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Research Article

Performance of Ceramic Pot Filters with Colloidal Silver for Rural Water Treatment

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Abstract

Household ceramic pot filters are promising for rural water treatment, but their performance depends on ceramic composition, pore-former content, and silver application. This study screened 20 physical filters fabricated from red or brown clay at five clay/sawdust ratios (82.5/17.5 to 72.5/27.5), with or without 300 mL of colloidal silver at 80 mg/L. Each filter treated three successive 3-L batches of the same composite rural water. These represented repeated measurements on a single filter rather than independent filter replicates. T1 (red clay, 17.5% sawdust, with silver) removed 81.13% of turbidity, 83.14% of viable mesophilic count (VMC), and 97.22% of fungi; T6 showed comparable performance. In all four clay-by-silver series, mean removal at 17.5% sawdust was greater than that at 27.5% for all three responses. VMC removal was higher in the presence of silver in all 10 matched formulation pairs (mean difference, 5.94 percentage points; median, 4.08; range, 0.26–17.92), whereas differences in turbidity and fungal removal were inconsistent. Because each treatment contained only one physical filter, these patterns are descriptive and do not estimate reproducible treatment effects. Total and thermotolerant coliforms were each not detected in 18 of the 20 filters under the applied conditions. The recorded direct-material subtotal was PEN 26.8–27.1 for filters with silver and PEN 2.8–3.1 for those without silver. In a separate first-filtrate pilot, silver was below the quantification limit of 0.007 mg/L. The 17.5% sawdust formulations require independent replication and long-term validation.

Keywords: Ceramic pot filter, Colloidal silver, Microbial removal, Point-of-use treatment, Rural water, Turbidity

1 Introduction

Access to safe drinking water remains a major public health and engineering challenge, particularly in dispersed rural settlements where centralized treatment and continuous disinfection are difficult to maintain. The 2025 update of the WHO/UNICEF Joint Monitoring Programme reported that, although safely managed drinking water coverage increased globally from 68% to 74% between 2015 and 2024, 2.1 billion people still lacked safely managed drinking water services and 106 million continued to collect drinking water directly from surface water sources [1]. These figures indicate that progress in infrastructure coverage has not eliminated the need for decentralized and point-of-use treatment technologies capable of improving microbial safety at household scale.

The Peruvian context illustrates this gap between access and safety. National statistics for 2024 reported high overall access to water supplied through public networks, but persistent territorial and rural limitations remained [2]. Moreover, a national spatial analysis using the 2021 Demographic and Health Survey found that only 29.22% of Peruvian households had access to safe drinking water when safety was defined by residual chlorine concentration equal to or greater than 0.5 mg/L [3]. This finding is especially relevant for rural and jungle areas, where piped water systems may be present but disinfection, continuity, and sanitary surveillance are frequently insufficient. Therefore, low-cost treatment barriers at the household level are not only emergency alternatives, but also complementary technologies for communities where network water does not consistently meet microbiological safety criteria.

Microbiological contamination is among the most important hazards in drinking water because fecal indicators and opportunistic microorganisms can persist during storage and distribution. The World Health

Organization emphasizes preventive risk management from catchment to consumer, including source protection, treatment, distribution control, and surveillance of microbial and physicochemical parameters [4]. Turbidity is also relevant because suspended particles can protect microorganisms, reduce disinfection effectiveness, and affect consumer acceptability. Technologies proposed for household water treatment should therefore be assessed for turbidity reduction, microbial removal, hydraulic performance, and operational feasibility. Silver-treated point-of-use devices require additional caution: WHO identifies 0.1 mg/L as a provisional reference or bounding value rather than a formal guideline value and does not recommend silver as a drinking-water disinfectant, including in point-of-use devices [5].

Ceramic water filters are established point-of-use technologies for settings where centralized treatment is unreliable. They are generally produced from clay and a combustible pore-forming material that burns out during firing. Performance depends on raw-material properties, particle size, clay/pore-former ratio, forming, firing, wall thickness, hydraulic loading, silver application, and source-water quality [6]. Manufacturing surveys and best-practice guidance therefore emphasize standardized raw materials, controlled firing, flow testing, quality assurance, and complete production records [7], [8].

Ceramic pot filters remove contaminants through physical straining, tortuous pore transport, adsorption, and, when silver is applied, antimicrobial action. Substantial bacterial removal has been demonstrated, although performance can decline with repeated loading or inadequate maintenance [9]. In a long-term experiment, storage/contact time contributed to *E. coli* inactivation, silver application location did not produce significant differences in log-reduction values, and virus removal remained a concern [10]. Increasing pore-former content can raise flow, yet excessive flow may reduce microbial retention or accelerate clogging [11].

Filtration rate is central to household usability: very low production discourages use, while excessive flow may indicate large pores or structural defects. Bacterial removal varies with hydraulic performance and microbial challenge conditions [12]. Formulation selection should therefore combine effluent quality with a rate compatible with the intended use.

Colloidal silver is used to suppress microbial survival on ceramic surfaces and in treated water, but its engineering value depends on dose, deposition, retention, elution, and water chemistry. Silver release can change with chlorination and source-water conditions [13], while controlled deposition methods can improve reproducibility [14]. Laboratory evidence also shows that silver application can alter bacterial removal efficacy [15]. Ceramic composition and silver should therefore be evaluated as interacting design features while retaining the safety caution stated above.

Sustainability also depends on local materials, manufacturing cost, user acceptance, and scalability [16]. Latin American studies have reported high coliform and *Escherichia coli* removal, but outcomes varied with filter model, maintenance, and hydraulic behavior [17], [18]. More complex silver-ceramic systems combined with adsorption can achieve high bacterial removal but add cost and operational complexity [19]. Locally manufacturable filters therefore require multiresponse comparison before a formulation is recommended for rural households.

The present study differs from previous ceramic pot filter investigations by comparing two clay sources across five regularly spaced sawdust fractions and matched silver/no-silver conditions under the same rural-water matrix. It also integrates three successive filtration cycles, hydraulic performance, turbidity, four microbiological indicators, direct material cost, and a separate pilot measurement of silver in the first filtrate. Twenty physical filters were evaluated, one per treatment; therefore, the objective was comparative screening of formulation and operating patterns rather than definitive optimization or industrial validation. The study aimed to identify candidate formulations for subsequent testing with independently replicated filters and long-term household operation.

2 Materials and Methods

2.1 *Study area and water sampling*

The study used water from the rural supply system of Caserío Antonio Raymondi-Las Vegas, Daniel Alomía Robles district, Leoncio Prado province, Huánuco, Peru. The community is located near 9°11′33.21″ S and 75°54′12.49″ W, at approximately 984 m above sea level, in a warm-humid area with annual precipitation of 2,000–2,500 mm and average relative humidity close to 88%. Water was collected from the catchment, storage reservoir, and one household connection to represent the supply pathway used by the community.

Sterile containers were used for collection, and water from the three points was combined into one 181-L composite sample. One liter was separated for initial characterization. The remaining 180 L were divided into three 60-L batches, each sufficient to supply 3 L to the 20 filters. The same composite source water was therefore used for the three successive filtration cycles. Samples were transported under cold conditions to the Environmental Microbiology Laboratory of Universidad Nacional Agraria de la Selva following the national water-quality sampling protocol [20].

2.2 *Raw materials, filter fabrication, and silver application*

Two clay sources were evaluated: commercial red clay and brown clay obtained from the Chillón River area, Puente Piedra, Lima, Peru. Sawdust from tornillo wood was used as the combustible pore former. The clays were air-dried for 3 d, milled, and passed through a No. 20 sieve to remove coarse material. Sawdust was air-dried for 2 d and passed through a nominal No. 400 sieve (38 µm). These sieve cutoffs describe preparation limits; full particle-size distributions of the clays and sawdust were not measured.

For each clay source, five mass ratios were prepared: 82.5/17.5, 80/20, 77.5/22.5, 75/25, and 72.5/27.5 clay/sawdust. The interval was selected as a structured screening series in 2.5-percentage-point increments to progressively increase pore-former content while retaining clay as the continuous phase. Water was added until a homogeneous, malleable paste was obtained. The paste was placed in a conical mold, compacted with a manually operated hydraulic press, demolded after 2 h, and air-dried for 12–15 d.

The dried units were fired in an industrial kiln using a nominal 12-h cycle that reached 880 °C. The available production record did not separate the heating ramp, exact dwell at 880 °C, and cooling profile. Each filter had a top diameter of 24.5 cm, bottom diameter of 16 cm, height of 15.5 cm, wall thickness of 2 cm, and nominal capacity of 3 L. Filters were washed and saturated in water for 4 h before use.

The commercial silver product (Vida Coloidal, 100 mg/L) was diluted by mixing 240 mL of product with 60 mL of water to obtain 300 mL at 80 mg/L per filter. This corresponded to a nominal applied mass of 24 mg Ag per filter. The solution was brushed onto the dry internal and external surfaces, base, and rim in three 100-mL layers separated by 30 min. Silver-treated units rested for 24 h before filtration. Control filters underwent the same fabrication and conditioning sequence without silver.

2.3 *Experimental design and repeated-cycle operation*

Twenty physical filters were evaluated, one for each treatment. The ten ceramic matrices comprised two clay sources and five clay/sawdust ratios. Silver-treated filters were coded T1–T10, and matched filters without silver were coded TC1–TC10. T1–T5 and TC1–TC5 contained red clay; T6–T10 and TC6–TC10 contained brown clay.

Each filter was mounted above an 8-L collection bucket and received 3 L of composite water per cycle. The same physical filter was then reused in cycles R1, R2, and R3, for a cumulative 9 L per filter and 180 L across the experiment. Thus, R1–R3 were repeated measurements of the same filter, not three independently manufactured filters. Silver was applied once before filtration.

2.4 *Water-quality analyses*

The initial composite water and the filtrate from each treatment cycle were analyzed for turbidity, total coliforms, thermotolerant coliforms, viable mesophilic count (VMC), and fungi. Turbidity was measured with a portable turbidimeter (HI93414, Hanna Instruments, Woonsocket, RI, USA).

Total and thermotolerant coliforms were enumerated by the Environmental Microbiology Laboratory's three-tube, three-dilution most-probable-number (MPN) procedure, documented as corresponding to Standard Methods 9221B and 9221E [21]. A 10-mL aliquot was homogenized in 90 mL of 0.1% peptone diluent, after which three consecutive decimal dilutions were prepared. From each dilution, 1 mL was inoculated into each of three tubes fitted with inverted Durham tubes. Brilliant Green Bile Broth was used for total coliforms and incubated at 35–37 °C for 24–48 h; EC broth was used for thermotolerant coliforms and incubated at 44.5 °C, with readings during the laboratory's 24–48 h observation period. Tubes showing growth and gas accumulation in the Durham tube were scored positive, and the resulting three-digit positive combination was converted with an MPN table and reported as MPN/100 mL. Because the sample-level positive-tube worksheets and numerical reporting threshold were not retained in the revision files, recorded zeros were treated as non-detection under the applied test configuration rather than proof of absolute absence; exact percentage removal was not calculated from non-detect records.

VMC and fungi were determined by plate-count procedures using Plate Count Agar and Sabouraud Glucose Agar, respectively, and expressed as CFU/mL. The confirmed initial fungal count was 24 CFU/mL; the value 30 reported in some thesis tables was a transcription error. The initial turbidity and VMC values used for removal calculations were 3.54 NTU and 253 CFU/mL, respectively.

2.5 *Hydraulic performance, removal efficiency, and direct cost*

Filtration rate was calculated from filtered volume and elapsed time:

$$Q = V/t \quad (1)$$

where Q is the filtration rate (L/h), V is filtered volume (L), and t is filtration time (h). For turbidity, VMC, and fungi, removal efficiency was calculated as:

$$R = [(C_0 - C_t)/C_0] \times 100 \quad (2)$$

where R is removal efficiency (%), C_0 is the initial value, and C_t is the value after filtration. The recorded direct-material subtotal included clay, sawdust, water, and silver solution. The corrected silver input was 240 mL of the 100 mg/L commercial product, equivalent to PEN 24 per treated filter. Energy and kiln allocation, labor, finished-water receptacles, transport, quality control, reusable equipment, and research logistics were not defensibly available per filter and were excluded. The subtotal is not a total production or life-cycle cost; cost per liter was not estimated because service life was not measured.

2.6 *Pilot measurement of silver in the first filtrate*

A separate pilot test assessed Ag in the first 3-L filtrate from three 82.5/17.5 filters: red-clay units treated at 50 and 70 mg/L and one brown-clay unit treated at 80 mg/L. One liter from each first filtrate was analyzed by inductively coupled plasma optical emission spectrometry using EPA Method 200.7. The laboratory reported a method detection limit of 0.002 mg/L and a quantification limit of 0.007 mg/L. One sample was analyzed per condition. Silver retained in the ceramic body was not measured, and the pilot was not a cumulative leaching test.

2.7 *Data analysis*

Cycle-specific values were retained. For each physical filter, the mean and standard deviation across R1–R3 summarize within-filter variation only and were not interpreted as variation among independently manufactured filters. Treatment-level plots and selected table entries were used to describe patterns across sawdust fractions, clay sources, and matched silver/no-silver formulations.

Paired differences were calculated as the mean response of each silver-treated filter minus that of the matched non-silver filter with the same clay source and sawdust fraction. Because only one physical filter represented each treatment combination, independent within-treatment replication was unavailable. Accordingly, the previously reported ANOVA and Tukey comparisons and the exploratory GEE p-values were excluded from the manuscript, and no causal treatment effects were estimated. Coliform results were summarized descriptively as detected or not detected under the applied conditions.

3 Results and Discussion

The corrected analysis treats the physical filter as the experimental unit and the three 3-L runs as repeated cycles. Results are therefore reported as treatment-level descriptive patterns. The complete cycle-level dataset is provided as supporting material.

3.1 *Hydraulic performance and direct material cost*

Filtration rate rose with sawdust fraction under both silver conditions (Figure 1A). At 17.5% sawdust, the rates were 0.75 L/h with silver and 0.74 L/h without silver. At 27.5%, they increased to 1.91 and 3.75 L/h, respectively. The rate records were available by clay/sawdust ratio and silver condition but were not resolved separately by clay source; consequently, no red-versus-brown hydraulic comparison was made.

The low-flow end has an important household implication. At 0.74 L/h, a 3-L fill requires approximately 4.1 h; four fills represent a 12-L/d production scenario. Household size, water-use categories, refilling adherence, and demand were not assessed, so 12 L/d should not be interpreted as evidence of household sufficiency. Large families or broader domestic uses may require additional units, larger pots, or more frequent refilling. Conversely, the 3.75 L/h

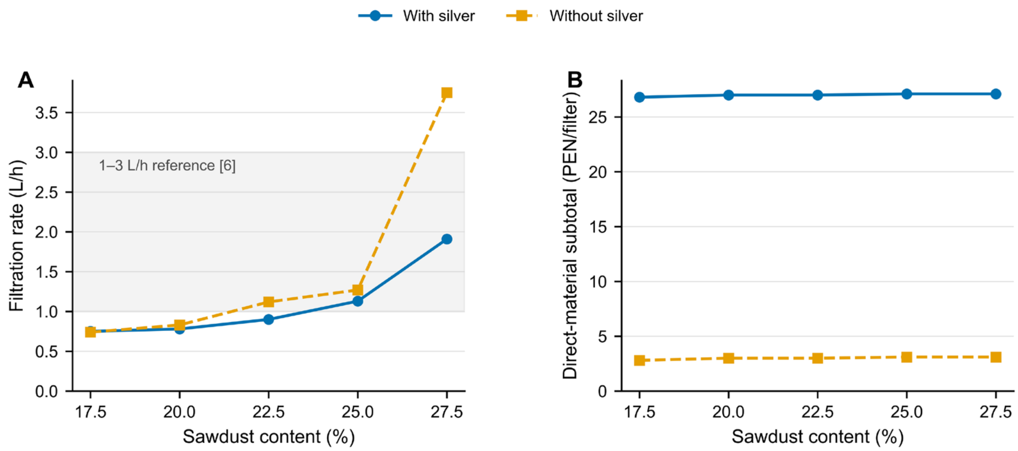

Figure 1: Hydraulic and cost implications of sawdust fraction. (A) Filtration rate under silver and non-silver conditions; the gray band shows the 1–3 L/h reference range reported in [6]. (B) Recorded direct-material subtotal. Rates were available by ratio and silver condition and were not resolved by clay source.

formulation completed one fill in approximately 0.8 h but showed weaker removal outcomes. This observed throughput–treatment tradeoff shows why maximum flow should not be the sole selection criterion.

The recorded direct-material subtotal was PEN 26.8–27.1 per filter with silver and PEN 2.8–3.1 without silver (Figure 1B). Silver alone contributed PEN 24, or 88.6–89.6% of that subtotal. The calculation excludes reusable equipment, energy and kiln allocation, labor, finished-water receptacles, transport, quality control, and service-life costs; it is therefore not a total production or life-cycle cost. Field evidence shows that the application method can change the quantity and cost of silver used [22]. Earlier silver-filter studies document performance and operational context but do not validate this local subtotal [23], [24].

The observed flow trend is consistent with the combustion of sawdust generating connected voids. Earlier production studies identified filtration rate as a critical quality-control response [25], while recent micro-CT work showed that sawdust size distribution changes hydraulic conductivity and pore architecture in low-cost filter materials [26]. A 2026 multiresponse optimization study likewise linked clay source, sawdust content, firing conditions, effective porosity, and microbial rejection [27]. Because the present study did not measure pore structure, the hydraulic mechanism is supported by the formulation trend but not directly demonstrated.

3.2 *Turbidity, VMC, and fungal removal across successive cycles*

The initial composite water had 3.54 NTU turbidity, 253 CFU/mL VMC, and 24 CFU/mL fungi. Treatment means across the three cycles ranged from 38.79 to 81.13% for turbidity removal, 35.18 to 83.14% for VMC removal, and 59.72 to 97.22% for fungal removal. Figure 2 shows the descriptive decline in removal as sawdust increased, while Table 1 summarizes the strongest candidates and the high-sawdust treatments relevant to the reviewers' questions.

T1 produced mean removals of 81.13 ± 4.31% for turbidity, 83.14 ± 1.83% for VMC, and 97.22 ± 2.41% for fungi (Figure 2). T6, prepared with brown clay at the same 82.5/17.5 ratio and silver condition, produced 79.62 ± 3.08%, 82.35 ± 1.65%, and 97.22 ± 2.41%, respectively. Their matched controls also performed well, especially TC6. These results identify the low-sawdust matrices as candidates but do not establish reproducibility because each treatment was represented by one physical filter. At 27.5% sawdust, T5 and TC5 had lower turbidity and VMC removal, while T10 and TC10 showed different response combinations. Such divergence may reflect source-specific mineralogy, shrinkage, connected pore pathways, firing heterogeneity, or variability of the single physical units, but the present data cannot distinguish these explanations. Clay color itself is not a mechanistic variable. Because XRD, XRF, porosity, and pore-size measurements were unavailable, the manuscript refers to different clay sources and does not attribute performance to color.

3.3 *Descriptive patterns across formulations*

Within each of the four clay-by-silver series, the 17.5% sawdust formulation had higher mean removal than the 27.5% formulation for turbidity, VMC, and fungi (12 of 12 endpoint comparisons). The 17.5-minus-27.5 percentage-point differences ranged from 9.36 to 42.34 for turbidity, 16.21 to 43.35 for VMC, and 19.44 to 36.11 for fungi. These endpoint contrasts describe the tested filters and do not establish a population-level formulation effect.

Across the 10 matched formulation pairs, mean VMC removal was higher with silver in all 10 pairs (mean difference, +5.94 percentage points; median, +4.08; range, +0.26 to +17.92). Turbidity differences were positive in only 4 of 10 pairs (mean, −4.36; median, −2.57; range, −26.46 to +7.81). Fungal-removal differences were positive in 7 pairs, tied in 1, and negative in 2 (mean, +3.61; median, +1.39; range, −9.72 to +18.06). With one physical filter per treatment, these paired summaries do not estimate reproducible silver effects.

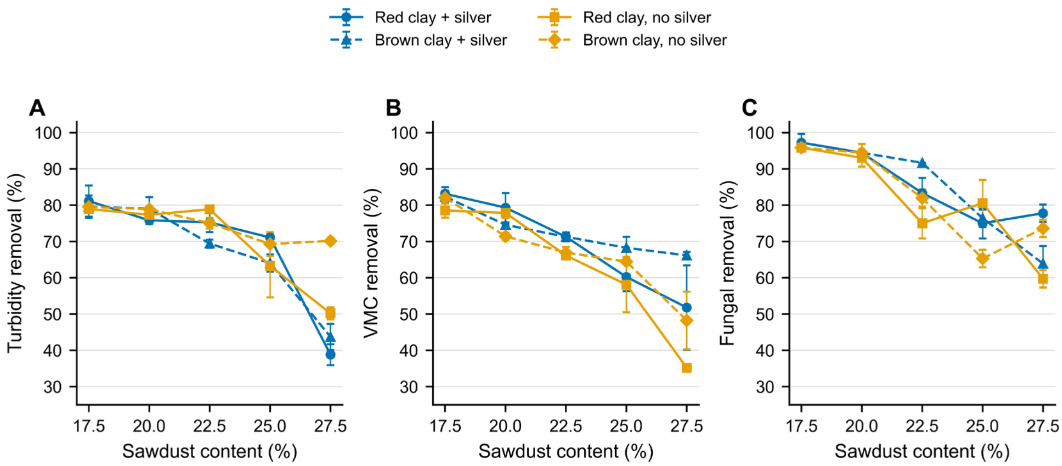

Figure 2: Observed removal patterns versus sawdust fraction. Points are means and error bars are SD across three successive cycles of the same physical filter; they do not represent independent filter replicates. Lines connect different physical filters and are descriptive only. VMC = viable mesophilic count.

Table 1: Selected treatment-level outcomes across three successive cycles.

Filter	Matrix clay/sawdust	Ag	Turbidity removal (%)	VMC removal (%)	Fungal removal (%)	Total/thermotol. coliforms
T1	Red 82.5/17.5	Yes	81.1 ± 4.3	83.1 ± 1.8	97.2 ± 2.4	ND/ND
TC1	Red 82.5/17.5	No	78.9 ± 0.8	78.5 ± 1.9	95.8 ± 0.0	ND/ND
T6	Brown 82.5/17.5	Yes	79.6 ± 3.1	82.3 ± 1.6	97.2 ± 2.4	ND/ND
TC6	Brown 82.5/17.5	No	79.5 ± 0.2	82.1 ± 0.5	95.8 ± 0.0	ND/ND
T5	Red 72.5/27.5	Yes	38.8 ± 2.9	51.8 ± 11.6	77.8 ± 2.4	ND/ND
TC5	Red 72.5/27.5	No	50.2 ± 1.7	35.2 ± 0.8	59.7 ± 2.4	ND/D
T10	Brown 72.5/27.5	Yes	43.7 ± 3.6	66.1 ± 1.0	63.9 ± 4.8	D/ND
TC10	Brown 72.5/27.5	No	70.2 ± 0.9	48.2 ± 7.9	73.6 ± 2.4	D/D

Note: Values are mean ± SD across three successive cycles of the same physical filter, not independently manufactured filters. D = detected; ND = not detected under the applied MPN conditions. The ND/D result for TC5 is internally discordant and was not used for mechanistic inference.

Mean removal across all 20 filters was 71.45%, 68.59%, and 69.85% for turbidity in cycles 1–3; 66.88%, 68.22%, and 68.48% for VMC; and 83.33% in each cycle for fungi. This three-cycle sequence provides no evidence about service life, progressive clogging, cleaning response, or long-term antimicrobial durability.

3.4 *Coliform detection patterns*

Total coliforms were not detected under the applied MPN conditions in 18 of 20 filters, and thermotolerant coliforms were not detected in 18 of 20 filters. Non-detect records were not converted to an exact 100% removal because the sample-level positive-tube worksheets and numerical reporting threshold were not retained in the revision files.

T5 and TC5 showed non-detection of total coliforms, whereas T10 and TC10 retained detectable total coliforms. With one physical filter per treatment and no pore characterization, this contrast cannot be attributed to clay source, color, silver, or pore connectivity. TC5 also showed thermotolerant-coliform detection despite total-coliform non-detection, an internally discordant hierarchy. That record was retained transparently but excluded from mechanistic interpretation. T10, with total-coliform detection and thermotolerant-coliform non-detection, is microbiologically possible because the thermotolerant group is a subset of total coliforms.

3.5 *Pilot silver release*

All three first-filtrate pilot samples were reported as <0.007 mg/L Ag, the laboratory quantification limit (Table 2), and were therefore below WHO's provisional 0.1 mg/L reference or bounding value [5]. This is not a formal guideline value, and WHO does not recommend silver for drinking-water disinfection, including in point-of-use devices [5]. Because only one first-filtrate sample was analyzed per condition, these results do not establish cumulative release, retained silver mass, coating durability, long-term safety, or antimicrobial persistence. Silver elution and post-filtration disinfection can depend on chlorination, source-water chemistry, loading, co-fired additives, and operating time [13], [28].

3.6 *Household applicability and limitations*

The experiment did not evaluate long-term clogging, cleaning frequency, or service life. In a 19-week study of 30 household ceramic filters, average flow declined from 1.94 to 0.93 L/h, and soft brushing provided only temporary recovery [29]. High-turbidity rural water can therefore shorten hydraulic life. Users require a simple cleaning protocol that avoids cracking or excessive abrasion; cleaning may also alter biofilm-related virus retention [30].

Ceramic pores also provide limited and variable virus removal. Extended tests with MS2 bacteriophage reported approximately 0.9–2.4 log removal depending on biofilm conditions, and surface cleaning reduced part of that benefit [30]. A secondary disinfection barrier should therefore be considered where viral contamination is plausible. The present filters were not evaluated for dissolved heavy metals, fluoride, nitrate, pesticides, or other chemical contaminants; the findings should not be generalized to those hazards.

Future work should use independently manufactured filter replicates, characterize particle size, mineralogy, porosity, pore-size distribution, and mechanical strength, and quantify retained silver and cumulative Ag release. Longitudinal testing should record flow decline, cleaning response, microbial regrowth during storage, and cost per liter. Recent ASEP membrane research combined SEM, XRD, porosity, mechanical properties, and antibacterial tests to connect material structure with permeability

Table 2: Pilot Ag concentration in the first 3-L filtrate.

Sample	Clay source	Clay/sawdust	Applied Ag (mg/L)	Sampled water	Ag result (mg/L)
M1	Red	82.5/17.5	50	First 3-L filtrate	<0.007
M2	Red	82.5/17.5	70	First 3-L filtrate	<0.007
M3	Brown	82.5/17.5	80	First 3-L filtrate	<0.007

Note: One sample per condition; EPA Method 200.7; laboratory-reported method detection limit = 0.002 mg/L and quantification limit = 0.007 mg/L. Retained silver and cumulative release were not measured.

and biological performance [31]; a comparable characterization strategy would strengthen the next ceramic-filter study.

4 Conclusions

Across three successive 3-L cycles, the 82.5/17.5 clay/sawdust filters provided the most balanced observed combination of hydraulic and treatment performance. T1 achieved mean removals of 81.13% for turbidity, 83.14% for VMC, and 97.22% for fungi; T6 showed comparable values. In all four clay-by-silver series, the 17.5% sawdust filter exceeded the 27.5% filter for all three removal responses. VMC removal was higher with silver in all 10 matched formulation pairs, but the one-filter-per-treatment design does not estimate a reproducible silver effect. Increasing sawdust increased filtration rate and coincided with lower removal, indicating an observed throughput–treatment tradeoff. Most filters showed non-detection of total and thermotolerant coliforms under the applied conditions, but discordant records were not used for mechanistic inference. The recorded direct-material subtotal was PEN 26.8–27.1 per silver-treated filter, and a separate first-filtrate pilot reported Ag below 0.007 mg/L. Pore structure, retained silver, cumulative leaching, clogging, cleaning response, viral removal, dissolved chemical contaminants, and service life require independently replicated, long-term evaluation before household-scale recommendation.

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Author Contributions

D.J.T.-S.: methodology, investigation, resources, data curation, and writing—original draft preparation; A.F.C.-C.: conceptualization, methodology, software, formal analysis, validation, visualization, supervision, project administration, and writing—review and editing; C.S.L.-L.: methodology, validation, investigation, and supervision. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

The authors used ChatGPT (OpenAI) to improve English-language clarity and readability. All AI-assisted suggestions were critically reviewed and edited by the authors, who take full responsibility for the scientific content, data interpretation, and final text.

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