2014). Iron-oxide biochar improves arsenic and fluoride removal, which makes the design perfect for South Asia.

6.2 Ceramic-Silver-GAC Composite Filters

Ceramic-silver-GAC hybrids combine ceramic filtration, silver-based disinfection, and activated carbon adsorption. Ceramic parts get rid of turbidity and protozoa, silver stops bacteria from growing back, and GAC adsorbs pesticides, DBP precursors, and taste and smell compounds. These systems can kill 99-99.999% of bacteria and get rid of a lot of organic micropollutants (Soppe et al., 2015). They protect peri-urban areas from multiple contaminants for a long time.

6.3 GDM-Adsorption Hybrid Systems

GDM-adsorption hybrids combine gravity-driven membrane filtration with adsorbent materials like charcoal, manganese oxide, or GAC. Pre-adsorption enhances the elimination of dissolved pollutants, such as heavy metals and organic carbon (Wei et al., 2025), diminishes organic loading on the membrane, stabilizes flux (Pronk et al., 2019), and mitigates fouling, thereby prolonging membrane longevity. These systems work best in areas where people depend on surface waters that are high in turbidity and organic matter.

6.4 Electrochemical-Filtration Hybrid Systems

Electrochemical oxidation (EO)-filtration hybrids integrate EO with sand, ceramic, or membrane filtration to eliminate a wide spectrum of microorganisms, including chlorine-resistant cysts (Hand & Cusick, 2021). HClO is produced on-site by EO, and drugs and emerging pollutants are broken down, meaning that reliance on externally supplied disinfectants is reduced (Lantagne, 2008). These systems are being used in refugee camps and remote clinics where there aren't many chemicals available.

6.5 Solar-Filtration Integrated Systems (SODIS + Media)

SODIS-filtration hybrids combine solar UV disinfection with ceramic, sand, or membrane filtration to make a treatment system that doesn't use any energy and has several barriers. First, filtration lowers turbidity so that UV light can get through. Then, SODIS kills any remaining microorganisms, including viruses that filtration doesn't remove very well (Berney et al., 2006). Because they are simple and don't need any energy, these systems are great for emergencies and places that are far away.

6.6 Hypochlorous Acid (HClO)-Integrated Hybrid Systems

HClO-integrated hybrids use chemical or electrochemical methods to make HClO and physical filtration to quickly kill microbes and protect against them. Filtration gets rid of turbidity and organic matter, which lowers the need for chlorine and the amount of disinfection by-products that are made (Deborde & von Gunten, 2008; WHO, 2017). Combining ceramic or biosand filters with on-site electrochlorination makes it possible to reliably disinfect in remote areas (Lantagne, 2008). Membrane-HClO systems, on the other hand, make it easier to get rid of bacteria and viruses (Peter-Varbanets et al., 2009). In areas with few resources, these hybrids help keep things clean after treatment (Clasen & Cairncross, 2004) and can reduce microbes by more than 4-6 log units (CDC, 2025; Sobsey et al., 2008).

7. CONCLUSIONS

This review indicates that point-of-use (POU) water filters can significantly enhance microbial safety in places where resources are limited. Biosand and ceramic filters get rid of more than 99% of bacteria and protozoa when they are properly utilized. Gravity-driven membrane systems make things even more reliable by keeping the flux stable even when nothing else is pushing on it. But most of the time, unmodified POU systems don't eliminate viruses or chemicals that are already in the water. Without things like silver, iron, or UV treatment, these harmful substances can still get to consumers. Cloth filters mostly reduce turbidity and lower the risk of cholera, but they do not kill germs in water. Granular activated carbon works well for organic pollutants, but it needs to be used together with a microbial barrier.

An integrated multi-barrier treatment approach is recommended for point-of-use (POU) water treatment. Hybrid systems that combine adsorption, membrane separation, biological treatment, and disinfection demonstrate improved removal of diverse chemical and microbial contaminants. Future research should prioritize durable, low-cost hybrid designs compatible with local water chemistry, field validation of advanced media (e.g., biochar and iron-coated materials), and development of simple performance monitoring tools. Long-term effectiveness also depends on community training for proper operation and maintenance. In practice, NGOs and engineers should select context-specific technology combinations, such as ceramic pot filters coupled with carbon pre-filtration and solar disinfection to address both arsenic and pathogens. While single-stage POU filters reduce waterborne disease, comprehensive household safety requires a transition to multi-barrier hybrid systems.

DECLARATION OF USE OF AI

During the preparation of this work, the authors used some AI tools, such as Grammarly, Quill Bot, Mendeley Cite, etc., for summarization, grammar refinement, spelling correction, and rearranging sentences to improve flow, clarity, and citation management. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for this published article.

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