

Abstract

Microplastic contamination of drinking water has emerged as one of the most pressing global public health concerns of the twenty-first century. These particles — smaller than five millimeters — form when larger plastics break down through physical and chemical processes and have been detected in oceans, bottled water, and tap water worldwide. When ingested, they may carry harmful chemical additives that accumulate in the body and have been linked to inflammation and oxidative stress. Despite growing concern, many conventional filtration systems cannot effectively remove microplastic particles due to their extremely small size, making low-cost removal solutions an urgent research priority — particularly for communities in low-income regions without access to advanced water treatment infrastructure.

This study investigated which of four low-cost filtration methods — cloth, plant-based fenugreek, biosand, and granular activated carbon (GAC) — most effectively reduces microplastic levels across five common drinking water sources, and which offers the most sustainable and affordable solution for underserved communities. Each filter was tested using Nile Red staining and ultraviolet imaging across four trials per filter and five water sources, yielding 80 total observations. Microplastic presence was quantified using a standardized ruler-based area estimation method. Results showed GAC achieved the greatest removal efficiency (~78%, mean 4.32 mm), followed by biosand (~58%), fenugreek (~43%), and cloth (~32%). A one-way ANOVA confirmed statistically significant differences between all filters ($F(3,76) = 163.373$, $p < 0.0001$), and a Tukey HSD post-hoc test confirmed all six pairwise comparisons were significant at $p < 0.01$.

While GAC demonstrated superior filtration performance, this study argues that biosand — constructed from large rocks, coarse stones, and fine silica sand at an estimated cost of ~\$0.002 per liter over its 2–5 year lifespan — represents the most practical and sustainable solution for communities without access to advanced water treatment, directly supporting UN Sustainable Development Goals 3 and 6.

Introduction

Microplastics — plastic particles smaller than five millimeters — have become one of the most widespread environmental contaminants in drinking water worldwide. Formed when larger plastics break down through physical and chemical processes, they are composed of synthetic polymers such as polyethylene and polypropylene and have been detected in oceans, bottled water, and tap water globally (Koelmans et al., 2019). When ingested, they may carry harmful chemical additives that accumulate in the body and have been linked to inflammation and oxidative stress (Cox et al., 2019). Studies suggest humans consume the equivalent of a credit card's worth of plastic per week, largely through drinking water. Despite growing concern, many conventional filtration systems cannot effectively remove microplastic particles due to their extremely small size (Liu et al., 2019). Low-cost, accessible filtration solutions are urgently needed — particularly for communities in low-income regions without advanced water treatment infrastructure. This study investigates which of four low-cost filtration methods — cloth, plant-based fenugreek, biosand, and granular activated carbon (GAC) — most effectively reduces microplastic levels in common drinking water sources, and evaluates each method's sustainability and affordability for potential deployment in underserved communities.

Methods

Five water sources were selected to represent common drinking water types: Poland Springs, Dasani, tap water, school water, and home-filtered water. Four filtration systems were tested — cloth (four layered coffee filters), plant-based fenugreek (ground fenugreek seeds in a coffee filter and cotton cloth), biosand (layered large rocks, coarse stones, and fine silica sand in a glass container), and granular activated carbon (GAC) (activated carbon packed in a 12-inch PVC pipe). Each filter was tested across four trials per water source, yielding 20 data points per filter and 80 total observations. For each trial, 150 mL of water was filtered and collected. Remaining microplastics were stained with Nile Red dye and visualized under UV light (365–405 nm). The distance from the nearest visible fluorescent particle to the inner edge of the petri dish was measured in millimeters using a standard ruler. Percent reduction was calculated as $((\text{before} - \text{after}) / \text{before}) \times 100$, averaged across all trials per filter. A one-way ANOVA and Tukey HSD post-hoc test were conducted using VassarStats to determine statistical significance between filters.

Results

GAC was the most effective filter, removing approximately 78% of microplastics across all five water sources with a mean reduction of 4.32 mm. Biosand followed with 58% removal (mean 3.17 mm), fenugreek achieved 43% (mean 2.39 mm), and cloth was least effective at 32% (mean 1.74 mm). A one-way ANOVA confirmed these differences are statistically significant ($F(3,76) = 163.373$, $p < 0.0001$). A Tukey HSD post-hoc test confirmed every pairwise comparison between filters was significant at $p < 0.01$ ($HSD_{0.01} = 0.40$), meaning each filter performed at a genuinely distinct level — the ranking of $GAC > biosand > fenugreek > cloth$ is real and reproducible, not due to chance.

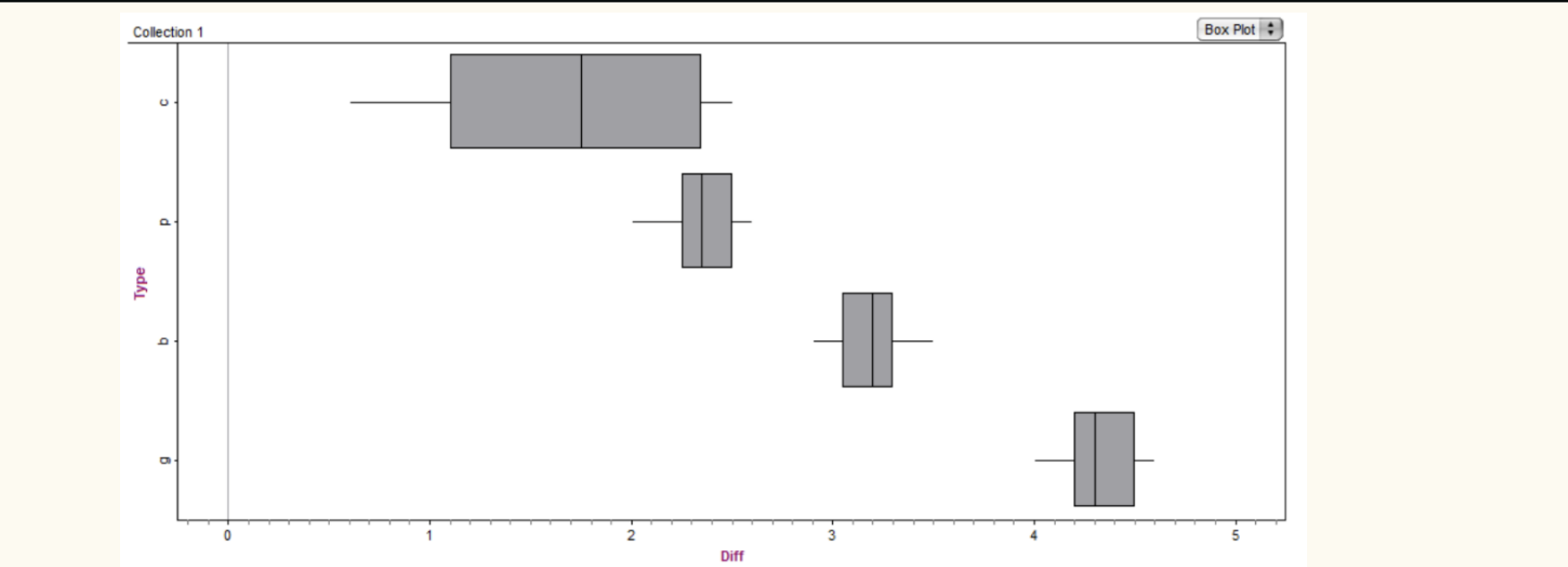


Figure 1: Mean microplastic reduction (mm) by filter type across all four trials. Error bars represent min/max values. GAC demonstrated the greatest reduction followed by biosand, fenugreek, and cloth.

Difference	Filter				Row Summary
	Cloth	Plant	Biosand	GAC	
mean	1.66	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 2: Distribution of microplastic reduction values across all 20 data points per filter, combining all four trials. GAC showed the highest median reduction with consistently low variance.

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			

Table 1: One-way ANOVA results. $F(3,76) = 163.373$, $p < 0.0001$. All pairwise Tukey HSD comparisons significant at $p < 0.01$ ($HSD_{0.01} = 0.40$).



Figure 4: School water sample before (left) and after (right) biosand filtration. Biosand achieved approximately 58% reduction through mechanical straining across its layered structure.

Discussion

These findings support the hypothesis that GAC would achieve the greatest microplastic removal, consistent with Liu et al. (2019), who demonstrated GAC's effectiveness in municipal water treatment due to its millions of microscopic pores that physically trap particles and attract hydrophobic plastic surfaces. Bio-sand's strong performance aligns with Dhir et al. (2019), who found layered sand and gravel systems effectively reduce suspended particles in household water treatment through a process called mechanical straining — where particles become physically trapped between grains as water passes downward. Fenugreek outperformed cloth, suggesting that chemical binding through its natural mucilage offers measurable advantages over simple physical barriers alone — a promising finding for future plant-based filter development. From a sustainability standpoint, biosand costs approximately \$0.002 per liter over its lifespan — up to 25 times cheaper than GAC — and uses entirely natural, locally sourceable materials. This directly supports UN SDG 6 (Clean Water and Sanitation) and SDG 3 (Good Health and Well-Being), suggesting bio-sand is the most practical solution for communities without access to advanced water treatment infrastructure.

Conclusion

This study confirmed that filtration method significantly affects microplastic removal from drinking water ($F(3,76) = 163.373$, $p < 0.0001$), directly answering the research question: GAC is the most effective filtration mechanism, removing approximately 78% of microplastics across all five water sources. The hypothesis was supported. However, bio-sand — at ~\$0.002 per liter using entirely natural materials — is the most practical and sustainable solution for low-resource communities. Future research should test a combined two-stage bio-sand + GAC system, which could maximize both removal efficiency and affordability. Additional studies should investigate nano-plastic detection using higher-resolution microscopy, test more water sources, and pilot community-scale deployment to assess real-world feasibility.

References

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