Sustainable Portable Water Purifier Device Using Natural Materials

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Abstract

Providing safe drinking water to communities that lack access to conventional infrastructure remains one of the most pressing challenges in environmental science today. In many parts of rural India and similarly resource-limited regions across the world, people continue to depend on untreated surface water that poses serious health risks. This study presents the design, construction, and evaluation of a gravity-driven, portable water purification device assembled entirely from natural, locally available materials.

The purification unit employs a sequential, multi-layer filtration approach. Each layer serves a distinct function: a wire mesh and cotton layer remove coarse and fine suspended solids; Moringa oleifera seed powder acts as a natural coagulant and flocculating agent; Tulsi (*Ocimum sanctum*) powder contributes broad-spectrum antimicrobial activity; activated charcoal derived from coconut shells adsorbs organic contaminants, odor, and color; and a ceramic filter provides microfiltration of bacterial pathogens. The entire system operates under gravity and requires no electricity, chemicals, or technical expertise to operate.

Experimental results demonstrated substantial improvements in all tested water quality parameters. Turbidity dropped from values in the range of 40 to 120 NTU down to 2 to 5 NTU post-filtration. Color and odor were effectively eliminated, and microbial contamination, including total coliform and E. coli, was significantly reduced. While total dissolved solids (TDS) remained relatively unchanged, the system proved highly effective at physical and biological purification. The simplicity of the design, combined with the use of inexpensive, renewable materials, makes this device a practical option for rural households, emergency relief situations, and outdoor environments.

Keywords: Water purification, natural coagulants, Moringa oleifera, *Ocimum sanctum*, activated charcoal, ceramic filtration, gravity-driven filtration, rural water treatment, sustainable technology.

1. Introduction

Water is fundamental to life, and yet for hundreds of millions of people around the world, access to safe drinking water is far from guaranteed. The World Health Organization estimates that waterborne diseases account for a substantial share of preventable deaths in low- and middle-income countries, particularly among children under the age of five. In India, rural communities face a disproportionate burden, often depending on surface water sources such as rivers, ponds, and lakes that are increasingly compromised by domestic waste, agricultural runoff, and industrial discharge [1,2].

The physical, chemical, and biological degradation of these water sources presents a serious public health challenge. Pathogens such as E. coli, Vibrio cholerae, and Salmonella typhi thrive in contaminated water and cause diseases including diarrhea, cholera, dysentery, and typhoid fever. Heavy metals, pesticide residues, and organic pollutants further complicate the picture, creating a burden of contamination that is difficult to address with any single treatment approach.

Conventional water treatment technologies, including reverse osmosis (RO), ultraviolet (UV) disinfection, and chlorination, have demonstrated effectiveness in controlled, centralized settings. However, they come with significant limitations when considered for rural or remote deployment. RO systems are energy-intensive and generate reject water that creates additional disposal problems. UV treatment requires a stable electricity supply and regular maintenance of the lamp and quartz sleeve. Chemical disinfection with chlorine can introduce taste and odor problems, and in the presence of organic matter, produces disinfection by-products (DBPs) that may pose their own health risks over extended exposure. The capital and operating costs of all these technologies place them out of reach for economically weaker communities [3].

This gap in affordable, accessible water treatment has driven growing interest in nature-based solutions. Researchers and practitioners have revisited traditional water purification knowledge and found scientific merit in several plant-based materials that have been used for centuries. Among these, Moringa oleifera is perhaps the most extensively studied natural coagulant, credited with the ability to destabilize suspended particles and promote their aggregation through a combination of charge neutralization and bridging mechanisms. Tulsi, or holy basil (*Ocimum sanctum*), is another material with a long history of use in Indian traditional medicine; its antimicrobial properties have been documented in modern phytochemical research. Activated charcoal, derived from renewable carbonaceous sources such as coconut shells or agricultural waste, is well established as an adsorbent for organic compounds, taste, and odor [4,5,6].

The central argument of this study is that these materials, assembled into a single, layered filtration column, can collectively deliver water quality improvements that come close to meeting or exceed baseline safety standards for drinking water, without requiring electricity, specialized expertise, or expensive consumables. The device described here is designed to be constructed and maintained by community members using locally available resources, making it genuinely appropriate for the settings where it is needed most.

The study systematically evaluates the performance of each filtration layer and of the integrated system as a whole, measuring changes in turbidity, color, odor, pH, total dissolved solids (TDS), electrical conductivity (EC), total coliform counts, and the presence of E. coli. In doing so, it contributes to a growing body of evidence supporting the integration of traditional ecological knowledge with applied environmental science to build practical, decentralized water treatment solutions.

2. Review of Related Literature

The use of plant-derived materials for water treatment is not a new idea. Historical records from South Asia, Africa, and the Middle East document the practice of using seeds, bark, leaves, and other botanical materials to clarify and purify water. What has changed is the application of modern analytical tools to understand the mechanisms behind these traditional practices, and the systematic effort to optimize them for practical deployment [4,7].

2.1 Moringa oleifera as a Natural Coagulant

Among all plant-based coagulants, Moringa oleifera has received the most scientific attention. Okuda et al., [8] demonstrated that cationic proteins in Moringa seed extracts are responsible for coagulation activity, functioning in a manner comparable to aluminum sulfate (alum) but without the risk of residual aluminum in treated water. Subsequent research by Sanchez-Martin et al. [9] confirmed that crude seed extracts could reduce turbidity by more than 90% in jar tests conducted on synthetic and natural surface water samples. Importantly, the effective dose of Moringa seed powder is low, typically in the range of 50 to 200 mg/L, making it economically viable. The coagulation mechanism involves the active protein component acting as a polymeric flocculant: positively charged protein molecules adsorb onto negatively charged colloidal particles, neutralizing surface charge and enabling particle aggregation and settling [10].

2.2 *Ocimum sanctum* as an Antimicrobial Agent

Tulsi has been described in Ayurvedic texts as a purifier of water and environment. Modern phytochemical analyses have identified a range of biologically active compounds in Tulsi leaves, including eugenol, rosmarinic acid, ursolic acid, and various terpenoids, which exhibit antibacterial, antifungal, and antiviral activity. Cohen [5] reviewed clinical and laboratory evidence and concluded that Tulsi extracts have broad-spectrum antimicrobial activity against both Gram-positive and Gram-negative bacteria. In the context of water treatment, Tulsi leaf powder added to filtered water has been shown to reduce coliform counts, though the mechanism is more likely related to leached phytochemicals than to simple physical filtration [6].

2.3 Activated Charcoal

Activated charcoal is produced by subjecting carbon-rich organic material to high temperatures in a low-oxygen environment, followed by activation with steam or chemical agents to create an extensive network of micropores. The resulting material has an extraordinarily high surface area per unit mass, typically ranging from 500 to 1500 m2/g, which makes it an exceptionally effective adsorbent for organic molecules, pigments, and volatile compounds responsible for taste and odor. Bansal and Goyal (2005) provide a comprehensive review of activated carbon adsorption theory and applications in water treatment. For low-cost applications, charcoal from coconut shells, rice husks, or wood represents an accessible and renewable source material [7].

2.4 Ceramic Filtration

Ceramic filters have a well-documented history in point-of-use water treatment, particularly in Latin America and sub-Saharan Africa, where they have been studied extensively by UNICEF, WHO, and academic research groups. The pore size of fired ceramic is typically in the range of 0.1 to 10 micrometers, which is sufficient to remove bacteria (typically 0.5 to 5 micrometers) and protozoa, though viral particles (0.02 to 0.3 micrometers) can pass through. Sobsey (2002) reviewed the evidence base for ceramic filtration in household water treatment and found consistent log reductions in total coliform and E. coli across multiple studies, even without silver impregnation. When silver nanoparticles are added to the ceramic matrix, both adsorption and antimicrobial action contribute to improved pathogen removal [11,12].

2.5 Multi-Stage Filtration Systems

Peter-Varbanets et al. [13] argued that decentralized, household-scale water treatment systems represent the most pragmatic near-term solution for communities without access to centralized infrastructure. Their review highlighted multi-stage filtration as particularly promising because combining physical, chemical, and biological treatment mechanisms allows each stage to compensate for the limitations of others. Shannon et al. [13] writing in Nature, similarly called for greater investment in appropriate technology solutions that can be manufactured and maintained locally. The present study builds directly on this body of evidence by integrating coagulation, antimicrobial treatment, adsorption, and microfiltration into a single, self-contained gravity device.

3. Materials and Methodology

3.1 Study Area and Sample Collection

Water samples for this study were drawn from three surface water sources in and around the Amravati region: a low-flow pond receiving agricultural drainage, a section of a local river with visible signs of anthropogenic contamination, and a seasonal lake used for bathing and washing by nearby residents. These three source types represent the range of contamination scenarios most commonly encountered by rural populations in central India.

Samples were collected in pre-cleaned polyethylene bottles of 5-liter capacity, transported to the laboratory within two hours of collection, and processed within four hours of arrival to minimize changes in microbial populations. All samples were collected in triplicate for each experimental run, and the average values of measured parameters are reported. The collected water was visibly turbid, yellowish to greenish in color, and had a distinctly unpleasant odor, confirming significant contamination.

3.2 Preparation of Filter Materials

Preparation of each layer material was carried out with care to avoid introducing secondary contamination and to ensure that the active properties of each material were preserved.

Moringa oleifera seeds were obtained from mature pods collected locally. Seeds were manually shelled, air-dried at ambient temperature for 72 hours, and then ground using a clean mortar and pestle into a fine powder. The powder was sieved through a 250-micrometer mesh to ensure a uniform particle size distribution. Freshly prepared powder was used within one week of grinding.

Tulsi leaves (*Ocimum sanctum*) were collected from cultivated plants, washed thoroughly with distilled water to remove surface dust and microbes, and then shade-dried for 48 hours to prevent degradation of heat-sensitive bioactive compounds. The dried leaves were ground and sieved similarly to the Moringa seeds.

Activated charcoal was prepared from coconut shells through controlled carbonization. Shells were dried, broken into small pieces, and subjected to pyrolysis in a clay pot at approximately 400 to 500 degrees Celsius for two hours, with minimal oxygen access. The resulting charcoal was ground, sieved through a 500-micrometer mesh, and washed repeatedly with distilled water until the wash water ran clear, removing fine ash and residual particles. The cleaned charcoal was then air-dried before use.

The cotton layer was formed from sterilized medical-grade cotton wool, ensuring no microbial contamination was introduced at this stage. The ceramic filter element was washed with clean water, dried, and inspected for cracks before assembly.

3.3 Design and Assembly of the Filtration Unit

The filtration unit was fabricated using a PVC pipe of 75 mm internal diameter and approximately 60 cm length,

Figure 1: Schematic Cross-Section of the Multi-Layer Filtration Column (Top to Bottom)

Table 1: Materials Used in the Filtration Device and Their Functions

Layer No.	Material	Primary Function	Mechanism
1	Wire Mesh / Sieve	Pre-screening	Physical interception of large particles
2	Cotton Wool	Coarse filtration	Mechanical trapping of suspended solids
3	Moringa Seed Powder	Coagulation	Cationic protein charge neutralization [7,8,10]
4	Tulsi Leaf Powder	Disinfection	Phytochemical antimicrobial action [5]
5	Activated Charcoal	Adsorption	Surface binding of organics, odor, color [6]
6	Ceramic Filter	Microfiltration	Size exclusion of bacteria and protozoa [12]

Each material was selected for its specific water treatment role and local availability.

chosen for its affordability, chemical inertness, and ready availability. The pipe was fitted with a removable end cap at the bottom to hold the ceramic filter element. Each filtration medium was loaded sequentially into the column, with thin cotton layers separating adjacent media to prevent intermixing and allow replacement of individual layers.

Each layer was packed to a depth of approximately 8 to 10 cm. The total active filtration depth was therefore around 50 cm. Water was introduced at the top and allowed to percolate downward under gravity, with the flow rate regulated naturally by the packing density of each layer. Typical flow rates observed were in the range of 0.5 to 1.5 liters per hour per unit, which is consistent with rates reported in the ceramic filter literature.

3.4 Experimental Procedure

For each experimental run, 3 liters of raw water sample were poured slowly into the top of the filtration column. Filtered water was collected in a sterile container at the outlet. All glassware and collection vessels were sterilized prior to each run. Physicochemical parameters were measured immediately upon collection of the filtered water to avoid changes due to standing.

A control sample of unfiltered raw water was maintained alongside each run, and parameter measurements were conducted simultaneously to enable direct before-and-after comparison. Three complete experimental runs were performed per water source, yielding nine data sets in total.

3.5 Water Quality Parameters Measured

The following parameters were measured before and after filtration using standard methods recommended by APHA (American Public Health Association) and WHO guidelines [2,11]:

- Color: Visual assessment and qualitative comparison
- Odor: Organoleptic assessment by trained evaluators
- Turbidity: Measured in Nephelometric Turbidity Units (NTU) using a calibrated nephelometer
- pH: Measured using a digital pH meter (calibrated with standard buffer solutions)
- Total Dissolved Solids (TDS): Measured gravimetrically (mg/L)
- Electrical Conductivity (EC): Measured using a conductivity meter (microsiemens/cm)
- Total Coliform: Most Probable Number (MPN) method
- E. coli: Membrane filtration method with MacConkey agar incubation

4. Results and Discussion

4.1 Raw Water Characteristics

The raw water samples collected from all three sources showed evidence of moderate to heavy contamination. Turbidity ranged from 40 to 120 NTU, far exceeding the WHO guideline of 4 NTU and the BIS (Bureau of Indian Standards) limit of 5 NTU for drinking water. A yellowish-green color was consistent across samples, attributable to suspended algal cells, fine clay particles, and dissolved organic matter. The odor was consistently described by evaluators as musty and unpleasant, suggesting the presence of decomposing organic material and microbial metabolites. Both total coliform and E. coli were detected in all samples, confirming fecal contamination from one or more sources [2].

4.2 Post-Filtration Water Quality

After passing through the complete six-layer filtration system, all measured parameters showed improvement. The degree of improvement varied by parameter and by original source water quality, but was consistently positive across all runs.

4.3 Physical Parameter Results

The change in water color from yellowish-green to visually clear was one of the most immediate and obvious results of filtration. This transformation can be attributed primarily to the combined action of the Moringa coagulant layer, which caused fine colloidal particles to aggregate and be retained in subsequent layers, and the activated charcoal, which adsorbed dissolved color-causing organic compounds including humic and fulvic acids.

Turbidity reduction was the most quantitatively striking result. The mean post-filtration turbidity of 2 to 5 NTU represents a greater than 95% reduction in most runs. Turbidity reduction of this magnitude suggests that the combination of coarse filtration, coagulation, and ceramic microfiltration is operating effectively across the particle size range. The cotton layer contributed to initial turbidity reduction; the Moringa layer then caused residual colloidal matter to flocculate; and the ceramic filter provided a final barrier against fine particles that passed through the upper layers. Odor elimination was complete in all runs, a result consistent with the strong adsorption capacity of the activated charcoal layer [12].

4.4 Chemical Parameter Results

pH values shifted slightly toward the neutral range following filtration, likely due to the buffering effect of the ceramic material and the mild alkalinity contributed by the charcoal. The values remained well within the WHO acceptable range of 6.5 to 8.5, suggesting that no pH correction is required downstream.

TDS and EC values changed minimally, which is an expected result given that none of the filter media are designed to remove dissolved ionic species. This is an important limitation of the device: it cannot address issues of hardness, heavy metal contamination, salinity, or fluoride excess. Users in areas with known dissolved contaminant issues would require an additional treatment step, potentially including a simple ion exchange resin or an activated alumina stage for fluoride-affected regions.

Table 2: Comparative Water Quality Parameters Before and After Filtration

Parameter	Before Filtration	After Filtration	WHO Standard	% Improvement
Color	Yellowish / Greenish	Clear	Colorless	Complete
Odor	Objectionable	No Odor	Inoffensive	Complete
Turbidity (NTU)	40 to 120	2 to 5	< 4	~95%
pH	6.2 to 7.5	6.5 to 7.8	6.5 to 8.5	Stabilized
TDS (mg/L)	200 to 450	190 to 430	< 500	Slight
EC (uS/cm)	300 to 700	290 to 680	< 750	Slight
Total Coliform	Present (high)	Greatly Reduced	0 / 100 mL	Significant
E. coli	Present	Absent / Trace	0 / 100 mL	Very High

Values represent means across three experimental runs per source. NTU = Nephelometric Turbidity Units.

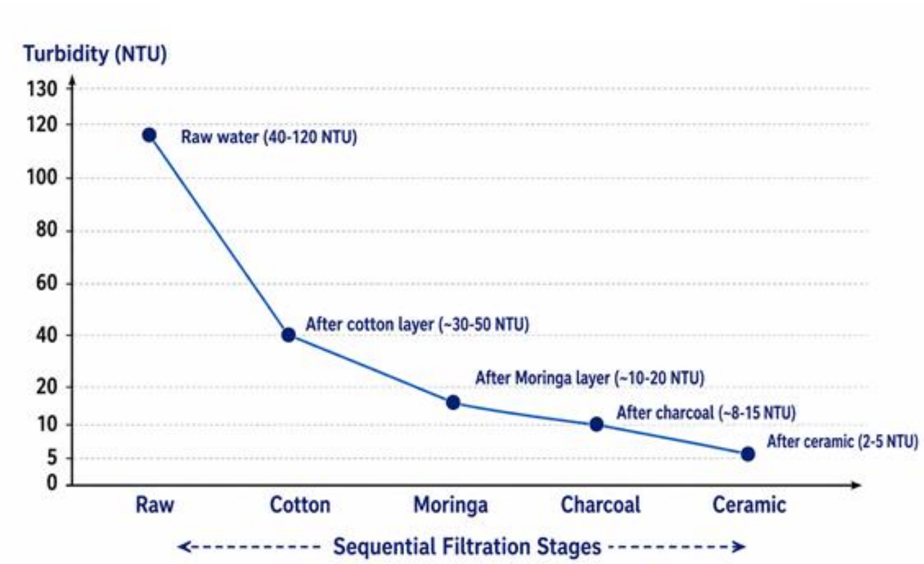

Figure 2: Turbidity Reduction Profile Across Filtration Stages

Table 3: Contribution of Each Layer to Overall Purification

Filtration Layer	**Turbidity**	**Color**	**Odor**	**Microbial**
Wire Mesh / Sieve	★★★ High	–	–	–
Cotton Wool	★★★ High	★ Low	–	–
Moringa Seed Powder	★★ Moderate	★★ Moderate	–	★ Low
Tulsi (*Ocimum sanctum*)	★ Low	★ Low	★ Low	★★ Moderate
Activated Charcoal	★ Low	★★★ High	★★★ High	★ Low
Ceramic Filter	★★ Moderate	★★ Moderate	★ Low	★★★ High

Legend: ★ = Low contribution ★★ = Moderate contribution ★★★ = High contribution

4.5 Microbiological Results

The microbiological performance of the system was encouraging. Total coliform counts were substantially reduced in all samples, though complete elimination was not consistently achieved. E. coli was absent in the majority of post-filtration samples, but trace levels were detected in two out of nine runs. This variability is consistent with the known performance envelope of ceramic filtration systems, which typically achieve two to four log reductions in E. coli but are not absolutely reliable barriers at high initial contamination loads [12].

The contribution of the Tulsi layer to microbial reduction is more difficult to isolate experimentally. The phytochemicals responsible for Tulsi's antimicrobial activity, particularly eugenol and rosmarinic acid, have finite solubility in water, and leaching of active compounds through a packed powder layer may be limited by contact time and flow dynamics. Further work with optimized extraction and contact time would help clarify Tulsi's contribution in this configuration.

4.6 Performance of Individual Layers

To understand the contribution of each layer to the overall purification process, intermediate sampling was conducted during selected runs by intercepting water at various depths within the column. Although this approach provides only approximate stage-by-stage data (since water is not collected under steady-state conditions at each midpoint), it gives a useful qualitative picture of how the treatment efficiency accumulates through the system.

The wire mesh and cotton layers together accounted for approximately 40 to 50% of the initial turbidity reduction by capturing large particles and flocculent material. The Moringa layer appeared responsible for a further 20 to 30% reduction by aggregating colloidal matter too small to be physically intercepted. The charcoal layer contributed relatively little to turbidity removal but was primarily responsible for color and odor elimination. The ceramic filter provided the final precision barrier, achieving the lowest turbidity levels and contributing most significantly to bacterial removal [8,9, 12].

5. Discussion

The results of this study confirm that a multi-layer, gravity-driven water filtration device using natural materials can achieve meaningful water quality improvements that approach, and in many parameters meet, the minimum standards for safe drinking water set by WHO. The technology is particularly well-suited to physical and biological contamination, which represents the primary health concern in most rural water sources in India [2, 14, 15].

From a practical standpoint, several features of the device merit attention. First, all materials used are locally available across most of India and many parts of the developing world. Moringa trees are widely cultivated, Tulsi is ubiquitous in households, coconut shells are an agricultural by-product, and cotton and basic ceramic are manufactured locally in most states. The cost of assembling one unit was estimated at below five hundred rupees in the current study, a cost that could be further reduced with community-scale production.

Second, the device requires no electricity and no chemical inputs once assembled. The replacement cycle for filter media will depend on source water quality and usage volume, but preliminary assessment suggests that charcoal and Moringa layers would need refreshing every four to six weeks under typical household usage, while the ceramic filter element can last several months if cleaned regularly.

Third, the cultural familiarity of materials like Tulsi and Moringa in the communities most likely to use this device is not a trivial consideration. Adoption of water treatment technologies is strongly influenced by community trust and cultural acceptability. A system built from plants that people already know and use is more likely to gain acceptance than one that relies on unfamiliar chemical inputs or complex mechanical components.

The limitations of the device also deserve honest discussion. The most significant is the incomplete removal of dissolved contaminants including TDS, heavy metals, nitrates, fluoride, and pesticide residues. In regions where groundwater or surface water is contaminated with arsenic or fluoride, this device alone would be insufficient to ensure safety. A second limitation is the variability in microbial removal efficiency, which, while generally high, was not absolutely reliable across all runs. This suggests that the device is best used as a primary treatment stage, with a simple boiling step or solar disinfection (SODIS) as a complementary measure for households where microbial risk is highest [12].

6. Conclusion

This study set out to design, build, and test a low-cost, electricity-free water purification device using natural materials that are readily available in rural India. The results support the conclusion that such a device can effectively address the primary forms of water contamination encountered in surface water sources, namely turbidity, organic pollutants, odor, color, and microbial contamination.

Turbidity was reduced by more than 95% on average, from values as high as 120 NTU to the range of 2 to 5 NTU. Color and odor were completely eliminated in all runs. Total coliform bacteria were substantially reduced, and E. coli was absent in the majority of filtered samples. pH was stabilized within acceptable limits. TDS and EC were not significantly altered, which, while a limitation for dissolved contaminant removal, does not impair the device's performance in the context of the surface water quality challenges it is designed to address.
The integration of Moringa coagulation, Tulsi antimicrobial activity, charcoal adsorption, and ceramic microfiltration into a single gravity column represents a practical expression of the principle that combining multiple treatment mechanisms produces outcomes greater than any single approach can achieve. Each layer compensates for the limitations of the others, and together they address the three main dimensions of water quality: physical clarity, chemical acceptability, and microbiological safety.

Beyond the technical performance of the device, this study makes a broader argument: that sustainable water treatment solutions for underserved communities do not necessarily require high-technology inputs. The knowledge, materials, and skills needed to build and maintain this device are already present in the communities that need it. What is required is the systematic organization of that knowledge into a reliable, evidence-based design, and the institutional support to make that design widely available. We hope this study contributes a small but useful step in that direction [14,15].

6.1 Recommendations for Future Research

1. Long-term performance trials over a period of three to six months to evaluate filter media fouling and replacement requirements.
2. Testing against WHO and BIS potability standards including heavy metal analysis (arsenic, lead, chromium) and pesticide residue screening.
3. Evaluation of solar disinfection (SODIS) as a complementary post-treatment stage to improve microbial safety margins.
4. Optimization of Tulsi layer depth, particle size, and contact time to maximize phytochemical leaching and antimicrobial effectiveness.
5. Community-based trials in two or three representative villages to gather real-world usage data and assess social acceptability.
6. Investigation of local alternatives to ceramic filtration in areas where fired clay filters are not accessible.
7. Life-cycle cost analysis comparing the device against commercially available point-of-use filters currently marketed in rural India.

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