Journal of Forestry Research and Management. Vol. 22 (2). 93-106; 2025, ISSN 0189-8418

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ASSESSMENT OF VARYING SAWDUST-CLAY MIXTURES ON WATER QUALITY, FILTRATION EFFICIENCY AND DURABILITY FOR PRODUCING HOUSEHOLD CERAMIC FILTERS

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ABSTRACT

Access to safe and affordable drinking water remains a major public health challenge, particularly in low-income and rural communities lacking centralized water treatment infrastructure. This study explored a sustainable solution by assessing the effect of varying sawdust-to-clay ratios on the performance of locally fabricated ceramic filters for household water purification. Three ceramic filter samples were produced using kaolinite clay and sawdust in volumetric ratios of 60:40, 50:50, and 40:60 (clay: sawdust). The filters were evaluated for filtration volume (L/h), water quality improvement (microbial and physicochemical parameters), and structural integrity (via water absorption percentage). Filtration tests were conducted in liters per hour, while water samples were collected from three well sources and analyzed using Nigerian Industrial Standard protocols. ANOVA was employed to determine statistical significance at a = 0.05. Results showed that increasing sawdust content significantly improved flow rate, with the 40:60 sample achieving the highest average filtration volume (0.463 L/h, $p<$ 0.001). All filters demonstrated complete removal of *Escherichia coli* and >93% reduction in total coliforms. Turbidity reductions exceeded 70%, with the 60:40 sample performing slightly better, though differences were statistically significant ($p<$ 0.001). Structural assessment confirmed all filters had acceptable water absorption rates below 7%, with the 60:40 filter showing the best mechanical stability (WA% = 3.51). The use of sawdust as a burnout material effectively enhances filter porosity and flow without compromising microbial safety or structural strength. The 60:40 sawdust-clay ratio offers optimal performance for decentralized water treatment, representing a low-cost, environmentally beneficial solution for safe household water access in underserved regions.

Keywords: Ceramic Filter Production,Filtration Efficiency, Household Water Purification,

Introduction

Access to safe and potable water remains one of the most pressing public health and developmental challenges of the 21st century, especially in low and middle income countries where centralized water treatment infrastructure is either inadequate or absent (WHO/UNICEF, 2006; Afangideh and Udokpoh, 2021). In such regions, households often rely on untreated water from wells, rivers, and boreholes that are frequently contaminated with microbial pathogens and chemical pollutants, leading to high incidences of waterborne diseases (Clasen *et al*., 2007; Yusuf and Suleiman, 2016). Addressing these challenges requires cost-effective, decentralized water treatment

technologies that are sustainable, socially adaptable and acceptable.

Ceramic water filtration, particularly point-of-use (POU) systems made from porous clay, has gained recognition as a viable and affordable method for improving water quality in underserved communities (Brown and Sobsey, 2006; Mwabi *et al*., 2011). These filters operate via mechanical straining and adsorptive mechanisms, effectively removing turbidity, pathogens, and some chemical contaminants (Lantagne, 2001; Van Halem, 2006). Water treatment through the combine use of ceramic filter, activated char and magnetic treatment has been found to reduce heavy metal concentration in water (Yusuf and Murtala, 2020). A key design element in ceramic filter development is the manipulation of porosity, typically achieved by incorporating burnout materials such as organic additives that combust during firing, creating microchannels through which water passes (Franz, 2005; Themba *et al*., 2012).

Among such burnout agents, sawdust has emerged as a promising alternate due to its high availability, combustibility, and pore-forming capacity (Rominiyi*et al*., 2017; Udokpoh and Nnaji, 2023). Nigeria's wood-processing industry, particularly in the southwestern States, generates an estimated 1.8 million tonnes of sawdust annually, much of which is discarded via environmentally harmful open burning (Ogunwusi, 2014; Okedere *et al*., 2017; Oyedepo *et al*., 2019). Repurposing this biomass waste for ceramic filter production presents an opportunity for integrated waste valorization and water sanitation, addressing both environmental and public health concerns.

Previous studies have shown that the inclusion of organic burnout materials such as rice husk, sawdust, and straw can significantly influence filter porosity and hydraulic conductivity (Rayner *et al*., 2013; Van der Laan *et al*., 2014; Bulta and Micheal, 2019**).** However, there is need to understand and further explore the precise relationship between sawdust-to-clay ratios and the interplay between filtration volume, water purification efficiency, and structural durability of ceramic filters to determine most suitable filter that can be produced and adopted for household water purification.

This study addressed this gap by systematically evaluating ceramic water filters fabricated using three different sawdust-to-clay volumetric ratios with locally sourced kaolinite clay. The objectives are to determine the effect of sawdust variation on filtrate volume, to assess microbial and physicochemical water purification performance, and to evaluate structural durability through water absorption testing. The research applies Nigerian Industrial Standards (NIS) benchmarks to determine the filters' suitability for household water treatment (NIS, 2015).

By integrating circular economy principles with rural water supply innovation, this work contributes toward the realization of key Sustainable Development Goals—namely, SDG 3 (Good Health and Well-Being), SDG 6 (Clean Water and Sanitation), and SDG 12 (Responsible Consumption and Production). Ultimately, the findings are expected to inform scalable, locally adaptable strategies for producing robust and efficient ceramic filters from agro-industrial waste in resource-constrained settings.

Materials and Methods

Study Location and Material Procurement

The study was conducted in the Department of Agricultural and Biosystems Engineering,

University of Ilorin, Kwara State, Nigeria (latitude 08º28' 59"N to 08º 29' 01"N and longitude 04º 40' 32"E to 04º 40' 39"E), a region with a tropical climate and average annual rainfall of approximately 1300 mm (Ejieji and Adeniran, 2009).Kaolinite clay, the primary ceramic material, was sourced from local pottery producers in Ilorin, while sawdust used as the burnout material was collected from sawmills across the Ilorin metropolis. The selection of kaolinite was based on its plasticity and vitrification properties suitable for filter production, while sawdust was chosen for its combustibility and pore-generating characteristics as described by the Ceramics Manufacturing Working Group (TCMWG, 2011).

Filter Design and Production

To investigate the effect of varying sawdust-to-clay ratios on ceramic filter performance, three grades of ceramic filter samples with three replicates for each grade was fabricated with different sawdust-clay mixing proportions by volume: Sample A: 60% clay:40% sawdust, Sample B: 50% clay:50% sawdust and Sample C: 40% clay:60% sawdust.

Both materials were air-dried and sieved through a 70-mesh (210 µm) screen to ensure uniform particle size. The sieved clay and sawdust were dry-mixed before water was gradually added to form a plastic moldable mass (figure 1). Each mixture was then shaped into a cylindrical filter using a manually operated press mold. The formed filters were left to dry at ambient temperature for several days to minimize cracking (figure2). Once fully dried, filters were fired in a kiln at temperatures ranging between 520°C and 950°C for five hours to allow burnout of the sawdust and sintering of the clay, thus forming the porous ceramic matrix as seen in figure3.



Figure 1: Varying Dry and Wet Mix of Sawdust-Clay for Ceramic Mold.



Figure 2: Drying Stage of Formed Ceramic Filter

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Figure 3: Produced Ceramic Filters with Varying Sawdust-to-Clay Ratios.

Evaluation of Filtration Performance

To assess the filtration volume, each filter sample was mounted on a standardized 5-liter container (figure 4) and assessed for volume of water filtered in liters per hour. The volume of water filtered was recorded at hourly intervals. The three replicates of each filter type were tested to ensure statistical reliability.

Water Quality Assessment

The performance of the filters in improving water quality was evaluated using well water samples obtained from three locations within Ilorin: Sango, Maraba, and Kulende. Raw and filtered water samples were analyzed in the laboratory of the Lower Niger River Basin Authority, Ilorin, according to Nigerian Industrial Standard (2015) guidelines. The parameters measured included: Physical (pH, turbidity, total dissolved solids (TDS), temperature, color, odor) and Bacteriological [*Escherichia coli* (cfu/100 mL), total coliform count (cfu/mL)]. The percentage reduction in contaminants and turbidity was compared to evaluate purification efficiency.

Water Absorption Test for Structural Integrity

To evaluate the structural integrity of the ceramic filters, water absorption capacity (WA%) were determined in accordance with the American Society for Testing and Materials (ASTM C373-18, 2018) standard method. Filters were first oven-dried at 100–150°C for 24 hours and weighed after oven drying (Wi), then immersed in water for another 24 hours and weighed again (W_f). Water absorption was calculated using the formula:

$$WA\ (\%) = \frac{(Wf - Wi)}{Wi} \times 100 \qquad \ldots\ldots\ldots\ldots (1)$$

Where: W_f = Wet weight of filter immersed in water.

Wi = Dry weight of ceramic filter after oven drying.

A WA% below 7% was considered acceptable, indicating good mechanical strength and low porosity saturation, based on ceramic filter production guidelines (TCMWG, 2011;ASTM C373-18, 2018).

Statistical Analysis

All experimental data were analyzed to evaluate the effects of varying sawdust-to-clay ratios on key performance metrics of the ceramic filters which includes: filtration rate, microbial and physical water quality improvement, and structural integrity. A one-way Analysis of Variance (ANOVA) was applied to test the null hypothesis that mean

values of each performance metric (for instance, filtration volume, turbidity reduction, total coliform reduction, and water absorption percentage) were equal across the three ceramic filter groups (Sample A, B, and C). The significance level was set at a = 0.05. Where the ANOVA indicated significant differences among group means, Tukey's Honestly Significant Difference (HSD) post-hoc test was employed to identify specific pairwise differences.

Results

Filtration Efficiency and Volume Output

The results of volume of water filtered in liters per hour (L/H) in nine observationswith the ceramic filters of varying contents of sawdust-clay ratios as seen in figure 4 are presented in Table 1.

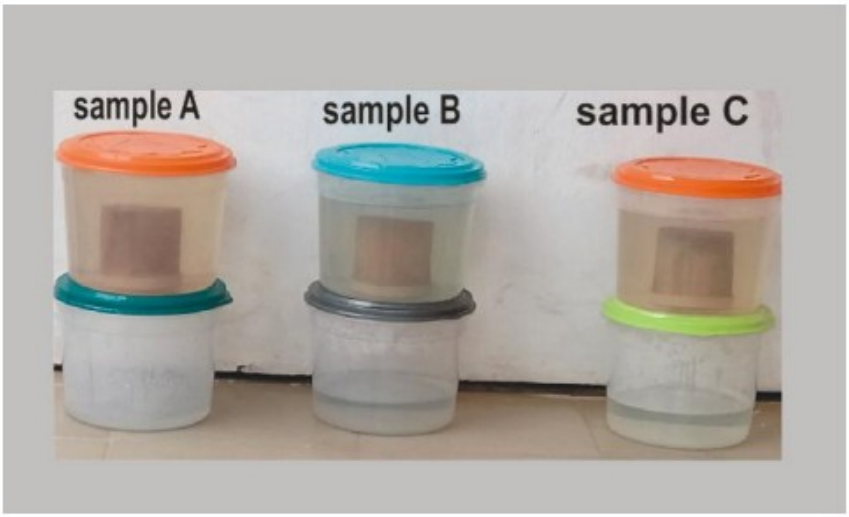


Figure 4: Ceramic Filters Time Test for Volume of Water Filtered

Table 1: Volume of water filtered in Liters/Hour

No of Runs	**Filter A** (l/h)	**Filter B** (l/h)	**Filter C** (l/h)
1	0.370	0.430	0.469
2	0.368	0.431	0.465
3	0.366	0.432	0.462
4	0.368	0.425	0.465
5	0.361	0.428	0.464
6	0.364	0.430	0.461
7	0.364	0.423	0.462
8	0.358	0.425	0.464
9	0.363	0.425	0.458
Total	3.282	3.849	4.170
Mean	0.365 ± 0.004	0.428 ± 0.003	0.463 ± 0.003

Filter A = (Clay–sawdust: 60–40%), Filter B = (Clay–sawdust: 50–50%), Filter C = (Clay–sawdust: 40–60%).

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The filtration performance of the three ceramic filter samples varied significantly with the sawdust-to-clay ratios for nine observations or runs. As shown in Table 1, Filter C (60% sawdust) yielded the highest average filtration rate of 0.463 ± 0.003 L/h, followed by Filter B (50% sawdust) at 0.428 ± 0.003 L/h, and Filter A (40% sawdust) with the lowest average of 0.365 ± 0.004 L/h. Increased sawdust proportion enhanced porosity due to greater burnout during firing, resulting in higher flow rates.

A one-way ANOVA result in Table 2 confirmed that the differences in flow rates were statistically significant ($F(2,24) = 121.0$, $p < 0.001$), indicating that sawdust content is a critical factor in hydraulic performance. Post-hoc Tukey's HSD test revealed significant differences between all filter types ($p < 0.05$), affirming that each increase in sawdust content yielded measurable improvement in flow rate without overlapping performance confidence intervals.

Table 2: ANOVA for Effect of Varying Percentage Content of Sawdust Volume of Water Filtered

SV	DF	SS	MSS	F-Statistic	P - Value
Treatment	2	4.356	2.178	121^{S}	5.570
Error	24	0.423	0.018		
Total	26	4.779	0.184		

S = Effect of varying the percentage content of sawdust in the ceramic filter was statistically significant at P = 1%

Microbial and Physical Water Quality Improvements

Water quality assessments using well water samples showed that all filters successfully reduced microbial and physical contaminants to meet the Nigerian Industrial Standards for potable water (table 3). Notably, all three filters achieved 100% removal of *Escherichia coli* (E. coli) and a >93% reduction in total coliforms.

Table 3: Test Results for Ceramic Filter Samples

s/n	Parameters	Raw Water sample	Filter A	Filter B	Filter C	NIS permissible levels
1	Temperature	27.6	27	27	27	Ambient
2	Turbidity	11.59	3.9	3.8	3.9	5.0
3	Total dissolved solid (mg/l)	213	194	196	197	500
4	Odour	Odourless	Odourless	Odourless	Odourless	Unobjectionable
5	Colour	2.90	2.08	2.07	2.08	15
6	E.coli (cfu/100ml)	1.00	0.00	0.00	0.00	0.00
7	Total coliform count (cfu/ml)	119	7.0	7.1	7.1	10

Table 4 and table 5 are results for descriptive statistic and analysis of variance for percentage reduction for the quality of water filtered in three replicates of each ceramic

samples A, B, and C. Thus, revealing significant effects on Turbidity (NTU) and Total Coliform Count (cfu/mg), from the well water sources.

Table 4: Descriptive statistics for percentage reduction in turbidity and total coliform count

Sample	Clay: Sawdust Ratio	Turbidity Reduction (%)			Total Coliform Reduction (%)		
		Mean	SD	CV (%)	Mean	SD	CV (%)
A	60:40	70.74	0.0015	0.02	93.90	0.016	0.02
B	50:50	70.67	0.021	0.03	93.81	0.006	0.01
C	40:60	70.30	0.061	0.09	93.85	0.010	0.01

Means are calculated from three well water source (three runs each, n=9 per filter).

Table 5: ANOVA for percentage reduction in turbidity and total coliform count

Parameter	**SV**	**DF**	**SS**	**MSS**	**F-statistics**	**p-value**
Turbidity reduction	Treatments	2	0.239	0.1197	85.668	<0.001
	Error	6	0.00838	0.001397		
	Total	8	0.24778			
Total coliform reduction	Treatments	2	0.0081	0.00405	92.74	<0.001
	Error	6	0.000262	0.00004367		
	Total	8	0.008362			

The ANOVA tests the null hypothesis that mean percent reduction are equal across filter types (A, B, C). A p-value<0.001 indicates significant differences among group means. Post-hoc Tukey's HSD test revealed significant differences for turbidity (A vs. C, B vs. C) and coliform (A vs. B).

Turbidity reductions were also significant across filters, with Filter A slightly outperforming others at 70.74%, followed by Filter B (70.67%) and Filter C (70.30%). ANOVA for turbidity reduction yielded $F(2,6) = 85.67$, $p < 0.001$, while for coliform reduction, $F(2,6) = 92.74$, $p < 0.001$, confirming significant differences among filters. Although the differences were numerically modest, Tukey's test indicated that Filter A significantly outperformed Filter C in turbidity removal, and Filter A also outperformed Filter B in coliform reduction.

Structural Integrity Via Water Absorption Test

The structural durability means of each ceramic filtersamples with three replicates was analyzedthrough the water absorption percentage (WA%) are presented in table 6 and while ANOVA is presented in table 7.

Table 6: Descriptive Statistic for Water Absorption Percentage (WA%) Of Ceramic Filter Samples

Sample	Clay: Sawdust Ratio	Mean WA%	Standard Deviation (SD)	Coefficient of variation (CV%)
A	60:40	3.51	0.380	10.83
B	50:50	4.89	0.214	4.38
C	40:60	5.27	0.442	8.38

Mean WA% and SD are calculated from three replicates per sample. CV is expressed as a percentage (SD/Mean x100).

Table 7: One Way ANOVA Results for Water Absorption Percentage (WA%) Across Ceramic Filter Samples

SV	DF	SS	MSS	F- Statistic	P-value
Treatments	2	5.16	2.58	20.05	0.002
Error	6	0.77	0.13		
Total	8	5.93			

Note: the ANOVA tests the null hypothesis that mean WA% is equal across sample (A, B, C). A p-value < 0.05 indicates significant difference among group means. Post-hoc Tukey's HSD test revealed significant difference between sample A and Samples B and C ($p<0.05$) but no significant difference between Sample B and C ($p > 0.05$)

Table 8: **Ceramic Filters samples Water Absorption Percentage**

Sample	Water Absorption (%)	Limit	Interpretation
Sample A	3.51%	<5–7%	Excellent strength, low porosity
Sample B	4.88%	<5–7%	Acceptable structural integrity
Sample C	5.27%	<5–7%	Slightly higher absorption but within acceptable limits

Water absorption percentage (WA%) was used as a proxy for porosity saturation and mechanical integrity. As shown in Table 8, Filter A had the lowest WA% (3.51%), indicating the greatest structural density, while Filters B and C recorded values of 4.89% and 5.27%, respectively

Statistical analysis confirmed a significant difference in WA% across the filters ($F(2,6) = 20.05$, $p = 0.002$). Post-hoc Tukey's HSD analysis showed that Filter A had significantly lower WA% than both Filters B and C ($p < 0.05$), though no significant difference was found between Filters B and C ($p > 0.05$). This suggests that higher clay content enhances strength but slightly reduces flow efficiency due to reduced porosity.

Trade-off between Performance and Durability

From table 9 it can be deduced that, while Filter C demonstrated superior filtration volume, Filter A provided marginally better microbial retention and mechanical durability. However, the relatively low variability (coefficient of variation, CV) in Filter B's performance suggests it may represent the best balance between throughput, pathogen removal, and structural resilience. These findings support a nuanced design decision: choosing between flow rate and structural or

microbial optimization based on user priorities and environmental conditions.

Table 9: Interpretation of Key Results

Metric	Filter A (60:40)	Filter B (50:50)	Filter C (40:60)
Filtration Rate (L/h)	0.365 ± 0.004	0.428 ± 0.003	0.463 ± 0.003
***E. coli* Removal (%)**	100	100	100
Total Coliform Reduction (%)	93.90	93.81	93.85
Turbidity Reduction (%)	70.74	70.67	70.30
Water Absorption (%)	3.51	4.89	5.27

Discussion

This study evaluated the influence of varying sawdust-to-clay ratios on the performance of ceramic water filters in terms of filtration rate, microbial and physical contaminant removal, and structural durability. The results strongly suggested that modifying the sawdust content directly affects filter porosity, which in turn impacts both filtration efficiency and mechanical properties.

Impact of Sawdust Ratio on Filtration Volume

The observed increase in filtration rate with higher sawdust content confirms previous assertions that organic burnout materials enhance the permeability of ceramic filters by creating more extensive pore networks during firing (Franz, 2005; Van Halem, 2006). The 60% sawdust filter (Sample C) achieved the highest mean flow rate of 0.463 L/h, outperforming both Sample B (50%) and Sample A (40%), indicating a positive correlation between sawdust content and hydraulic conductivity.

This behavior is consistent with the findings of Rayner *et al*. (2013), who highlighted that increased pore connectivity results in higher volumetric throughput. However, while greater porosity improves flow, it may also compromise other performance aspects such as microbial retention and mechanical stability (Lantagne, 2001). Therefore, optimization must account for a balance between permeability and other operational parameters.

Microbial and Physical Contaminant Removal

All three filter compositions achieved complete removal of *Escherichia coli* and over 93% reduction in total coliforms. This confirms that the pore structures, despite variations in clay content, remained fine enough (typically 0.2–10 µm) to physically retain microbial pathogens (Brown and Sobsey, 2006; Mwabi *et al*., 2011). The consistency in microbial elimination across all filter types underscores the suitability of kaolinite clay as a base material, even when highly modified with sawdust.

Interestingly, although Sample C had the highest porosity and flow rate, Sample A demonstrated slightly higher turbidity and coliform removal efficiency. This supports the assertion by Lantagne, (2001) that smaller pores, formed in filters with higher clay content, enhance contaminant retention through size exclusion and longer contact time.

These findings are in line with those of Van der Laan *et al*., (2014) and Bulta and Micheal, (2019) who observed that although higher porosity filters allow greater flow, they often exhibit higher variability in microbial removal. This trade-off underscores the need for performance tuning in ceramic filter

design, particularly in decentralized and resource-limited settings.

The reduction in turbidity (>70%) is also important, as turbidity serves as a proxy for both microbial load and aesthetic quality (Sobsey*et al*., 2008). While filters did not significantly reduce total dissolved solids (TDS), such results are expected since ceramic filters are primarily designed for physical and microbial removal rather than ionic or dissolved chemical filtration (Clasen and Boisson, 2006). For enhanced chemical removal, complementary technologies such as addition of activated carbon in to filtering component were found to be effective in reducing chemical contaminants of water (Yusuf and Murtala, 2020).

Structural Integrity and Mechanical Suitability

Structural testing via water absorption percentage (WA%) revealed all filters remained within the acceptable range of <7%, indicating their mechanical viability for regular use. Filter A, with the highest clay content, exhibited the lowest WA% (3.51%), suggesting greater material density and mechanical resilience. These findings corroborated with the guidelines by The Ceramics Manufacturing Working Group (TCWMG, 2011) and American Society for Testing and Materials (ASTM C373-18, 2018), which considered low WA% a proxy for high structural strength.

Statistical analyses showed that WA% varied significantly across filter types ($p = 0.002$), with Filter A having significantly better mechanical integrity than B and C. However, Filters B and C still fell within structurally safe limits, demonstrating that moderate increases in sawdust do not compromise filter strength beyond functional thresholds.

These results also reflect Rominiyi *et al*., (2017) who noted that sustainable materials like sawdust can be safely incorporated into engineered products when appropriate formulation and processing controls are applied. The relatively low coefficient of variation (CV) in Filter B's structural and microbial performance further suggests it offers a balanced trade-off reasonably high flow, consistent microbial retention, and acceptable mechanical durability.

Practical and Sustainability Implications

The reuse of wood waste (sawdust) as burnout material for ceramic filter production and the quality of water filtered meeting the NIS standard, the broader significance of this research lies in its implications for circular economy and sustainable development. With an estimated 1.8 million tonnes of sawdust generated annually in Nigeria (Oyedepo *et al*., 2019), its reuse addresses two critical environmental issues: Waste Valorization—open burning of sawdust contributes to air pollution (Okedere *et al*., 2017)and Clean Water Access—inadequate drinking water remains a pressing public health issue (WHO/UNICEF, 2006 and Clasen *et al*., 2007).

TheWA% <7% of the produced ceramic indicating their mechanical viability aligns with Sustainable Development Goals (SDGs 3, 6, and 12), offering a low-cost, locally adaptable solution to improve household water security while minimizing environmental degradation. The decentralized nature of the proposed filters makes them especially appropriate for rural and semi-urban communities, where centralized water treatment infrastructure is often absent or underperforming.

This study reinforced the potential of augmenting ceramic filters with secondary treatment components, such as activated carbon or magnetic media to expand their effectiveness beyond microbial and physical contaminants to chemical purification (Yusuf and Murtala 2020).

Conclusion

This study demonstrated that varying sawdust-to-clay ratios significantly influence the filtration efficiency, microbial purification, and structural durability of household ceramic filters. Filters with higher sawdust content (notably 60%) exhibited superior filtration rates due to increased porosity, while all filter compositions achieved complete *E. coli* removal and over 93% reduction in total coliforms, in compliance with national water quality standards. Although filters with higher clay content showed slightly better microbial and turbidity removal performance, all designs remained within acceptable structural limits, confirming their suitability for decentralized water treatment. These findings validate the controlled use of sawdust as a sustainable burnout material for enhancing the performance of ceramic water filters in resource-limited settings.

Recommendations

Based on these findings, it is recommended that the 60:40 sawdust-to-clay ratio can be adopted for optimizing flow rate without compromising microbial removal or structural integrity, making it ideal for household-level water purification. To promote broader adoption, stakeholders such as governmental agencies, NGOs, and rural development organizations should invest in localized capacity-building programs to train artisans and small-scale producers in fabricating these filters using accessible raw materials.

Integrating this technology into national water access and public health strategies would enhance decentralized water treatment efforts, especially in underserved and off-grid communities. The transformation of sawdust into a valuable filtration medium not only addresses critical public health needs but also aligns with sustainable development objectives by reducing environmental pollution and promoting resource circularity.

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