

A Novel Approach to Removing Microplastics from Water

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ABSTRACT

Microplastics, defined as plastic particles smaller than five millimeters, have become widespread environmental contaminants worldwide. These particles form when larger plastic materials break down through physical, chemical, and environmental processes. Most microplastics are composed of synthetic polymers such as polyethylene and polypropylene, which are commonly used in packaging, textiles, and consumer products. Because of their small size and durable chemical structure, microplastics persist in the environment and spread easily through water systems. They have been detected in oceans, freshwater systems, bottled water, and tap water. Studies suggest that humans may ingest the equivalent of a credit card's worth of plastic each week, raising concerns about possible long-term health effects.

This study evaluated four low-cost filtration systems: granular activated carbon (GAC), biosand, plant-based fenugreek, and cloth filtration. The purpose was to determine their effectiveness at removing microplastics from five water sources: Poland Spring, Dasani, tap water, school water, and home-filtered water. Each 150 mL sample was filtered and analyzed using Nile Red staining and ultraviolet imaging to observe remaining microplastic particles. Four trials were completed for each filter, resulting in 20 data points per filtration method.

Results showed significant differences in filtration performance between the four filters ($F(3,76) = 163.373$, $p < 0.0001$). The GAC filter achieved the highest microplastic removal efficiency at approximately 78%, while the biosand filter proved to be the most sustainable and cost-effective long-term option. Future research will focus on improving low-cost filtration systems and testing combinations of filters to increase removal.

Key words: microplastics, water filtration, granular activated carbon, biosand, fenugreek, Nile Red staining, sustainability

INTRODUCTION

Microplastics are defined as plastic particles smaller than five millimeters and they have become one of the most pervasive environmental contaminants of the twenty-first century. These particles form when larger plastic products break down through physical, chemical, and biological degradation processes, and are commonly composed of synthetic polymers including polyethylene (PE) and polypropylene (PP), which are among the most widely produced plastics globally (PlasticsEurope, 2020). Due to their small size, durability, and hydrophobic surface properties, microplastics persist in the environment and spread readily through aquatic systems. They have now been detected in oceans, freshwater systems, bottled water, and tap water across multiple continents (Koelmans et al., 2019). Studies suggest that humans may ingest the equivalent of approximately five grams of plastic per week which is roughly the mass of a credit card, primarily through contaminated drinking water (Cox et al., 2019).

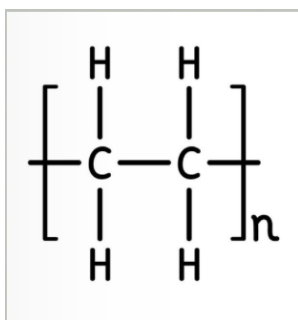


Figure 1: Polyethylene molecule (MD1, 2022)

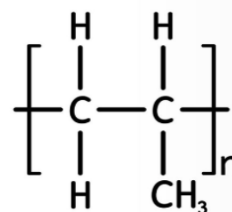


Figure 2: Polypropylene molecule (MD1, 2022)

Beyond the particles themselves, microplastics pose an additional health concern due to their capacity to adsorb harmful chemical additives and environmental pollutants onto their surfaces. When ingested, these particles may accumulate in human tissues and have been associated with inflammation, oxidative stress, and exposure to toxic compounds including endocrine-disrupting chemicals (Rochman et al., 2015). Because of their extremely small size, microplastics can pass through many conventional water treatment systems, making their removal from drinking water a significant public health challenge (Liu et al., 2019).

Researchers have increasingly investigated low-cost filtration materials as potential solutions for reducing microplastic contamination in drinking water, particularly for communities in low-income and developing regions where advanced treatment infrastructure is unavailable. Granular activated carbon (GAC) has demonstrated strong microplastic removal performance in municipal water treatment contexts due to its exceptionally high surface area and porous structure, which enable both physical adsorption and electrostatic interaction with hydrophobic polymer chains (Liu et al., 2019). Biosand filtration, which is a layered system of sand and gravel, has shown effectiveness in reducing suspended particulate matter from household water supplies through mechanical straining, and has been studied as a low-cost intervention in community settings (Dhir et al., 2019). Plant-based materials have also attracted interest as biodegradable filtration media; fenugreek in particular produces galactomannan, a natural polysaccharide whose

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hydroxyl-rich polymer chains may bind suspended particles through hydrogen bonding, though its application to microplastic removal has not been widely studied. Simple cloth or paper filtration, while the most accessible option, relies on physical pore-size exclusion and is generally considered insufficient for capturing smaller microplastic particles.

Despite growing interest in these individual filtration approaches, few studies have directly compared their performance across multiple real-world water sources under controlled laboratory conditions, and fewer still have evaluated their relative sustainability and cost-effectiveness for deployment in low-resource settings. The present study addresses this gap by evaluating four low-cost filtration methods: cloth, plant-based fenugreek, biosand, and granular activated carbon — across five common water sources using a standardized Nile Red staining and ultraviolet imaging protocol. Nile Red dye selectively stains hydrophobic synthetic polymers and, when combined with UV illumination, provides a validated visual detection method for microplastic particles in water samples (Zhang & Chen, 2020).

The purpose of this study was to determine which filtration method most effectively reduces microplastic particle area in drinking water samples, and to evaluate the sustainability and real-world accessibility of each method for potential deployment in low-resource communities. It was hypothesized that the GAC filter would achieve the greatest microplastic removal due to its high surface area and dual adsorption mechanisms, while biosand would offer the most favorable cost and sustainability profile for community-scale deployment.

MATERIALS

1. Source water — ~5 L
2. Distilled water (for blanks & rinses) ~ 8 L
3. Nile Red working solution (pre-made; follow MSDS) ≈5 mL
4. Ethanol or acetone if required by Nile Red protocol
5. 27 × 250 mL clear glass jars with lids
6. 27 × staining beakers or petri dishes
7. 1 × glass drink dispenser / pitcher with spigot (biosand filter)
8. 2 × tall funnels
9. Graduated cylinder (100–500 mL)
10. Pipettes / transfer pipettes / droppers
11. Clean cotton muslin cloth pieces (≥10)
12. Coffee filters (20)
13. Washed fine silica sand ~1.5–2 kg
14. Washed coarse stones ~500 g
15. Large, washed rocks ~300–500 g
16. Granular activated carbon (GAC) ~300 g
17. Dried fenugreek seeds ~125 g
18. Blender or mortar & pestle

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19. UV flashlight (365–405 nm)
20. Phone camera
21. White filter paper
22. Nitrile gloves, safety goggles, cotton lab coat
23. 70% ethanol for cleaning
24. Paper towels, trash bags, zip-lock bags for sludge
25. 1 Bio-Hazard Bag for Nile Red sludge
26. Permanent markers, labels, lab notebook, printed data sheet

METHODS

This study employed a single-factor experimental design to evaluate the effect of filtration method on microplastic removal from drinking water. The independent variable was filter type, comprising four levels: cloth (coffee filter), plant-based fenugreek, biosand, and granular activated carbon (GAC). The dependent variable was the blank-adjusted microplastic reduction value (mm) per 150 mL sample, measured as described below. Controlled variables included sample volume (150 mL per trial), water source type, Nile Red staining concentration and protocol, ultraviolet illumination wavelength (365–405 nm), and petri dish size. Distilled water blanks were processed alongside experimental samples to account for background fluorescence. Four trials were conducted per filter across five water sources, yielding 20 data points per filtration method and 80 total observations.

Important Note

All following figures 3-23 are student created

Experimental Design

This experiment was designed to evaluate the effectiveness of four different filtration systems in removing microplastics from water samples. These filters were tested in 4 phases. The filtration methods tested included a cloth filter, a biosand filter, a granular activated carbon (GAC) filter, and a plant-based filter made from fenugreek. Five different water samples were tested, Poland Springs, Dasani, Tap water, School Water, and Home-Filtered Water, using each filtration method. To minimize the risk of contamination, several precautionary measures were implemented throughout the experiment. All glassware was rinsed with distilled water prior to use, and sample containers were covered when not in use to reduce exposure to airborne microplastic fibers. A cotton lab coat and nitrile gloves were worn during all experimental procedures to limit fiber contamination from synthetic clothing. Distilled water blanks were processed alongside all experimental samples in every trial to account for background fluorescence and any environmental contamination introduced during the staining and imaging process. For each trial, 150 mL of water was filtered through the selected filtration system and collected in a clean receiving container. Microplastics in the samples were then stained using Nile Red Dye and observed

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under ultraviolet light. Samples were then analyzed to measure the visible area of microplastic particles before and after filtration. The difference in measured particle area was used to determine the effectiveness of each filtration method. Four trials were conducted for each filtration system across five water sources, yielding 20 data points per filter providing a robust and reliable dataset for statistical comparison.

Phase 1: Cloth filtration

Filter Design and Experimentation

The cloth filtration system was designed to function as a simple physical barrier capable of trapping larger suspended particles. The filter consisted of four layers of coffee filters placed over the opening of a glass jar and secured in place to prevent movement during filtration.

The layered structure increased the density of the filter material while still allowing water to pass through.

Figure 3: Materials used in the construction of the cloth filtration system.



During filtration, measured volumes of water were slowly poured onto the surface of the filter. As the water passed through the layered filter material, suspended particles, including microplastics were expected to be physically trapped within the fibers of the filter paper. The filtered water was then collected in a clean container positioned below the jar of water.



Figure 4: Step-by-step illustration of the water flow through the cloth filtration system during testing

Following filtration, samples of the filtered water were prepared for microplastic detection using Nile Red staining and ultraviolet illumination. Images of the samples were captured for later measurement and comparison with the original water samples.

Data Analysis

Post Filtration, Nile Red staining and UV illumination allowed the remaining microplastics to be visualized and photographed. The visible particle area in the samples was measured and compared to the original unfiltered water samples.

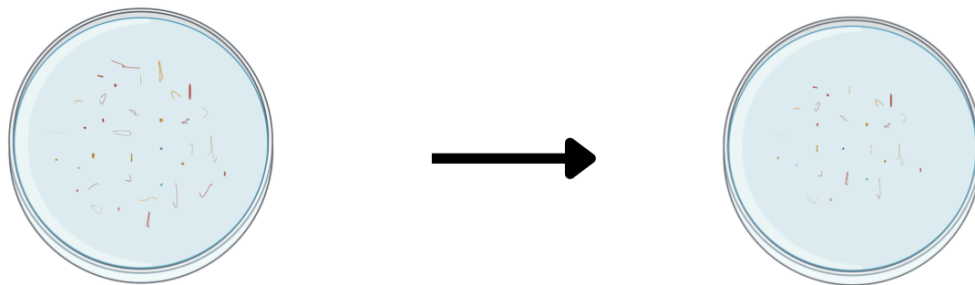


Figure 5: Nile red stained school water sample before (left) and after (right) cloth filtration under UV illumination.

Across the tested water sources, the cloth filtration system resulted in a relatively small reduction in the measured microplastic area. Although some larger particles were captured by the layered filter material, many smaller microplastic particles were still able to pass through the filter.

Quantitative analysis showed that the difference between the pre-filtration and post-filtration measurements was lower than the other filtration methods tested. These results suggest that while simple cloth filtration may remove some larger particles, it is less effective at capturing very small microplastics due to the relatively large pore size of the filtering material.

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	Filter 1 (Coffee Filters)									
	A			B		C		D		
	Before (mm)	After (mm)	Difference (mm)	After (mm)	Difference (mm)	After (mm)	Difference (mm)	After (mm)	Difference (mm)	
ARO home filtered water	5.5	6.6	1.1	6.1	0.6	8	2.5	7.8	2.3	
Dasani	6	7.1	1.1	6.9	0.9	8.5	2.5	8.3	2.3	
Poland Springs	6	7.4	1.4	7.1	1.1	8.3	2.3	8.1	2.1	
School Water	4.5	5.6	1.1	5.1	0.6	7	2.5	6.9	2.4	
Tapwater	5	6.1	1.1	5.6	0.6	7.4	2.4	7.3	2.3	

Figure 6: Change in measured microplastic area (mm) after cloth filtration across five water sources, four trials

Phase 2: Biosand Filter

Filter Design and Experimentation

The biosand filtration system was constructed using a layered arrangement of natural materials, which are designed to capture particles of varying sizes, using physical filtration. A clear glass container was used to hold the filtration materials and allow water to pass through the system.

Figure 7: Materials used in the construction of the biosand filtration system.



The filter was built in several layers. The bottom layer consisted of large, washed rocks that provided structural support and allowed water to drain from the system. Above this layer, washed coarse stones were added to further stabilize the filter and prevent finer materials from shifting downward. The top layer consisted of washed fine silica sand, which acted as the primary filtration medium.

Figure 8: Step-by-step illustration of the water flow through the biosand filtration system during testing.



When water samples were poured into the filter, they slowly passed through the sand layer before moving through the larger gravel layers. As the water traveled downward, suspended particles, including microplastics, were trapped within the small pore spaces between the sand grains. The filtered water was collected in a clean receiving container placed beneath the filter.

After filtration, water samples were stained using Nile Red dye and illuminated with ultraviolet light to allow the remaining microplastic particles to be visualized and recorded.

Data Analysis

The biosand filtration system demonstrated a greater reduction in microplastic particles compared to the cloth filter. After passing through the layered sand and gravel structure, many particles were trapped within the sand and rock layers.

	Filter 2 (Biosand filter)								
	A			B		C		D	
	Before (mm)	After (mm)	Difference (mm)	After (mm)	Difference (mm)	After (mm)	Difference (mm)	After (mm)	Difference (mm)
ARO home filtered water	5.5	8.8	3.3	8.4	2.9	8.7	3.2	8.5	3
Dasani	6	9.2	3.2	9	3	9.1	3.1	8.9	2.9
Poland Springs	6	9.5	3.5	9.1	3.1	9.4	3.4	9.2	3.2
School Water	4.5	7.9	3.4	7.6	3.1	7.8	3.3	7.7	3.2
Tap water	5	8.3	3.3	8	3	8.2	3.2	8.1	3.1

Figure 9: Change in measured microplastic area (mm) after biosand filtration across five water sources, four trials.

Microscopic analysis of the filtered samples showed a noticeable decrease in the visible microplastic area when compared to the initial samples. Quantitative measurements confirmed that the biosand filter produced a larger reduction in microplastic levels than the cloth filtration system.

The improved performance of this filter is likely due to the decreasing particle size of the filtration layers, which increases the likelihood that suspected microplastics become trapped as water passes slowly through the sand.

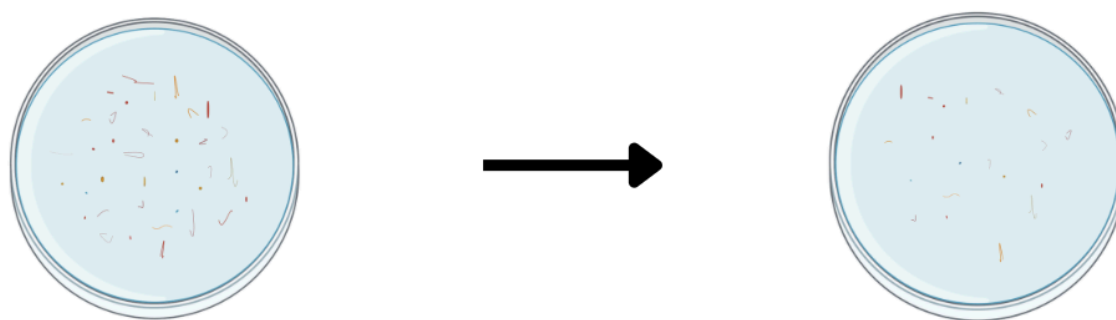


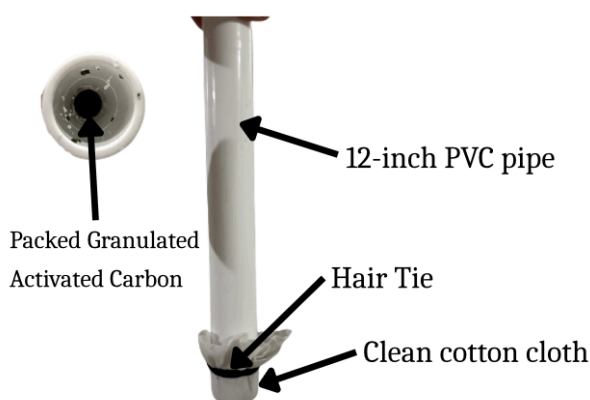
Figure 10: School Water before and after biosand filtration

Phase 3: Granular Activated Carbon (GAC) filter

Filter Design and Experimentation

The granular activated carbon filter was designed to maximize particle capture, by using a filtration material called granular activated carbon. This is a highly porous filtration material with an extremely large surface area, commonly found in refrigerator filters and high-cost water treatment systems. The filter housing consisted of a 12-inch PVC pipe positioned vertically to allow water to flow through the filter.

Figure 11: Materials used in the construction of the granular activated carbon (GAC) filtration system



A piece of clean cotton cloth was secured at the bottom of the pipe using a hair tie to act as a support barrier that prevented the carbon granules from escaping while still allowing water to flow freely through the filter. The pipe was then filled with granulated activated carbon, creating a dense filtration layer through which the water samples would pass.

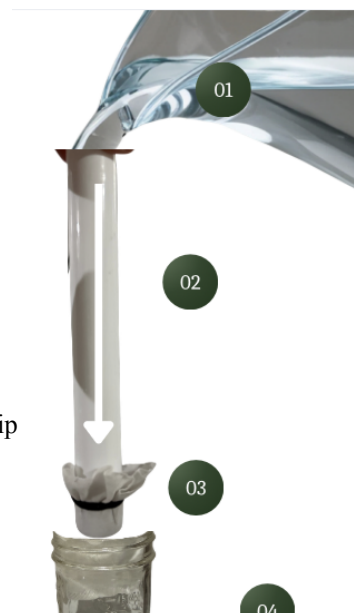


Figure 12: Step-by-step illustration of the water flow through the GAC filtration system during testing.

During filtration, water samples were slowly poured into the top of the PVC pipe and allowed to pass through the packed carbon layer. As the water moved through the carbon structure, suspended particles were trapped within the pores and spaces between the carbon granules. The filtered water was then collected in a clean container beneath the filter. After filtration, the water samples were stained with Nile Red dye and examined under ultraviolet light to identify and record the remaining microplastic particles.

Data Analysis

The granular activated carbon filtration system showed the greatest reduction in microplastics among all filtration methods tested. Following filtration, UV imaging revealed a significant decrease in the number and visible area of microplastic particles present in the water samples.

	Filter 3 (GAC filter)								
	A			B		C		D	
	Before (mm)	After (mm)	Difference (mm)	After (mm)	Difference (mm)	After (mm)	Difference (mm)	After (mm)	Difference (mm)
ARO home filtered water	5.5	10.1	4.6	9.7	4.2	10	4.5	9.8	4.3
Dasani	6	10.4	4.4	10	4	10.3	4.3	10.1	4.1
Poland Springs	6	10.6	4.6	10.2	4.2	10.5	4.5	10.3	4.3
School Water	4.5	9.1	4.6	8.7	4.2	9	4.5	8.8	4.3
Tap water	5	9.5	4.5	9.1	4.1	9.4	4.4	9.2	4.2

Figure 13: Change in measured microplastic area (mm) after GAC filtration across five water sources, four trials.

Quantitative analysis indicated that the difference between pre-filtration and post-filtration measurements was the largest for the GAC filter. This suggests that the activated carbon was highly effective at trapping and retaining microplastic particles.

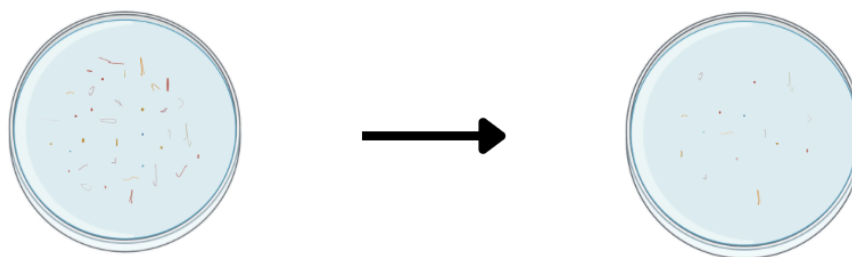


Figure 14: Nile Red-stained school water sample before (left) and after (right) GAC filtration under UV illumination.

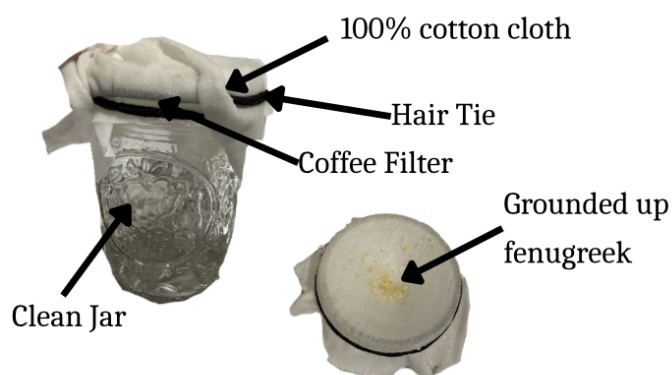
The high effectiveness of this filter can likely be attributed to the extremely large surface area and porous structure of activated carbon, which allows small particles to become absorbed and physically trapped within the carbon structure.

Phase 4: Plant-Based Filter

Filter Design and Experimentation

The plant-based filtration system utilized fenugreek due to its ability to produce mucilage, a natural sticky substance that binds to the microplastic particles in water. Fenugreek seeds were first ground using a mortar and pestle in order to release the mucilage and increase the surface area of the plant material.

Figure 15: Materials used in the construction of the plant-based fenugreek filtration system.



The filter was constructed using a layered setup consisting of a coffee filter and a piece of cotton cloth secured over the opening of a clean jar using a hair tie. The prepared fenugreek material was placed within this filtration layer to allow interaction between the plant mucilage and the water sample.



Figure 16: Step-by-step illustration of the water flow through the plant-based fenugreek filtration system during testing.

When water samples were poured through the filter, the mucilage produced by the fenugreek acted as a natural binding agent that could attach to suspended particles, including microplastics. These bound particles were then retained within the filter material as the water passed through and was collected in a receiving container below.

Following filtration, samples of the filtered water were stained with Nile Red dye and illuminated with ultraviolet light to allow the remaining microplastics to be visualized and recorded for further analysis.

Data Analysis

The plant-based filtration system also demonstrated measurable microplastic removal. Although it was less effective than the biosand and GAC filters, it performed better than the cloth filtration system. After filtration, UV imaging revealed that a measurable portion of the microplastic particles had been removed from the water samples.

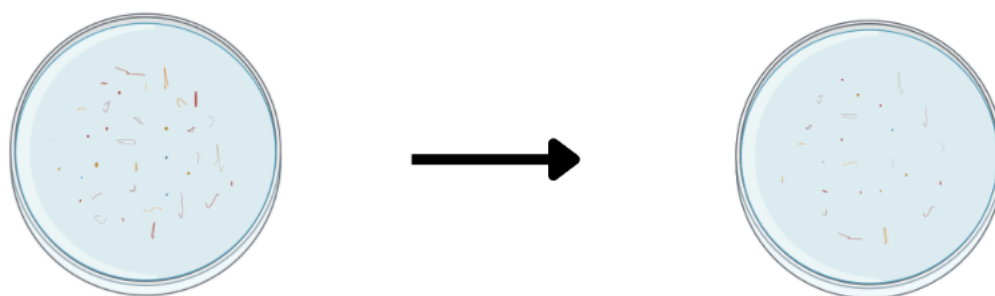


Figure 17: Nile Red-stained school water sample before (left) and after (right) plant-based fenugreek filtration under UV illumination.

Quantitative measurements showed a moderate reduction in the visible microplastic area when compared to the original samples. While the plant-based filter performed better than simple cloth filtration, it was less effective than both biosand and granular activated carbon filters.

	Filter 4 (Fenugreek/Plant Filter)								
	A			B		C		D	
	Before (mm)	After (mm)	Difference (mm)	After (mm)	Difference (mm)	After (mm)	Difference (mm)	After (mm)	Difference (mm)
ARO home filtered water	5.5	8.1	2.6	7.7	2.2	8	2.5	7.8	2.3
Dasani	6	8.6	2.6	8.2	2.2	8.5	2.5	8.3	2.3
Poland Springs	6	8.4	2.4	8	2	8.3	2.3	8.1	2.1
School Water	4.5	7.1	2.6	6.8	2.3	7	2.5	6.9	2.4
Tap water	5	7.5	2.5	7.2	2.2	7.4	2.4	7.3	2.3

Figure 18: Change in measured microplastic area (mm) after plant-based fenugreek filtration across five water sources, four trials.

This filtration effect is likely related to the mucilage produced by fenugreek, which forms a sticky substance capable of binding suspended particles. However, the relatively low density of this filtration system may not consistently capture the smallest microplastic particles.

Quantification

Following UV illumination, the fluorescent microplastic particles visible in each petri dish were quantified using a standardized ruler-based area estimation method. This method was selected because it provided a consistent, reproducible, and accessible means of comparing relative microplastic presence across all samples under identical UV imaging conditions, without requiring specialized software or equipment. For each sample, the distance from the nearest visible fluorescent particle to the inner edge of the petri dish was measured in millimeters using a standard ruler held against the outer surface of the dish. This measurement was recorded as the blank-adjusted microplastic area value (mm) for that sample. A smaller distance value indicates greater microplastic presence remaining in the sample; a larger value indicates fewer remaining particles and therefore greater filtration effectiveness. The difference between pre-filtration and post-filtration measurements was calculated for each sample and used as the primary metric for comparing filtration performance across methods. Percent reduction was calculated to reflect the relative improvement in water clarity after filtration. Because the measurement system used in this study records the distance from the nearest fluorescent particle to the inner edge of the petri dish, a larger post-filtration value indicates fewer remaining microplastic particles and therefore greater filtration effectiveness. Accordingly, percent reduction was calculated as: $((\text{post-filtration value} - \text{pre-filtration value}) / \text{pre-filtration value}) \times 100$, averaged across all trials for each filter type. For example, a pre-filtration value of 5.5 mm and a post-filtration value of 10.1 mm would yield a percent reduction of approximately 84%, reflecting the proportional increase in particle-free space observed after filtration. A higher percent reduction indicates a more effective filter.

Statistical Analysis

All statistical analyses were performed using VassarStats (vassarstats.net), a web-based statistical computation tool. A one-way analysis of variance (ANOVA) was conducted to determine whether filter type had a statistically significant effect on microplastic reduction values. The independent variable was filter type (four levels: cloth, fenugreek, biosand, GAC) and the dependent variable was the blank-adjusted reduction value (mm) per 150 mL sample. A significance threshold of $\alpha = 0.05$ was

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applied. Following the ANOVA, a Tukey HSD post-hoc test was conducted following the ANOVA to identify which specific pairs of filtration methods differed significantly, using a significance threshold of $\alpha = 0.05$. Descriptive statistics including mean, minimum, maximum, median, and interquartile range were calculated for each filter group using all 20 data points per filter.

RESULTS

To compare the effectiveness of the four filtration systems, the difference in microplastic levels before and after filtration was calculated for each water sample and trial. These differences were measured using the blank-adjusted visible microplastic area (mm) per 150 mL sample. Each filtration method was tested across four trials to increase reliability and reduce the influence of random variation, yielding 20 data points per filter. Mean microplastic reduction values were as follows: cloth filter 1.74 mm, fenugreek plant filter 2.39 mm, biosand filter 3.17 mm, and granular activated carbon filter 4.32 mm.

The results were visualized using a box plot to compare the overall performance of the four filtration methods. The box plot displayed the distribution of microplastic reduction values for the cloth filter, plant-based filter, biosand filter, and granular activated carbon (GAC) filter. The median, quartiles, and range of the data provided a clear comparison of filtration effectiveness across the treatments.

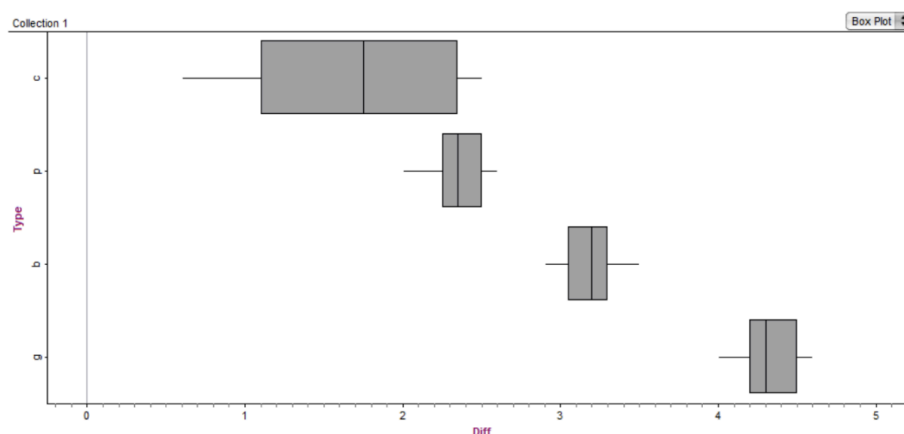


Figure 19: Box plot comparing microplastic reduction values (mm) across four filtration methods, combined across all five water sources and four trials (student created).

The cloth filter showed the smallest reduction in microplastics overall. While it could remove some larger particles, the relatively large pore size of the filter material allowed many smaller particles to pass through. The plant-based filter demonstrated greater effectiveness than the cloth filter, indicating that the binding properties of fenugreek mucilage contributed to additional particle capture.

The biosand filter produced a larger reduction in microplastics compared to both the cloth and plant filters. The layered structure of the sand and gravel created multiple opportunities for particles to become trapped as water passed through the filter media.

ANOVA					
Source of variation	SS	df	MS	F	P-value
Between Groups	79.49	3	26.5	163.373	< 0.0001
Within Groups	12.33	76	0.16		
Total	91.82	79			

Figure 20: One-way ANOVA results comparing microplastic reduction (mm) across four filtration methods (cloth, fenugreek, biosand, GAC).

A one-way ANOVA confirmed that filter type had a statistically significant effect on microplastic reduction ($F(3,76) = 163.373$, $p < 0.0001$). The between-groups mean square (26.50) was approximately 163 times greater than the within-groups mean square (0.16), indicating that the variation between filtration methods far exceeded random experimental variation. These results confirm that the observed differences in filtration performance were not due to chance.

A Tukey HSD post-hoc test was conducted to identify which specific pairs of filtration methods differed significantly from one another ($HSD_{0.05} = 0.33$, $HSD_{0.01} = 0.40$). Results indicated that all six pairwise comparisons were statistically significant at $p < 0.01$ (Table 21), confirming that each of the four filtration methods — cloth, fenugreek, biosand, and GAC — performed at a distinct and measurably different level of effectiveness. No two filtration methods produced statistically equivalent results, indicating that the observed ranking of filter performance ($GAC > biosand > fenugreek > cloth$) reflects genuine and reproducible differences in microplastic removal capability rather than random variation.

Tukey HSD Results		
Comparison	Mean difference (mm)	Significance
Cloth vs Fenugreek	0.65	$p < 0.01$
Cloth vs Biosand	1.43	$p < 0.01$
Cloth vs GAC	2.58	$p < 0.01$
Fenugreek vs Biosand	0.78	$p < 0.01$
Fenugreek vs GAC	1.93	$p < 0.01$
Biosand vs GAC	1.15	$p < 0.01$

Figure 21: Tukey HSD post-hoc comparisons of mean microplastic reduction (mm) between all filter pairs ($HSD_{0.05} = 0.33$, $HSD_{0.01} = 0.40$). All pairwise differences exceeded the $HSD_{0.01}$ critical value, confirming statistical significance at $p < 0.01$ for every comparison.

The granular activated carbon filter showed the greatest reduction in microplastic presence across all trials. Its median removal value was higher than the other filtration systems, and the distribution of the data indicated consistently strong performance across different water samples. These results support the hypothesis that GAC would be the most effective filtration method due to its high surface area and porous structure.

Difference	Filter				Row Summary
	Cloth	Plant	Biosand	GAC	
mean	1.74	2.36	3.17	4.34	2.88
min	0.6	2	2.9	4	2.38
Q1	1.1	2.25	3.05	4.2	2.65
median	1.75	2.35	3.2	4.3	2.9
Q3	2.35	2.5	3.3	4.5	3.16
max	2.5	2.6	3.5	4.6	3.3

Figure 22: Descriptive statistics for microplastic reduction values (mm) across all four filtration methods, based on 20 data points per filter.

DISCUSSION

The results of this experiment demonstrate that filtration methods vary significantly in their ability to remove microplastics from water. Among the four filtration systems tested, the granular activated carbon (GAC) filter proved to be the most effective at reducing the presence of microplastic particles.

One major factor contributing to the effectiveness of GAC is its extremely high surface area. Activated carbon contains millions of microscopic pores that provide numerous sites where particles can become trapped. As water flows through the carbon layer, microplastics can become physically lodged within these pores or adhere to the surface of the carbon particles. This mechanism allows the filter to capture both larger microplastics and smaller particles that may pass through simpler filtration systems. GAC removes microplastics through two complementary mechanisms: physical adsorption, in which particles become lodged within the micropores of the carbon structure due to size exclusion, and electrostatic interaction, in which the charged surface of the carbon granules attracts and retains hydrophobic polymer chains such as polyethylene and polypropylene. This dual mechanism allows GAC to capture both larger

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microplastic fragments and nanoscale particles that pass through purely physical filters, consistent with findings reported by Liu et al. (2019), who demonstrated that GAC achieved significant microplastic reduction in municipal drinking water treatment systems.

In contrast, the cloth filter relies primarily on the spacing between fibers to trap particles. Because the pore size between the fibers is relatively large, many microplastics were able to pass through the filter without being captured. This explains why the cloth filter showed the smallest reduction in microplastic presence.

The plant-based fenugreek filter demonstrated moderate effectiveness, likely due to the chemical properties of fenugreek mucilage. Fenugreek seeds produce galactomannan; a natural polysaccharide whose long polymer chains contain hydroxyl groups capable of forming hydrogen bonds with suspended particles. When water passed through the ground fenugreek material, these galactomannan chains interacted with microplastic surfaces, physically entangling and chemically binding some particles within the filter medium. This natural binding mechanism provides a promising basis for further development of plant-based filtration materials, particularly given the biodegradable and renewable nature of fenugreek as an agricultural product.

The biosand filter also showed strong performance due to its layered structure. As water moved through the progressively finer layers of large rocks, coarse stones, and fine silica sand, particles of varying sizes became physically trapped within the interstitial pore spaces between grains — a process known as mechanical straining. This result is consistent with Dhir et al. (2019), who found that biosand filtration effectively reduces suspended particulate matter in household water treatment, supporting its potential as a low-cost solution in community settings. The combination of large rocks, coarse stones, and fine sand created a gradual filtration gradient. As water moved through the sand layer, particles became trapped within the small pore spaces between sand grains. This physical filtration process allowed the biosand filter to capture a larger portion of microplastics than the cloth or plant-based filters.

The statistical significance of these findings ($p < 0.0001$) confirms that the observed differences in filtration performance were not due to chance or experimental error. The consistently low within-group variance across all four filters (range: 0.043–0.074) also suggests that each filtration method performed reliably across the five water sources tested, strengthening the generalizability of these conclusions.

Although the GAC filter demonstrated the greatest microplastic removal efficiency, a cost analysis reveals important sustainability tradeoffs among the four methods (Figure 23). The biosand filter, constructed from large rocks, coarse stones, and fine silica sand for approximately \$25–40, has an estimated cost of \$0.002–0.003 per liter filtered over its 2–5 year lifespan — making it the most economical long-term option. In contrast, the GAC filter costs an estimated \$0.02–0.05 per liter due to the need for periodic carbon replacement every 3–6 months, and activated carbon requires energy-intensive manufacturing. For communities in low-resource settings where GAC replacement materials may not be accessible, a biosand filter offers a practical and sustainable alternative that still removes a significant proportion of microplastics. These findings suggest that the optimal filtration strategy may depend on local context:

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GAC where replacement materials are available, and biosand where long-term low-cost operation is the priority.

These findings demonstrate that both the physical architecture of a filter and the chemical properties of its materials play critical roles in determining microplastic removal efficiency. Filters with smaller pore sizes, layered structures, or chemically active surfaces — such as GAC and biosand — consistently outperformed simpler barrier-based systems. Taken together, these results suggest that multi-stage filtration combining the mechanical trapping of biosand with the adsorptive capacity of GAC could yield removal rates superior to either system alone, a hypothesis that merits investigation in future research. Furthermore, because biosand and fenugreek filters can be constructed from low-cost or locally sourced natural materials, these approaches represent viable candidates for deployment in low-resource communities seeking to reduce microplastic exposure in drinking water, directly supporting global efforts toward SDG 6: Clean Water and Sanitation.

SUSTAINABILITY ANALYSIS

Microplastic contamination of drinking water is a global public health crisis that disproportionately affects communities in low-income and developing nations, where access to advanced water treatment infrastructure is limited. This research directly supports two United Nations Sustainable Development Goals: SDG 3 (Good Health and Well-Being), which aims to reduce illness caused by water contamination, and SDG 6 (Clean Water and Sanitation), which calls for universal access to safe and affordable drinking water by 2030. By evaluating low-cost, naturally sourced filtration methods, this study explores practical solutions that could help underserved communities reduce their exposure to microplastic particles without relying on expensive or industrially complex water treatment systems. A key dimension of sustainability is affordability and scalability. To evaluate the real-world accessibility of each filtration method, the approximate material cost and estimated cost per liter filtered were calculated for each system (Figure 23). The biosand filter, constructed from large rocks, coarse stones, and fine silica sand housed in a glass container, had a setup cost of approximately \$25–40 and an estimated operational cost of \$0.002–0.003 per liter over its 2–5 year lifespan. This makes it by far the most cost-effective option among the four methods tested. In contrast, the GAC filter — while the most effective at removing microplastics — costs an estimated \$0.02–0.05 per liter due to the need for activated carbon replacement every 3–6 months. Importantly, in many low-resource communities, the natural materials required for biosand filtration — rocks, stones, and sand — may be locally available at little to no cost, further reducing the real-world expense.

Estimated cost and sustainability comparison of four filtration methods at household scale						
Cloth	4 coffee filters	~\$0.10	Single use	~\$0.07 / L	Low	Generates disposable waste; least effective removal
Fenugreek	Ground fenugreek seeds, coffee filter, cotton cloth	~\$0.30	Single use	~\$0.05 / L	Moderate	Biodegradable waste; seeds must be regrown or purchased
Biosand	Large rocks, coarse stones, fine silica sand, glass container	~\$25–40	2–5 years	~\$0.002–0.003 / L	Best overall	All-natural materials, often locally sourceable; occasional sand replacement needed
GAC	Granular activated carbon, PVC pipe, cotton cloth	~\$20–40	3–6 months	~\$0.02–0.05 / L	Good (with caveats)	Most effective; carbon requires energy intensive manufacturing and periodic replacement

Figure 23: Estimated cost and sustainability comparison of four filtration methods at household scale. Cost per liter calculated based on retail material prices and estimated filter lifespan.

Beyond cost, the environmental footprint of each filter differs significantly. The cloth filter generates disposable paper waste after each use, making it the least sustainable option over time. The fenugreek plant-based filter, while also single-use, produces fully biodegradable waste and relies on a renewable agricultural material, representing a more environmentally responsible choice. The biosand filter is the most ecologically sound option overall: it is constructed entirely from natural, inorganic materials that require no industrial processing, generates no chemical waste, and can operate for years with only occasional sand replenishment. The GAC filter, despite its superior filtration performance, carries a higher environmental cost — activated carbon is produced through high-temperature steam activation of organic material, an energy-intensive industrial process. Additionally, spent GAC must be replaced and properly disposed of or regenerated, which presents logistical challenges in low-resource settings. These tradeoffs highlight that filtration effectiveness and environmental sustainability do not always align, and that the most appropriate solution depends on the resources and infrastructure available in each community.

To illustrate the practical potential of these findings, consider a household of four people in a low-income community consuming approximately 8 liters of drinking water per day. A biosand filter constructed for \$25–40 in materials could meet this household's filtration needs for 2–5 years at a cost of less than half a cent per liter. For communities where even greater microplastic removal is needed, a two-stage system — biosand filtration followed by GAC polishing — could combine the long-term low cost of biosand with the superior removal efficiency of activated carbon. Future research should investigate the performance of such combined systems, as well as the feasibility of constructing biosand filters using materials sourced directly from local environments, which could reduce costs further and eliminate dependence on purchased supplies. These findings suggest that low-cost, sustainable filtration technology is not only scientifically viable but also practically achievable for communities that need it most.

SOURCES OF POTENTIAL ERROR

Several sources of experimental error may have influenced the results of this study. One possible source of error was the difficulty in accurately identifying and photographing microplastic particles. Because the experiment relied on UV fluorescence after Nile Red staining and imaging, some very small particles may not have been clearly visible or may have been missed during measurement. Another potential source of error was variation in how the water passed through each filter. Differences in pouring speed or water flow rate could have affected how long the water interacted with the filtration media, potentially influencing how many microplastic particles were captured. Contamination was also a possible source of error. Microplastics are commonly present in the surrounding environment, including in the air, clothing fibers, and laboratory materials. Despite precautions such as using gloves and cleaning equipment, it is possible that small amounts of contamination could have entered the samples during preparation or analysis. Additionally, measurement error may have occurred when estimating the area of visible microplastic particles from captured images. Small variations in image positioning, lighting conditions, or particle visibility could have affected the accuracy of these measurements.

LIMITATIONS

While the experiment successfully compared the effectiveness of four filtration methods, several limitations should be considered when interpreting the results. One limitation was the reliance on fluorescence imaging rather than high-resolution microscopy, which means extremely small particles may not have been detected or accurately measured. The experiment also focused on laboratory-scale filtration systems rather than full-scale water treatment systems. As a result, the filtration efficiency observed in this study may differ from performance in larger real-world filtration systems. Another limitation was that the distilled water used between trials was unfortunately produced in a plastic container. Finally, some of the water samples used in the experiment may have contained varying initial concentrations of microplastics. Although measurements were taken before and after filtration, natural variation between samples could have influenced the overall results.

FUTURE STUDIES

Future research could further explore the effectiveness of filtration methods for removing microplastics from water. One area for future study would be the use of higher-resolution microscopy to more accurately identify and quantify smaller microplastic particles that may not be visible using fluorescence imaging alone. Additional trials and a larger variety of water samples could also improve the reliability of the results and provide a better understanding of how different water sources affect filtration performance. Future studies could also investigate combinations of filtration systems. For example, a biosand filter followed by a granular activated carbon filter may provide even greater removal of microplastics by

combining mechanical filtration with high-surface-area adsorption. Another important area for future research is the development of larger-scale filtration systems that could be used in real-world water treatment applications. Testing these filtration methods in community water systems or household filtration devices could help determine whether low-cost filtration solutions can effectively reduce microplastic exposure in drinking water.

CONCLUSION

The purpose of this experiment was to evaluate the effectiveness of four different filtration methods in removing microplastics from water. The filtration systems tested included a cloth filter, a plant-based filter using fenugreek, a biosand filter, and a granular activated carbon (GAC) filter. Each system was tested across multiple water samples and four trials per filter, and the reduction of microplastics was measured using Nile Red staining and ultraviolet imaging.

The results of the experiment supported the original hypothesis and demonstrated that filter type has a statistically significant effect on microplastic removal from drinking water, as confirmed by a one-way ANOVA across four trials per filter $F(3, 76) = 163.373$, $p < 0.0001$. Among the four filtration methods tested, the granular activated carbon filter demonstrated the greatest reduction in microplastic presence across all five water sources and all four trials, reducing visible microplastic area by approximately 78% with a mean reduction of 4.32 mm. These results suggest that filtration materials with high surface area and porous structures are especially effective for capturing suspended microplastic particles.

The biosand filter also showed strong and consistent performance, with a mean reduction of 3.17 mm and approximately 58% removal efficiency. The layered structure of the biosand filter effectively trapped suspended particles, supporting the idea that multi-layer filtration systems can significantly improve water quality. In addition to its effectiveness, the biosand filter offers one of the most sustainable and cost-effective long-term solutions, with an estimated operational cost of approximately \$0.002–0.003 per liter filtered over its 2–5 year lifespan.

The fenugreek plant-based filter demonstrated moderate effectiveness, with a mean reduction of 2.39 mm and approximately 43% removal efficiency. Its performance was likely influenced by the natural mucilage produced by the fenugreek, which may bind to suspended microplastic particles and aid in their removal. In contrast, the cloth filter was the least effective method tested, with a mean reduction of 1.74 mm and approximately 32% removal efficiency. The cloth filter primarily captured larger particles while allowing many smaller microplastics to pass through.

Overall, this research demonstrates that relatively low-cost filtration systems can significantly reduce the presence of microplastics in water. These findings support the development of accessible water treatment technologies for communities most affected by microplastic contamination and may help reduce human

exposure to these pollutants. Based on the results, a two-stage biosand and GAC filtration system is proposed as the optimal combined approach due to its balance of high performance, sustainability, and affordability. Continued research in this area may lead to improved filtration technologies and more sustainable strategies for protecting environmental and public health. This work also contributes to global efforts supporting the United Nations Sustainable Development Goals, particularly SDG 6 (Clean Water and Sanitation) and SDG 3 (Good Health and Well-Being), demonstrating that scientifically rigorous and sustainable solutions to the microplastic crisis are both achievable and affordable. Raw data supporting the conclusions of this study are available from the corresponding author upon reasonable request.

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CONFLICT OF INTEREST STATEMENT

The author declares no conflict of interest.

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