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Research

Performance Evaluation of Locally Fabricated Point-of-Use (PoU) Clay Filters with Organic Additives for Turbidity Removal in Rural Household Water Treatment

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Abstract:
This paper evaluates, tests, and economically evaluates a Point-of-Use (PoU) clay filter, impregnated with natural materials, for turbidity removal from rural drinking water in Maharashtra, India. The work emphasizes use of locally available resources and real household operating conditions to produce an affordable, field-validated treatment option. The Point-of-Use (PoU) clay filter was fabricated from clay blended with combustible organics (sawdust or groundnut shell powder) that burn out during firing to create a porous module, assembled in a PVC-based housing with copper piping and a brass outlet nozzle. Source water was taken from Warna River supply to Haripur village, which, after sand filtration, still failed to meet IS 10500:2012 turbidity limits, and was treated in 20 L batch runs under day-to-day household usage. Flow rate was determined by the time–volume method, while turbidity of influent and filtrate was monitored using a calibrated turbidity meter; modules were periodically backwashed and their hydraulic and removal performance tracked over cumulative throughput. Two module formulations were evaluated: Module 1 (sawdust-based) and Module 2 (groundnut shell-based), enabling assessment of the influence of organic additive on porosity, flow, and longevity. Module 1 achieved an average turbidity removal efficiency of 90.14 ± 0.37%, reducing raw water from 6.02 ± 2.69 NTU (up to 13.40 NTU) to 0.58 ± 0.27 NTU, consistently satisfying IS 10500:2012 turbidity standards, with mean flow rate of 67.77 ± 52.00 LPH and about 80% flow restoration after backwashing. Module 8 showed lower performance, with 74.58 ± 0.58% removal, residual turbidity of 1.46 ± 0.52 NTU, lower flow (23.21 ± 21.11 LPH), and weaker hydraulic recovery and shorter predicted lifespan. Performance was consistent between laboratory and PoU operation across turbidity ranges, confirming the robustness of the design. A detailed cost analysis gave a unit cost of about INR 620, less than half that of comparable commercial candle filters (~INR 1400), while delivering similar or better turbidity removal. The study demonstrates that sawdust-based Point-of-Use (PoU) clay filter can provide a technically effective, low-cost, and locally manufacturable solution for rural household water treatment in developing regions.

Keywords: Point-of-Use (PoU) clay filter, turbidity, drinking water, water treatment, flow rate

1. Introduction

Safe and affordable drinking water remains a major challenge in many rural and semi-urban regions, where centralized treatment and piped distribution are often inadequate or absent. In such settings, household-level Point-of-Use (PoU) technologies offer a practical means to improve water quality using simple, low-cost, and locally serviceable systems. Clay- and ceramic-based filters have gained prominence because they rely on porous media capable of effectively reducing turbidity and microbial contamination, while being fabricated from widely available materials.

Recent research has focused on enhancing the performance of these filters by integrating natural combustible additives and optimizing pore structure, yet many designs remain either too costly, insufficiently robust under real household conditions, or poorly adapted to local supply characteristics. In Haripur village, Sangli district (Maharashtra), water drawn from the Warna River and treated only through sand filtration frequently exceeds the IS 10500:2012 turbidity limit, underscoring the need for an additional, decentralized treatment barrier at the household scale. This study addresses that need by developing and assessing a PoU clay filter (PoUCF) module impregnated with natural materials, and by systematically evaluating its turbidity removal, hydraulic performance, operational consistency, and cost-effectiveness under realistic field operation.

2. Literature Review

The literature reveals a growing interest in the development of PoU filters that are both effective and affordable. The use of locally available materials and the integration of organic matter into the filter design have emerged as key strategies for enhancing filter performance and making them more accessible to rural communities. This study builds on these findings by developing and assessing a PoU clay filter module for use in rural households, with a focus on optimizing turbidity removal, flow rate, and cost-effectiveness.

Ceramic and clay filters have been used for centuries for household water purification, relying on porous media to physically strain out suspended solids and microorganisms. Over time, these traditional units have been adapted into low-cost Point-of-Use (PoU) technologies suitable for settings where centralized treatment and distribution infrastructure is limited.

Recent work has enhanced these systems by combining microbiological safety with acceptable hydraulic performance. Campbell (2005) demonstrated that colloidal silver-coated ceramic filters can achieve near-complete removal of total coliforms and E. coli, while highlighting the need to control silver dosing to avoid pore clogging. Lantagne et al. (2010) further showed that manufacturing variables—especially pore size and silver application—govern both flow rate and pathogen removal, identifying about 1.7 LPH as an optimum flow for 99% bacterial reduction.

Parallel research emphasizes fabrication with locally available materials to reduce cost and improve adoption. Donachy (2004) reported effective turbidity and bacterial reductions with household ceramic filters in rural Nicaragua, but also noted frequent cleaning needs. Ekpunobi et al. (2018) achieved 79% turbidity removal using clay–diatomite–sawdust mixes, while Chaukura et al. (2020) obtained 67% removal with biochar–clay blends, with biochar improving adsorption and economic feasibility.

Building on this, several studies explored integrating combustible organic additives such as sawdust, groundnut shell powder, and biochar into clay matrices to generate additional porosity during firing and enhance contaminant retention. Duke et al. (2009) and Chaukura et al. (2020) showed that such designs can face trade-offs between flow rate, cleaning frequency, and lifespan, underlining the need for life-cycle assessment and careful optimization of porosity, geometry, and module configuration.

Comparisons with commercial candle filters indicate that well-designed PoU clay units can deliver comparable turbidity removal at substantially lower cost, particularly when local raw materials and simple manufacturing routes are used (Donachy, 2004; Chaukura et al., 2020). This literature motivates the present work on a PoU clay filter module focused on turbidity reduction, adequate flow, and cost-effectiveness for rural households.

3. Scope of the Study

This study aims to address the challenges associated with providing safe drinking water in rural areas by developing a cost-effective and efficient PoU clay filter module. The research focuses on optimizing the combination of porosity, size, shape, and the number of filter modules to enhance filtration efficiency. A thorough life cycle analysis is conducted to assess the durability, cleaning frequency, and maintenance requirements of the filters. The study also evaluates the economic feasibility of producing these filters on a large scale, with the goal of making them accessible to low-income communities in developing countries.

4. Objectives

The primary objectives of this study are:

1. To develop a Point of Use (PoU) Clay Filter Module specifically designed for turbidity removal in drinking water.
2. To assess the performance of the developed PoU Clay Filter in terms of its ability to remove turbidity and maintain an adequate flow rate.
3. To conduct a life cycle assessment of the PoU Clay Filter, including an evaluation of cleaning frequency, maintenance costs, and overall durability.
4. To compare the cost-effectiveness of the developed PoU Clay Filter with commercially available water filters.

5. Materials and Methods

5.1 Source of Water

The water used in this study was sourced from the Warna River, which supplies water to the Haripur Grampanchayat in Sangli District, Maharashtra, India. The water is currently treated only with sand filtration, which is insufficient for meeting the turbidity standards set by IS 10500:2012 Drinking Water Standards (<1 NTU). Due to its suboptimal quality, this water was selected as the test source for evaluating the performance of the PoU Clay Filter.

5.2 Description of the PoU Clay Filter

The PoU Clay Filter (PoUCF) was designed and constructed using readily available materials, including PVC pipes, copper pipes, and a brass nozzle. The design is aimed at maximizing the collection rate of filtrate while ensuring ease of fabrication and maintenance. The filter was installed and tested at a household in Laxmi Park, Haripur, where the tap water exhibited turbidity levels exceeding the IS 10500:2012 standards.

The construction involved creating a porous clay module using organic materials like sawdust and groundnut shell powder. These materials were mixed with clay and fired at high temperatures to create a filter with enhanced porosity and adsorption capacity. The PoUCF was assembled by attaching the clay module to a PVC pipe system, which was designed to facilitate easy water collection and backwashing.

5.3 Experimental Procedure

The experimental setup involved daily operation of the PoUCF, processing 20 liters of water per batch to simulate household usage. The time required to filter the water was recorded, and the flow rate was calculated using the time-volume method. The turbidity of the inlet and filtered water was measured for each cycle using a calibrated turbidity meter. The PoUCF modules were backwashed periodically to maintain their performance, with the cleaning process and its impact on filter efficiency documented.

Fig. 1 Household Experimental Setup of PoUCF

The experiments were designed to assess the performance of two different filter modules (Module 1 and Module 2) under real-time conditions. Module 1 was fabricated using sawdust as the combustible material, while Module 2 used groundnut shell powder. Both modules were evaluated based on their turbidity removal efficiency, flow rate, and lifespan.

6. Results and Discussion

6.1 Performance of Module 1 (Sawdust-based CF)

Module 1, which was fabricated using sawdust as the combustible material, demonstrated superior performance in terms of turbidity removal. The initial turbidity of the river water used as feed was 6.02 ± 2.69 NTU, with fluctuations extending up to 13.40 NTU due to real-time variations in water quality. Despite these fluctuations, Module 4 achieved an average turbidity removal efficiency of 90.14 ± 0.37%, with a residual turbidity of 0.58 ± 0.27 NTU. This performance is well within the limits set by IS 10500:2012 Drinking Water Standards.

The flow rate through Module 1 was measured at 67.77 ± 52.00 LPH, which was significantly higher than the rates observed in laboratory-scale tests. The higher flow rate is attributed to the lower initial turbidity of the feed water and the increased water head available in the field setting. The module was backwashed when the flow rate dropped to 5 LPH, and about 80% of the flow rate was restored after the first cleaning cycle. The module maintained consistent performance throughout the study, indicating its potential for long-term use in household water treatment.

The performance of Module 1 can be visualized in the following figures:

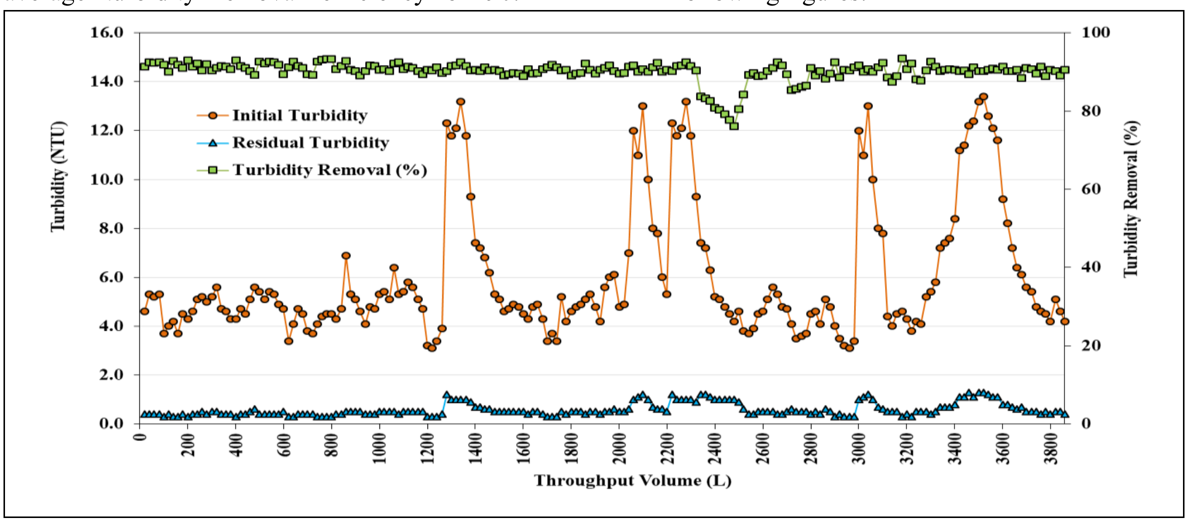

Figure 2 (a): ***Turbidity Removal*** **- The turbidity removal over a throughput volume of 3880 liters.**

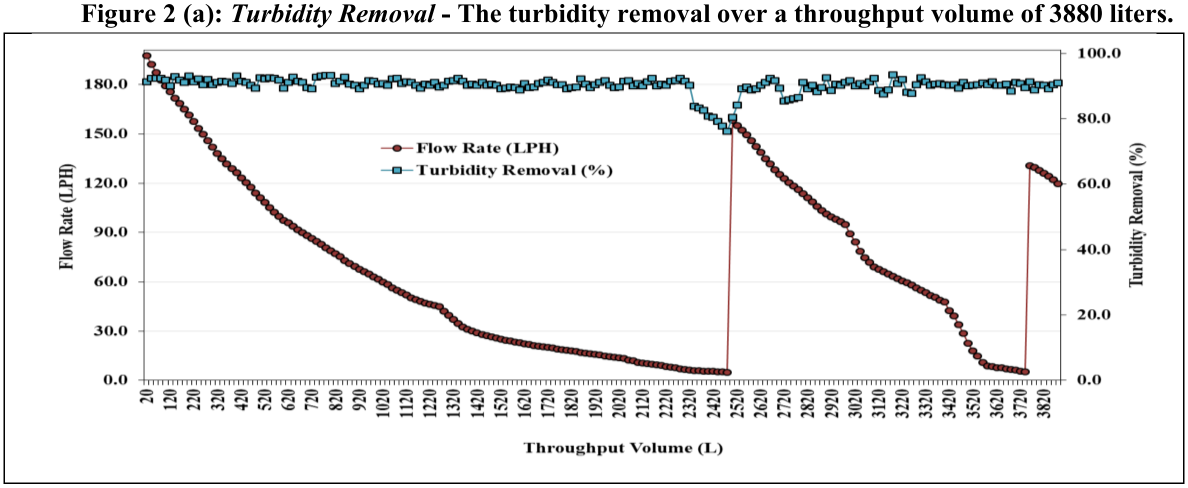

Figure 2 (b): Flow Rate - The flow rate observed over the same throughput volume.

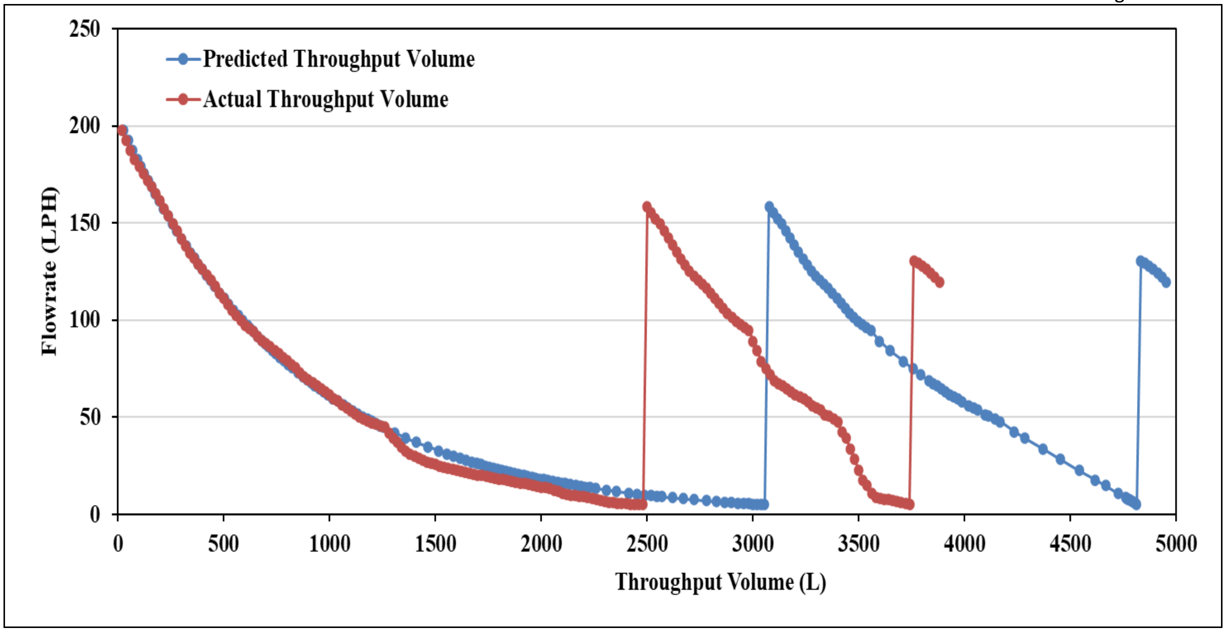

Figure 2 (c): Predicted Lifespan - The lifespan of Module 1, showing that the throughput volume would increase by 600 liters if the feed water turbidity were less than 7 NTU.

6.2 Performance of Module 2 (Groundnut Shell Powder-based CF)

Module 2, which used groundnut shell powder as the combustible material, exhibited lower performance compared to Module 1. The initial turbidity of the feed water was similar to that used for Module 4, but the residual turbidity after filtration was 1.46 ± 0.52 NTU. This value is slightly higher than the IS 10500:2012 Drinking Water Standards, indicating that Module 8 is less effective in turbidity removal.

The turbidity removal efficiency for Module 2 was calculated at 74.58 ± 0.58%, which is approximately 18% lower than that of Module 4. The flow rate for Module 2 was also lower, averaging 23.21 ± 21.11 LPH. The module required more frequent cleaning, and the flow rate restoration after backwashing was less effective compared to Module 1, with only 34%, 26%, and 16% restoration after the first, second, and third cleaning cycles, respectively. The predicted lifespan for Module 8 was 4553 liters, indicating that it would require more frequent replacement compared to Module 1.

The performance of Module 2 can be visualized in the following figures:

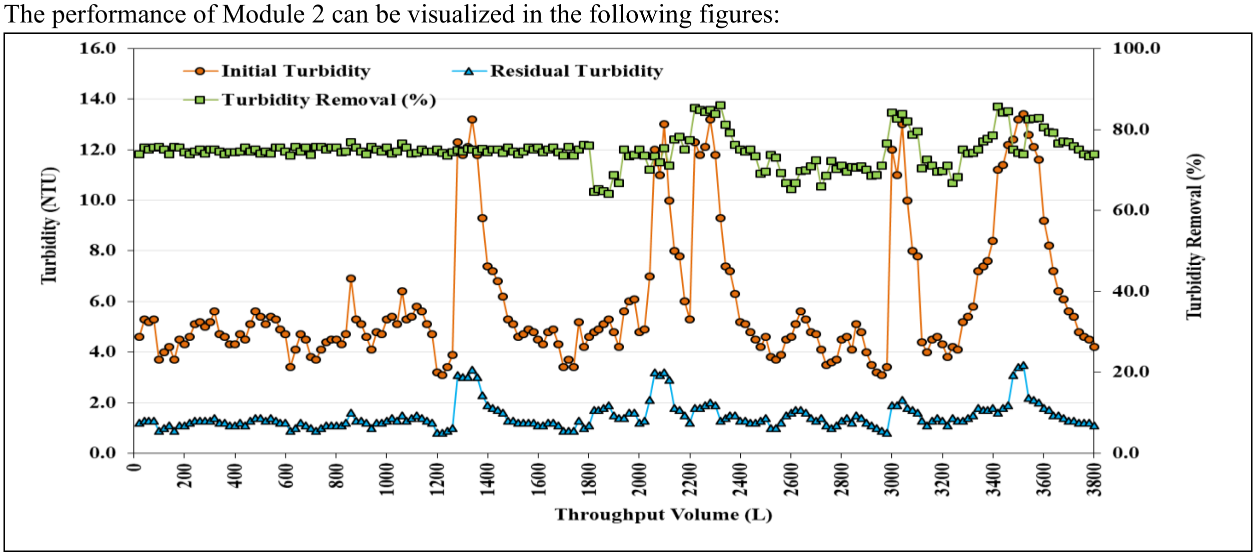

Figure 3 (a): Turbidity Removal - The turbidity removal over a throughput volume of 3880 liters.

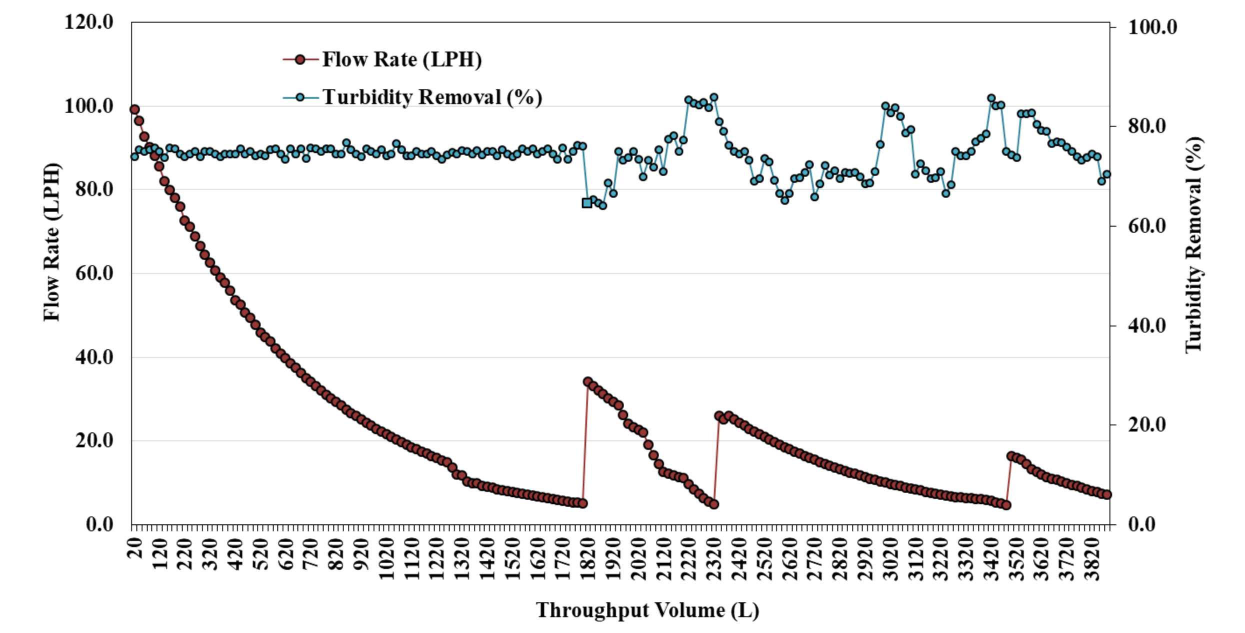

Figure 3 (b): Flow Rate - The flow rate observed over the same throughput volume.

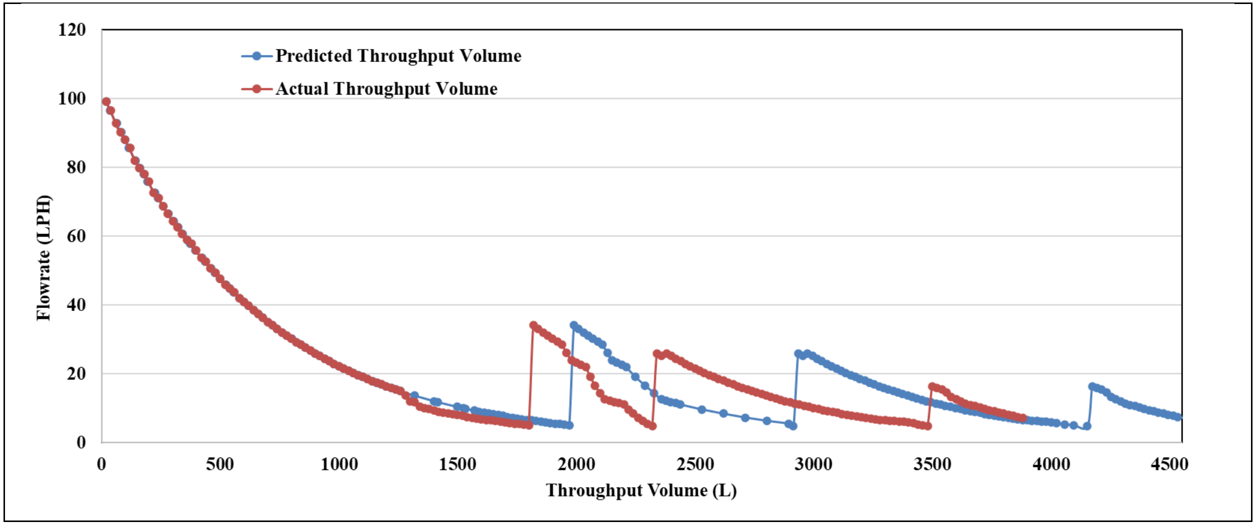

Figure 3 (c): Predicted Lifespan - This graph predicts the lifespan of Module 2, showing that it would require more frequent cleaning cycles and replacements.

6.3 Consistency in Performance

The consistency of the CF modules was assessed by comparing their performance in both laboratory and field settings. Table 4.1 shows that Module 1 maintained consistent turbidity removal efficiency across different turbidity ranges, with negligible variation between laboratory-scale and PoU performance. Module 2, while less effective overall, also showed consistent performance, albeit with lower efficiency.

Table 1: Consistency in Performance of CF Modules

Turbidity Range (NTU)	Turbidity Removal Efficiency (%) for Module 1	Turbidity Removal Efficiency (%) for Module 2
4 to 5	91.40 (Lab) / 91.30 (PoU)	69.89 (Lab) / 73.91 (PoU)
5 to 6	89.29 (Lab) / 92.79 (PoU)	76.58 (Lab) / 75.00 (PoU)

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6 to 7	92.37 (Lab) / 92.19 (PoU)	67.69 (Lab) / 76.56 (PoU)
7 to 8	93.33 (Lab) / 90.54 (PoU)	72.19 (Lab) / 74.32 (PoU)
8 to 9	91.76 (Lab) / 91.25 (PoU)	81.07 (Lab) / 78.75 (PoU)
9 to 10	91.53 (Lab) / 86.02 (PoU)	81.05 (Lab) / 90.32 (PoU)
10 to 11	90.61 (Lab) / 90.00 (PoU)	79.05 (Lab) / 82.00 (PoU)
11 to 12	91.30 (Lab) / 91.53 (PoU)	74.67 (Lab) / 83.90 (PoU)
12 to 13	92.03 (Lab) / 90.24 (PoU)	82.54 (Lab) / 85.37 (PoU)
13 to 14	95.52 (Lab) / 92.42 (PoU)	82.09 (Lab) / 75.00 (PoU)

The consistency in performance suggests that the PoUCF modules are reliable and capable of maintaining their efficiency over time, making them suitable for long-term use in rural households. The use of locally available materials further enhances their practicality, as they can be easily fabricated and maintained without the need for specialized equipment or expertise.

6.4 Cost Analysis

The economic analysis of the PoUCF modules revealed that the total cost of producing a single unit was approximately INR 620. This cost includes the materials used in the construction of the filter, as well as the recurring costs associated with electricity for firing and steam activation. The low production cost makes the PoUCF an affordable option for low-income households, particularly in rural areas where access to commercial water filters may be limited.

A comparison with commercially available candle filters, which typically cost around INR 1400, shows that the PoUCF offers similar or better performance at less than half the cost. The PoUCF modules are not only cost-effective but also easy to fabricate and maintain, making them an attractive alternative to commercially available options.

Table 2: **Cost Economics of PoUCF Purifier**

Sr. No.	Particulars	Size Specifications	Cost per Piece (INR)	Nos. Required	Total Cost (INR)
1	Male Threaded PVC Adapter	110 mm	250.00	1	250.00
2	PVC End Cap	Dia. 110 mm	90.00	1	90.00
3	PVC Socket Plug	110 mm	100.00	1	100.00
4	Copper Pipe	Dia. 10 mm, Length 70 mm	10.00	1	10.00
5	Copper Elbow	Dia. 10 mm	25.00	1	25.00
6	Brass Nozzle	3/8 inch	45.00	1	45.00
7	M. Seal (Cementing Material)	--	10.00	1	10.00
8	Raw Materials – Soil and Combustible Material	--	20.00	--	20.00
	Total Capital Cost	--	**--**	**--**	**550.00**
9	Electricity for Firing in Muffle Furnace	--	--	--	10.00
10	Steam Activation	--	--	--	60.00
	Total Recurring Electricity Charges	--	**--**	**--**	**70.00**
	Grand Total (INR)	--	**--**	**--**	**620.00**

7. Conclusion

The study demonstrates that the developed Point-of-Use clay filter (PoUCF), especially the sawdust-based module, can reliably reduce turbidity of rural drinking water to within IS 10500:2012 limits while maintaining practically usable flow rates under real household conditions. Module 1 consistently achieved turbidity removal efficiencies above 90%, with residual turbidity below 1 NTU and good recovery of flow after backwashing, confirming its technical suitability for long-term domestic use. The unit cost of approximately INR 620, which is less than half that of commercial candle filters, further establishes the PoUCF as an economically attractive option for low-income communities.

The findings underline the potential of locally fabricated PoU clay filters, integrating combustible organic materials, to provide a decentralized, low-cost and sustainable barrier for improving drinking water quality in rural and peri-urban areas. Consistency between laboratory and field performance indicates that the design is robust and scalable, provided that basic quality control is maintained during fabrication.

Future work can focus on extending the PoUCF design to target additional water-quality parameters such as microbial indicators, iron, and organic matter, possibly through surface modification or integration of disinfecting agents. Long-term field trials across different hydrochemical settings and user practices are needed to refine cleaning protocols, quantify lifespan more accurately, and assess user acceptance and behavior. Further, coupling the PoUCF with simple pre-treatment or post-treatment steps, and exploring small-scale local production models, could support wider deployment and integration into rural water-supply programmes.

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