LOW-COST HOUSEHOLD WATER FILTRATION: EFFICIENCY, LIMITATIONS AND OPTIMIZATION

A performance analysis of DIY multi-layer filtration system

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Abstract: Water contamination causes 3.4 million deaths annually, with 2.2 billion people lacking access to safe drinking water. This research investigates the development and efficacy of a low-cost water filtration system constructed from readily available materials for use in emergency situations and resource-limited environments. The system employs a multi-layer filtration design incorporating activated charcoal, sand, and gravel within a repurposed plastic container, with a total cost under $15 USD. Performance testing with three distinct water samples demonstrated significant improvements in water quality parameters including turbidity reduction (87.6%, 95% CI: 84.2-91.0%), pH normalization (to 7.1-7.4 range), and odor removal. Microbial analysis showed moderate reduction in total coliform counts (68.3%) but insufficient pathogen removal for safe drinking without additional disinfection. Comparative analysis with commercial filters showed the home-built system achieved 76% of the filtration efficiency at approximately 12% of the cost. While effective for improving aesthetic water qualities and removing certain contaminants, limitations include incomplete microbial decontamination, flow rate degradation over time, and partial heavy metal removal. Future development opportunities include integration of disinfection methods, modular design implementation, and incorporation of improved adsorption materials. This system is not intended to replace municipal treatment but provides an immediate, cost-effective improvement in water quality for emergency use and resource-limited areas. This research contributes to the growing body of knowledge on accessible water treatment solutions that can be rapidly deployed in crisis scenarios or implemented in communities with limited infrastructure.

***Index Terms* - Low-cost water filtration, Household water treatment, Turbidity reduction, Activated charcoal filtration, Emergency water treatment, Resource-limited settings**

I.INTRODUCTION

Access to clean drinking water remains a critical global challenge, with approximately 2 billion people lacking consistent access to safely managed drinking water services (WHO, 2023). This issue is exacerbated during natural disasters, humanitarian crises, and in regions with limited infrastructure. While commercial water filtration technologies offer effective solutions, they are often prohibitively expensive or unavailable in resource-constrained settings.

The development of low-cost, locally constructed water filtration systems represents a practical approach to addressing immediate water quality challenges. Such systems can be rapidly deployed during emergencies or implemented as intermediate solutions in developing communities (Thompson et al., 2021). Recent studies have demonstrated the potential of simple filtration systems to significantly improve water quality parameters using locally sourced materials (Garcia-Avila et al., 2020; Palanisamy & Kaliappan, 2021).

This research builds upon previous work by focusing specifically on optimizing a layered filtration design using activated charcoal, sand, and gravel within a repurposed plastic container. Our approach prioritizes:

1. Accessibility of materials and construction methods
2. Cost-effectiveness (target cost under $15 USD)
3. Measurable improvements in key water quality parameters
4. Practical implementations in emergency and resource-limited settings

The research aims to quantify the performance of the proposed filtration system, identify its limitations, and suggest future improvements. By providing detailed construction and performance data, this study contributes to the development of practical water treatment solutions that can be implemented with minimal resources and technical expertise.

II. MATERIALS AND METHODOLOGY

2.1 Materials

The following materials were used in the construction of the water filtration system.

Material	Quantity	Cost (USD)	Local alternatives
5- Gallon plastic bucket with lid	1	3.50	Repurposed food containers, clay pots
Activated charcoal	500g	4.25	Locally produced biochar, carbonized coconut shells
Fine sand	2kg	1.20	River sand (washed and sun-dried)
Coarse sand	2kg	1.20	Crushed and sieved local stone
Small gravel	1kg	0.75	Crushed brick, small pebbles
Large gravel	1kg	0.75	River stones, broken ceramic pieces
Coffee filter	3	0.30	Clean cotton cloth, fine mesh fabric
Cotton cloth	1 sq. foot	0.50	Repurposed cotton clothing
Plastic spigot	1	2.00	Modified bottle cap, bamboo spout (sealed)
Total cost		**14.45**	

All materials were sourced from local hardware stores, garden centres, and household supply shops to ensure accessibility. The activated charcoal used was food-grade quality, commonly sold for water filtration purposes.

2.2 Filter Construction

The filtration system was constructed using the following procedure:

1. A 3/4-inch hole was drilled approximately 2 inches from the bottom of the plastic bucket.
2. The plastic spigot was installed in the drilled hole and sealed with waterproof adhesive.
3. The filtering materials were layered in the following order (from bottom to top):
    a. Layer 1: Large gravel (5 cm depth, lightly compacted by hand)
    b. Layer 2: Small gravel (5 cm depth, lightly compacted by hand)
    c. Layer 3: Coarse sand (7 cm depth, moderately compacted to remove air pockets)
    d. Layer 4: Fine sand (7 cm depth, moderately compacted to remove air pockets)
    e. Layer 5: Activated charcoal (8 cm depth, lightly compacted to ensure even distribution)
    f. Layer 6: Coffee filter covered with cotton cloth (secured with a rubber band around the bucket rim)
4. Each layer was washed thoroughly before placement to remove dust and impurities (minimum 3 rinses until water runs clear).
5. Between each layer, a coffee filter was placed to prevent mixing of the materials.
6. The system was flushed with 10 litres of clean water before testing to remove any residual material particles.

2.3 Water samples

Three distinct water samples were collected for testing:
1. Sample A: Turbid surface water from a local pond (high turbidity, organic matter content)
2. Sample B: Tap water with deliberately added soil and organic debris (moderate turbidity)
3. Sample C: Simulated emergency water from a rain barrel with added sediment (variable turbidity, slightly acidic)

Each sample (5 litres) was filtered through the system, and pre- and post-filtration measurements were recorded. Additionally, control samples of each water type were left standing for the same duration as the filtration process to account for natural settling effects.

2.4 Testing parameters and methods

The following water quality parameters were measured before and after filtration:

Parameter	Method/Equipment	Units	Detection Limit
Turbidity	Portable turbidimeter (HACH 2100Q)	NTU	NTU
pH	Digital pH meter (Apera pH 60)	pH units	pH
Color	Visual comparison with standard color chart	TCU	5 TCU
Odor	Threshold Odor number (TON)	TON	1 TON
Total dissolved solids (TDS)	TDS meter	mg/litre	1 mg/L
Flow rate	Timed volume collection	litre/hour	0.1 L/hour
Lead content	Commercial lead test kit (Water safe)	ppb	5 ppb
Total coliform bacteria	Membrane filtration & m-Endo culture	CFU/100mL	1 CFU/100mL
E.coli	Membrane filtration & m-FC culture	CFU/100mL	1 CFU/100mL |

Each test was conducted in triplicate to ensure reliability, and the mean values were calculated. The system's efficiency was evaluated by calculating the percentage improvement in each parameter.

A power analysis was conducted prior to experimentation using G*Power 3.1 software. Based on previous studies suggesting an expected effect size (Cohen's d) of 1.8 for turbidity reduction, we determined that a minimum of three replicates per water type would provide 90% power to detect significant differences ($\alpha = 0.05$, two-tailed test). This sample size also provided adequate power (>80%) for detecting differences in other parameters with expected moderate to large effect sizes.

2.5 Comparative Analysis

The performance of the home-built system was compared against two commercial water filters:

1. A mid-range commercial gravity filter (price: $85)
2. A basic commercial pitcher filter (price: $23)

Identical water samples were processed through each system, and the same parameters were measured to establish performance benchmarks.

2.6 Longevity and Maintenance Testing

To assess long-term performance, the filtration system was subjected to extended testing over a 60-day period, processing 10 litres of moderately turbid water (similar to Sample B) daily. Key parameters (flow rate, turbidity reduction, and pH) were measured at 10-day intervals.

After observable performance decline (defined as >50% reduction in flow rate or <50% turbidity reduction efficiency), the system was disassembled, cleaned according to a standardized protocol, and reassembled to assess recovery of performance. This cycle was repeated three times to establish maintenance requirements and durability metrics.

2.7 User Experience Assessment

A group of 10 volunteers with no prior filter-building experience was provided with written and pictorial instructions to construct identical filtration systems. The time required for construction, difficulties encountered, and quality of the finished product were recorded. Participants also completed a brief survey rating the ease of construction and maintenance on a 5-point Likert scale.

2.8 Statistical Analysis

Statistical analysis was performed using R version 4.2.1. The following analyses were conducted

1. Calculation of mean, standard deviation, 95% confidence intervals, and coefficient of variation for all measurements
2. Paired t-tests to determine statistical significance of pre- and post-filtration differences
3. ANOVA to compare performance across the three water samples and between the home-built system and commercial filters
4. Cost-effectiveness analysis (performance improvement per dollar spent)

5. Multiple regression analysis to identify key factors affecting filtration efficiency

Statistical significance was established at $p < 0.05$. Effect sizes (Cohen's d) were calculated for all significant findings. One-way ANOVA was conducted to determine whether filtration performance significantly differed across water samples ($p < 0.05$). Paired t-tests compared pre- and post-filtration results for each parameter. Regression modeling was applied to predict long-term flow rate degradation, showing a projected decline of 72% after 15 cycles without maintenance.

III. RESULTS

3.1 Filtration Performance

The filtration system demonstrated significant improvements across multiple water quality parameters, as summarized in Table 1.

Table 1: Mean filtration performance across three water samples

Parameter	Pre-Filtration (Mean ± SD)	Post-Filtration (Mean ± SD)	Control (Mean ± SD)	Improvement (%)	95% CI	p-value	Effect Size (d)
Turbidity (NTU)	86.3 ± 24.7	10.7 ± 3.2	72.1 ± 21.5	87.6	84.2-91.0	<0.001	4.32
pH	6.2 ± 0.8	7.2 ± 0.3	6.3 ± 0.7	N/A (normalized)	7.0-7.4	0.003	1.57
Colour (TCU)	65.7 ± 18.3	12.3 ± 4.1	58.3 ± 15.7	81.3	76.8-85.8	<0.001	3.86
Odor (TON)	4.3 ± 1.2	1.0 ± 0.0	4.0 ± 1.0	76.7	70.3-83.1	<0.001	3.91
TDS (mg/L)	423.3 ± 102.4	312.7 ± 68.2	411.7 ± 98.6	26.1	21.4-30.8	0.022	1.25
Lead (ppb)	12.3 ± 4.2	5.7 ± 2.1	11.7 ± 4.0	53.7	47.2-60.2	0.018	1.93
Total Coliform (CFU/100mL)	1856 ± 423	588 ± 167	1784 ± 401	68.3	62.5-74.1	<0.001	3.89
E.coli (CFU/100mL)	237 ± 86	86 ± 42	226 ± 79	63.7	57.2-70.2	<0.001	2.23

The control samples showed minimal improvement in most parameters over the same time period, confirming that the observed improvements were primarily due to the filtration process rather than natural settling.

3.2 Sample-Specific Performance

The system exhibited varying levels of effectiveness depending on the initial water quality, as detailed in Table 2.

Table 2: Filtration performance by water sample

Sample	Initial Turbidity (NTU)	Final Turbidity (NTU)	Turbidity Reduction (%)	Initial pH	Final pH	Initial TDS (mg/L)	Final TDS (mg/L)	Initial Coliform (CFU/100mL)	Final Coliform (CFU/100mL)
A	112.4	14.2	87.4	5.8	7.1	532	378	2310	742
B	76.8	9.8	87.2	6.3	7.4	386	298	1642	523
C	69.7	8.1	88.4	6.5	7.3	352	262	1616	499

3.3 Flow Rate Analysis

The initial flow rate of the filtration system was 2.8 L/hour. However, a notable decrease in flow rate was observed over time and with continued use. After filtering 20 liters of water, the flow rate decreased to 1.6 L/hour (42.9% reduction).

The long-term flow rate degradation followed a non-linear pattern, with rapid initial decline followed by more gradual reduction, as shown in Figure 3. The regression analysis yielded the following predictive equation for flow rate (FR) as a function of cumulative filtered volume (V): -

$FR = 2.8e^{(-0.023V)}$ ($R^2 = 0.94$)

This equation can be used to predict maintenance intervals based on acceptable minimum flow rates for specific applications.

3.4 Comparative Analysis with Commercial Filter

The performance of the home-built system compared to commercial alternatives is summarized in Table 3.

Table 3: Comparative performance and cost analysis

Filter System	Turbidity Reduction (%)	TDS Reduction (%)	Lead Reduction (%)	Coliform Reduction (%)	Flow Rate (L/hour)	Cost (USD)	Performance/Cost Ratio*
Home-built	87.6	26.1	53.7	68.3	2.8	$14.45	16.3
Commercial Gravity	96.2	42.3	84.5	99.2	3.2	$65.00	5.0
Commercial Pitcher	83.1	18.7	46.2	74.6	4.5	$25.00	8.9

Performance/Cost Ratio calculated as: (Average % reduction across all measured parameters)/Cost

The home-built system demonstrated competitive performance in turbidity reduction compared to both commercial systems. However, it underperformed in lead and microbial reduction compared to the commercial gravity filter. Despite these limitations, the home-built system's significantly lower cost resulted in a superior performance-to-cost ratio.

3.5 Longevity and Maintenance Testing

Long-term performance testing revealed predictable degradation patterns across multiple parameters (Figure 4). After processing approximately 100 liters of water (10 days of testing), turbidity reduction efficiency decreased from 87.6% to 64.2%, while flow rate decreased from 2.8 L/hour to 0.9 L/hour.

Table 4: System performance recovery after maintenance

Maintenance Cycle	Pre-Maintenance Turbidity Reduction (%)	Post-Maintenance Turbidity Reduction (%)	Recovery (%)	Pre-Maintenance Flow Rate (L/hour)	Post-Maintenance Flow Rate (L/hour)	Recovery (%)
1	64.2	83.7	95.5	0.9	2.5	89.3
2	61.8	79.5	90.8	0.8	2.3	82.1
3	58.3	75.2	85.8	0.7	2.1	75.0

System maintenance, involving disassembly, cleaning, and reassembly, successfully restored a significant portion of the original performance, though with diminishing returns over successive maintenance cycles (Table 4). By the third maintenance cycle, performance recovery decreased to 85.8% for turbidity reduction and 75.0% for flow rate.

3.6 User Experience Assessment

The volunteer construction exercise provided valuable insights into the practical aspects of system implementation. The average construction time was 73 minutes (range: 52-98 minutes), with no significant correlation between prior technical experience and completion time.

Table 5: User experience ratings (5-point Likert scale, 5 = very easy)

Aspect	Mean Rating	SD	Range
Clarity of Instructions	4.2	0.6	3-5
Ease of Material Preparation	3.8	0.8	2-5
Difficulty of Assembly	3.9	0.7	3-5

Perceived Maintenance Complexity	3.5	0.9	2-5
Overall Satisfaction	4.3	0.5	4-5

The most commonly reported difficulties were:
1. Securing the spigot without leakage (7/10 participants)
2. Maintaining distinct separation between layers (5/10 participants)
3. Determining appropriate compaction levels (4/10 participants)

These findings informed the development of improved construction guidelines and educational materials for wider implementation.

IV. DISCUSSION

4.1 Water Quality Improvements

The home-built filtration system demonstrated significant improvements in several key water quality parameters, particularly those related to aesthetic properties such as turbidity, color, and odor. The system's ability to reduce turbidity by 87.6% across various water samples is particularly noteworthy and comparable to findings by Rivera-Jaimes et al. (2022), who reported 82-90% turbidity reduction in similar low-cost systems.

The pH normalization effect (bringing pH values close to the neutral 7.0-7.4 range) represents an important benefit, as it reduces the corrosiveness of the water and improves taste. This normalization is likely due to the buffering capacity of the mineral components in the sand and gravel layers, consistent with observations by Ahmed et al. (2021).
The activated charcoal layer proved particularly effective for odor removal, completely eliminating detectable odors in all filtered samples. This aligns with the known adsorption properties of activated carbon for organic compounds that typically cause odors (Zhao et al., 2021).

4.1.1 Microbial Reduction

The system demonstrated moderate effectiveness in reducing microbial contamination, with 68.3% reduction in total coliform bacteria and 63.7% reduction in E. coli. While substantial, these reductions are insufficient to ensure microbiological safety according to WHO drinking water standards, which stipulate the absence of indicator organisms in 100mL samples (WHO, 2023). The observed microbial reduction is primarily attributed to physical filtration mechanisms in the fine sand layer, which can trap bacteria attached to larger particles and within the complex pore structure.

However, the lack of a dedicated disinfection mechanism limits the system's capability to consistently produce microbiologically safe water.
This finding underscores the critical need to combine the filtration system with a supplementary disinfection method (e.g., chlorination, solar disinfection, or boiling) to ensure comprehensive water safety in practical applications.

4.2 Cost-Effectiveness Analysis

At a total construction cost of $14.45, the home-built system achieved approximately 76% of the filtration efficiency of a commercial gravity filter costing $65, resulting in a significantly higher performance-to-cost ratio (16.3 vs. 5.0). This demonstrates the economic advantage of the proposed design for resource-limited settings.

The cost breakdown reveals that activated charcoal represents the most significant expense (29.4% of total cost). Future iterations might explore locally produced biochar as a potential substitute, as suggested by recent studies (Owoade et al., 2022), which could further reduce costs while maintaining adequate performance.

4.2.1 Long-Term Cost Comparison

When considering long-term operational costs, the economic advantages of the home-built system become even more pronounced:

Table 6: Long-term cost comparison over 1,000 liters of filtered water

System	Initial Cost (USD)	Replacement Materials	Replacement Frequency	Cost per 1,000L (USD)
Home-built	$14.45	Activated charcoal, sand	After ~200L	$21.68
Commercial Gravity	$65.00	Filter cartridge	After ~300L	$86.67
Commercial Pitcher	$25.00	Filter cartridge	After ~150L	$66.67

Commercial filters require complete cartridge replacements (average cost: $15 for pitcher filters, $35 for gravity systems) at regular intervals, while the home-built system only requires replacement of the upper filtration media (primarily activated charcoal and fine sand) at an approximate cost of $6.50 per maintenance cycle. Furthermore, the reusable container and hardware components of the home-built system represent a one-time investment, amortized over the system's operational life of approximately 2-3 years with proper maintenance.

This analysis demonstrates that the home-built system maintains its cost advantage throughout its operational life, with a cost per liter approximately 75% lower than commercial alternatives. This factor is particularly significant in resource-limited settings where ongoing operational costs often determine the sustainability of interventions.

4.3 Material Adaptability and Regional Availability

A critical aspect of the system's utility in diverse settings is the adaptability of its design to locally available materials. Table 7 summarizes potential regional substitutions based on material availability assessments in different geographical contexts.

Table 7: Regional material adaptations and their impact on performance

Component	Standard Material	Regional Alternative	Region	Expected Performance Impact
Container	Plastic bucket	Clay pot	South Asia, Africa	↓ Durability, ↑ Cooling, – Filtration
Activated Charcoal	Commercial charcoal	Coconut shell charcoal	Southeast Asia, Pacific	– Filtration, ↓ Cost
Activated Charcoal	Commercial charcoal	Wood biochar	Sub-Saharan Africa	↓ Odor removal, – Filtration, ↓ Cost
Fine Sand	Construction sand	Crushed and sieved quartz	Andean region	↑ Filtration, ↑ Cost
Coarse Media	Gravel	Crushed brick	South Asia	↑ Microbial reduction, ↓ Flow rate
Filter Membrane	Coffee filter	Nylon stocking material	Global	– Performance, ↓ Cost

Key: ↑ = Improvement, ↓ = Reduction, – = Neutral/Minimal change

This adaptability assessment provides implementation guidance for different regional contexts, highlighting the system's versatility while acknowledging potential performance trade-offs when using alternative materials.

4.4 Practical Applications

The system's design and performance characteristics make it particularly suitable for:

1. **Emergency response:** The system can be rapidly constructed during natural disasters or other emergency situations where normal water supply is compromised. The 73-minute average construction time with basic instructions suggests feasibility for emergency deployment.

2. **Transitional settlements:** In refugee camps or temporary settlements, the system could provide an intermediate solution between emergency water supply and permanent infrastructure.

3. **Rural communities:** For communities with limited access to treated water or financial resources, the system offers an affordable improvement to water quality.

4. **Educational purposes:** The transparent design allows visualization of the filtration process, making it valuable for educational demonstrations about water treatment principles.

4.5 Limitations

While this system demonstrates significant improvements in water quality, real-world implementation in resource-limited settings presents challenges. Maintenance requirements, user compliance, and long-term filter effectiveness must be studied further in field conditions.

Several important limitations of the current design were identified:

1. **Microbial contamination:** The system does not provide reliable disinfection against pathogens. While moderately effective at reducing microbial load (68.3% for total coliforms), this reduction is insufficient to guarantee microbiologically safe water without additional treatment.

2. **Flow rate degradation:** The significant reduction in flow rate over time (42.9% after filtering 20 liters) presents a practical limitation for continuous use. This issue, also noted by Singh et al. (2020), is primarily caused by clogging within the fine filtration layers.

3. **Partial heavy metal removal:** While some reduction in lead content was observed (53.7%), this removal is insufficient to guarantee safety in highly contaminated waters. The system's performance for other heavy metals was not tested but is likely similarly limited.

4. **Maintenance requirements:** The need for periodic disassembly and cleaning to maintain performance adds complexity to long-term use, particularly in settings with limited technical capacity.

5. **Durability concerns:** The plastic bucket and spigot may deteriorate over time, especially when exposed to sunlight, potentially leading to leaks or structural failure.

These limitations, while significant, should be viewed as opportunities for future development rather than fundamental flaws in the approach.

4.6 Comparison with Recent Studies

Our findings broadly align with recent research on low-cost filtration systems. Kaur et al. (2022) reported 85-92% turbidity reduction using a similar layered approach, while Oyedotun et al. (2021) achieved pH normalization comparable to our results. However, our system showed better odor removal efficiency than those reported by Zhang et al. (2020), likely due to the thicker activated charcoal layer in our design.

A key distinction of our research is the comprehensive cost-performance analysis, which provides practical metrics for implementation decision-making. Few studies in the literature provide this level of economic evaluation alongside technical performance data.

Additionally, our inclusion of user experience assessment and long-term maintenance testing addresses practical aspects often overlooked in similar studies, providing valuable insights for field implementation.

V. CONCLUSION

5.1 Summary of Findings and Practical Implications

This research demonstrates that a low-cost water filtration system constructed from readily available materials can significantly improve several key water quality parameters, particularly turbidity, pH, color, and odor. The system's simple design, accessibility of materials, and cost-effectiveness make it a viable solution for emergency situations and resource-limited settings.

The comparative analysis revealed that the home-built system achieves a substantial portion of the performance of commercial alternatives at a fraction of the cost, resulting in a superior performance-to-cost ratio. This makes the system particularly valuable in contexts where financial resources are constrained.
However, important limitations exist, particularly regarding microbial decontamination, flow rate degradation, and partial heavy metal removal. These limitations highlight the need for further development and potential integration with complementary treatment methods.
The user experience assessment demonstrated that individuals with minimal technical training can successfully construct the system, though certain aspects of the construction process warrant improved guidance and instruction.

This research contributes to the growing body of knowledge on accessible water treatment solutions and provides a practical, evidence-based approach to addressing immediate water quality challenges in settings where more sophisticated technologies are unavailable or unaffordable.

Based on the findings and limitations identified in this study, several promising directions for future development emerge:

5.2 Integrated Disinfection

Future iterations of the system should incorporate affordable disinfection methods to address microbial contamination. Potential approaches include:

1. Integration of a solar disinfection (SODIS) chamber following filtration
2. Incorporation of locally produced silver-impregnated ceramic elements

3. Development of a companion chlorination protocol using locally available bleach products
4. Evaluation of copper mesh layers for antimicrobial properties

5.3 Modular Design Implementation

A modular approach to system design could address maintenance challenges and extend operational life. This might include:

1. Separate, replaceable filter cartridges for different filtration stages
2. Quick-disconnect components for easier cleaning and replacement
3. Transparent components to allow visual monitoring of filter condition
4. Standardized connectors to facilitate integration with additional treatment components

5.4 Improved Adsorption Materials

Investigation of alternative, locally available materials could enhance performance and sustainability:

1. Locally produced biochar as a substitute for commercial activated charcoal
2. Integration of crushed brick or ceramic materials for enhanced pathogen removal
3. Incorporation of locally available ion-exchange materials (e.g., zeolites) for improved heavy metal removal
4. Assessment of agricultural by-products (e.g., rice husks, crushed coconut shells) as filtration media

5.5 Advanced Performance Optimization

Further research could focus on optimizing the system's performance for specific contaminants of concern:

1. Layer thickness optimization for different water quality challenges
2. Incorporation of pH adjustment mechanisms for acidic or alkaline source waters
3. Development of site-specific configurations based on local water quality profiles
4. Integration of natural coagulants (e.g., Moringa seeds) as pre-treatment steps

These future directions aim to address the identified limitations while maintaining the core advantages of accessibility, simplicity, and cost-effectiveness that make the current design valuable.

VI. ACKNOWLEDGEMENT

The research was conducted independently without external funding or institutional sponsorship.

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