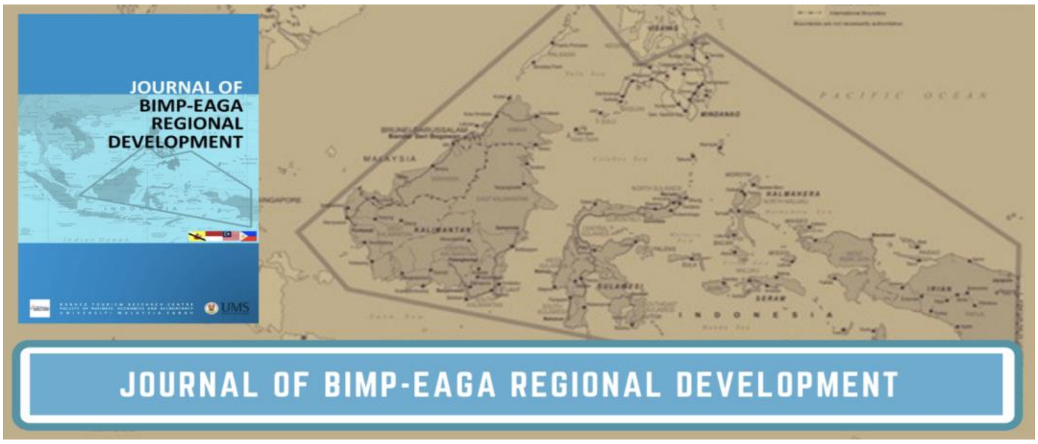

DESIGN AND PROTOTYPE OF AN EASY-ACCESS PORTABLE WATER FILTRATION SYSTEM FOR HOUSEHOLD WASHING

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Abstract

Access to relatively clean water for household use is increasingly problematic due to limited water supply. Existing filtration systems on the market are often prohibitively expensive and rely on materials that are not locally available. This study explores alternative and vernacular filtration materials. It involves modeling a filtration system to test substitute mediums for prototyping. Pre- and post-water sample testing was conducted to assess the water's color, turbidity, and pH levels. The Water Quality Guidelines and General Effluent Standards of 2016 served as the framework for these tests and results. The study found that a portable filtration system made from locally sourced materials can significantly improve access to clean (non-potable) water for households. Post-testing showed visibly cleaner water, and the water sample test results were favorable. The proposed filtration mediums in this study offer a more affordable solution due to the lower market value of the materials. This approach can also ideally address campus sustainability concerns by promoting responsible water consumption, aligning with the United Nations Sustainable Development Goal (UNSDG) 6 for 2030, which focuses on clean water and sanitation.

Keywords: Portable Water Filtration, Sustainable Water Solutions, UNSDG 6, Water Quality

1. Introduction

The Philippines is one of the most disaster-prone countries in the world, frequently experiencing typhoons, earthquakes, and volcanic eruptions. In 2020 alone, the country faced multiple catastrophic events, including a volcanic eruption, major earthquakes, and successive typhoons that inundated more than 60 towns and cities. Due to its geographical location, approximately 74% of its population of over 100 million is vulnerable to various natural hazards. The country consistently ranks among the top 10 most disaster-prone nations globally and was identified as the most disaster-prone country in 2024, according to the World Risk Index (GMA News Online, 2024; UNSDG, 2020; Statista, 2023).

Corresponding author: Eisley John S. Tiongson
Received: 2.03.2025
Accepted: 5.03.2025
Revised: 14.03.2025
Published: 17.03.2025
DOI: 10.51200/jberd.v11i1.6220

Beyond immediate destruction, natural disasters in the Philippines exacerbate challenges in accessing clean water, a persistent issue in many communities. According to data from the United Nations and UNICEF, 53% of households in the Philippines lack access to a safely managed water supply, and 39% lack safe sanitation. The situation in schools is even more critical, with 55% lacking access to a safely managed water supply and 26% lacking safe sanitation. Additionally, the high cost and limited availability of water filtration systems create further barriers, particularly for low-income households, underscoring the urgent need for sustainable and affordable solutions (Planet Water Foundation, 2025).

Filtration is a fundamental water treatment process that removes suspended solids, turbidity, microorganisms, and particulates. The use of granular media combined with coagulants enhances the removal of impurities, improving water clarity and safety (Cheremisinoff, 2002). While commercial filtration systems are effective, they often rely on expensive and non-locally available materials, making them inaccessible to many communities. Portable filtration systems, typically weighing between 0.5 to 1 kg, use a combination of filter pads composed of activated carbon, silica sand, zeolite, bio ball, and mineral sand to remove contaminants (El-Harbawi et al., 2010). However, these systems remain costly and may not be viable for widespread household use.

This study aims to address these issues by exploring alternative and vernacular filtration materials that are both cost-effective and locally sourced. The methodology involves modelling a filtration system and testing substitute mediums through a prototyping process. By conducting pre- and post-water sample testing, the study assesses key water quality parameters such as color, turbidity, and pH levels. The Water Quality Guidelines and General Effluent Standards of 2016 serve as the benchmark for these tests, ensuring that the results are aligned with established regulatory standards.

2. Literature Review

2.1. Water Filtration System

Filtration is a crucial unit operation in water treatment, aimed at enhancing water quality by eliminating suspended solids and various impurities. This process predominantly utilizes physical mechanisms, wherein water passes through a granular media bed that traps and separates solid particles from the water stream (Mamuad, R., Pascual, M., & Choi, A., 2022). The effectiveness of filtration is significantly improved by the addition of coagulants, which facilitate the aggregation of colloidal particles, thereby enabling the removal of finer contaminants (Matilainen, A., Vepsäläinen, M., & Sillanpää, M., 2010). Filtration systems are designed to address a wide spectrum of impurities, including turbidity, color, microorganisms, and particulates, irrespective of their origin or any prior treatment applied (Shivraj, S., Quraishi, W., & Basu, 2023; Bratby, S., 2006).

Traditional filtration systems, while effective, often depend on expensive and non-locally available materials, limiting their accessibility for households in need of clean water. The concept of water filtration extends beyond purification to include any method that removes sediment, bacteria, or undesirable contaminants. Any system equipped with a filtration medium, regardless of complexity or scale, qualifies as a filtration system (Mifflin, M., 2021). However, commercial systems may not be feasible for many communities due to cost and availability constraints.

This study explores alternative and locally sourced filtration materials to develop a cost-effective and portable filtration system suitable for household washing. By leveraging vernacular materials, the study aims to provide a more accessible water filtration solution while promoting sustainability. The research aligns with United Nations Sustainable Development Goal (UNSDG) 6, which emphasizes clean water and sanitation. A broader approach to filtration that includes locally adapted solutions can help communities improve water access, particularly in areas where conventional filtration methods are impractical or unaffordable.

2.2. Filter Medium

The filter medium is a critical component in water filtration systems, serving as a porous barrier that removes suspended materials from water. Filtration occurs as water flows through this medium, where particles larger than the pore diameter are retained while smaller particles pass through. The effectiveness of filtration depends on the choice of medium, which influences the removal of contaminants such as turbidity, color, microorganisms, and heavy metals. Studies have shown that alternative filter media, such as glass media, can offer advantages over traditional sand/anthracite filters, including higher filtration performance in removing residual particles and turbidity, minor modification requirements to existing filtration configurations, and slower head loss development (Zhang, X., & Cheng, X., 2020).

Many filtration systems utilize multi-layered filter cartridges composed of various materials, each serving a distinct function in water purification. For instance, activated carbon is highly effective in adsorbing organic contaminants, odors, and tastes. Silica sand functions as a mechanical filter, trapping larger particles and reducing turbidity. Zeolite, with its microporous crystalline structure, removes bacteria, viruses, heavy metals, and harmful chemicals. Bio-balls act as biological filtration media, promoting beneficial bacterial growth to maintain water clarity. Mineral sand, rich in specific gravity minerals, releases essential minerals into the water, adjusting pH levels to a mild alkaline state and improving overall water quality (El-Harbawi, et al., 2010).

While conventional filtration materials are effective, their high cost and reliance on non-local resources limit accessibility, particularly in disaster-prone and resource-limited areas. To address these challenges, alternative and locally sourced filter media offer a cost-effective solution for household water filtration. For example, ion exchange resins are commonly used in water softeners to remove minerals responsible for water hardness, such as calcium and magnesium (Bennett, 2007). These resins can also eliminate heavy metals and bacteria, improving water safety. Bead filtration media, including conventional bead media and mineral beads, enhance water clarity by reducing turbidity and color (Nerdymind, 2018). Mineral beads, often used in ceramic water filters, help neutralize acidic content, increasing the pH level to around 7–7.5 and further eliminating biological contaminants (Ajayi, B., & Yinusa, D., 2015).

This study explores the feasibility of using vernacular filtration materials to develop a portable, affordable, and efficient filtration system for household washing. By leveraging alternative materials, the research aims to provide a sustainable water filtration solution that aligns with United Nations Sustainable Development Goal (UNSDG) 6, which promotes clean water and sanitation. Locally sourced filtration materials offer an accessible approach to improving water quality, especially for communities with limited access to clean water, whether due to economic constraints or disaster-related disruptions.

2.3. Standard Physical Quality of Water

In assessing water quality, three key physical parameters are considered: color, turbidity, and pH. These indicators help determine the effectiveness of filtration systems in improving water clarity and usability for household washing. According to the Philippine National Standards for Drinking Water (PNSDW) of 2017, the standard values for these parameters are as follows: color should not exceed 10 color units (CU), turbidity should be less than 5.0 nephelometric turbidity units (NTU), and pH levels should range between 6.5 and 8.5 (Department of Health, 2017).

Color in water is often unnoticed unless concentrated, but it can vary due to natural or chemical factors such as iron and tannin concentrations, which can give water a reddish or brown hue. Color assessment typically involves comparing a water sample to a standard color scale (Sharma, S., & Bhattacharya, A., 2016). Water color is classified into two types: true color, which is measured in a filtered sample free of suspended particles, and apparent color, which includes the effects of turbidity and other suspended materials (Unrau, J., & Motter, K., 2015).

Turbidity results from suspended chemical and biological particles and affects both water aesthetics and safety. While not inherently harmful, high turbidity levels can indicate contamination and reduce disinfection effectiveness, potentially harboring pathogens (WHO, 2017). Turbidity is measured in Nephelometric Turbidity Units (NTU), with visible turbidity beginning at approximately 5 NTU. Clean lakes typically have levels of up to 25 NTU, while heavily turbid water can reach 2,000 NTU, rendering it completely opaque (Myre & Shaw, 2006). The standard regulatory measurement detects turbidity at a 90-degree angle, though color interference can affect readings at low turbidity levels.

The pH measures the concentration of hydrogen ions in water, indicating its acidity or alkalinity on a 0 to 14 scale, with 7 being neutral. Drinking water quality guidelines recommend a pH range between 6.5 and 8.5 for safety and palatability (Amodu et al., 2016). Surface water generally falls within this range, while groundwater can exhibit slight variations. Additionally, alkalinity represents water's ability to neutralize acids, influencing its overall pH stability.

This study evaluates pre- and post-filtration water quality using these parameters to determine the effectiveness of a portable, low-cost filtration system made from locally sourced materials. By improving water clarity and adjusting pH levels, the proposed filtration approach aligns with United Nations Sustainable Development Goal (UNSDG) 6, which promotes clean water and sanitation. The research findings aim to contribute to sustainable water management practices, particularly in communities with limited access to clean water sources.

3. Methodology

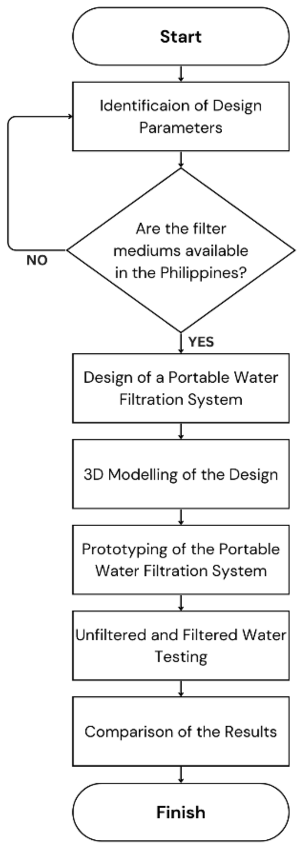

Figure 1.Research Design

Figure 1 illustrates the design and development process of a portable water filtration system. The process begins with identifying the design parameters. A crucial decision point follows, determining whether the required filter mediums are available in the Philippines. If they are unavailable, the process loops back to reassess the design parameters. If the filter mediums are available, the design phase proceeds with the creation of a portable water filtration system, followed by the development of a 3D model. Once the design is finalized, a prototype of the filtration system is constructed. The prototype undergoes testing by analyzing the quality of unfiltered and filtered water. The results are then compared, and based on the findings, recommendations are made. The process concludes once the filtration system meets the intended performance standards.

3.1. Identification of Design Parameters

In developing a sustainable and cost-effective water filtration system, it is essential to establish key design parameters that determine the system's efficiency. These parameters include color, turbidity, and pH level, which serve as primary indicators of water quality. The identification of these parameters is based on the Philippine National Standards for Drinking Water (PNSDW, 2017) and existing research on filtration mediums, particularly the study conducted by El-Harbawi, et al. (2010).

Table 1. Physical properties of the parameters considered

Parameters	Standard Values/ Max Values	Method of Analysis
Color	50 True Color Unit	Visual Comparison
Turbidity	5 Nephelometric Turbidity Unit	Nephelometric
pH range	6.5 – 8.5	Electrometric

To evaluate the effectiveness of the proposed filtration system, the study considers the standard values for color, turbidity, and pH range, as presented in Table 1. These values represent the maximum allowable limits for safe water, ensuring that the filtered water meets acceptable quality levels. Color (measured in True Color Units, TCU) should not exceed 5 TCU, as per PNSDW guidelines, since excessive coloration often indicates the presence of dissolved organic matter, metals, or industrial pollutants. A visual comparison method is used for analysis. Turbidity, which affects water clarity and indicates the presence of suspended particles, should remain below 5 NTU (Nephelometric Turbidity Units). The nephelometric method is used to assess this parameter. pH Level, which determines the acidity or alkalinity of water, should range between 6.5 and 8.5 to prevent corrosion, scaling, and potential health risks. The electrometric method is applied for accurate pH measurement. These parameters serve as the basis for assessing the filtration system's efficiency before and after water treatment.

Table 2. Filter mediums and its significance to the design

Filter Medium	Significance
Activated Carbon	Removes taste, odor, and color of unprocessed or unfiltered water.
Silica	Removes undesired materials found in water i.e., dirt, rust, clay materials and even pathogens.
Bio ball	Bio balls are significant in housing bacteria to ensure clear water.
Zeolite	Eliminates bacteria, viruses, heavy metals, detergents, and other contaminants.
Mineral Sand	Adjust water pH level to mildly alkaline.

To optimize water filtration, El-Harbawi, et al. (2010) identified various filter mediums that effectively remove contaminants as shown in table 2. Each filter medium plays a critical role in improving one or more of the identified water quality parameters. This study adopts those mediums, provided they are readily available in the Philippine market. If certain materials are unavailable, alternatively sourced materials will be tested as replacements.

3.2. Modification of Filter Mediums

During the development of the portable water filtration system, the study identified the need to modify three filter mediums due to performance issues observed during initial testing. The modifications involved replacing Bio balls with Energy Beads, Zeolites with Ion Resin, and Mineral Sand with Mineral Beads. The primary reason for these changes was the unexpected impact of certain filter materials on water quality. Upon conducting the first round of testing, it was observed that the filtration process resulted in increased turbidity, giving the water a distinct discoloration. Further examination revealed that Zeolites and Bio balls were the primary contributors to this discoloration, as they easily mixed with other filtering materials, affecting the overall clarity of the filtered water. Additionally, Mineral Sand was replaced with Mineral Beads to enhance its functionality and optimize filtration efficiency.

The newly selected filter mediums, namely Energy Beads, Ion Resin, and Mineral Beads were chosen as they serve the same purpose as the original materials while being readily available in the market. These modifications aimed to improve the filtration performance, ensuring that the system effectively removes impurities without compromising water clarity.

3.3. Designing the Portable Filtration System

The portable water filtration system was designed for easy assembly, maintenance, and efficient filtration, incorporating a modular filtration body, optimized inlet and outlet suctions, and an integrated manual pump. The filtration body, made of clear plastic, consists of five identical filter medium compartments (60 mm diameter, 35 mm height) with 31 holes (2 mm radius) for water flow. Each unit has male and female threads, allowing easy stacking, installation, and replacement. To improve filtration efficiency, Bio balls were replaced with Energy Beads, Zeolites with Ion Resin, and Mineral Sand with Mineral Beads, preventing turbidity and discoloration while maintaining functionality.

The inlet and outlet suctions (25 mm diameter, 35.2 mm height) were modified to fit standard household hoses, ensuring a secure connection. With an overall system height of 270 mm, its threaded design prevents leakage and allows quick filter replacements, making it cost-effective compared to traditional systems. A 200 CC manual pump (315 mm length, 45 mm diameter) was integrated, enabling water filtration from natural sources like rivers, enhancing portability and versatility. This user-friendly system provides an efficient solution for household cleaning applications.

3.4. 3D Modelling the Model

This study modeled the Portable Water Filtration System using SolidWorks as shown in figure 2, creating a detailed 3D sketch and diagram of the system and its hardware. A 3D model assembly was developed, incorporating the system’s structure, filtering materials, and a detachable manually operated pump. The design included the inlet and outlet suction, lid, and main body, where the filtration process took place. Each component was individually designed and assembled to create an accurate 3D representation. To distinguish the filtering mediums, different colors were assigned to each layer inside the system.

Following the concept of El-Harbawi et al. (2010), the filtration system initially consisted of five layers: Activated Carbon (first layer), Silica Sand (second layer), Zeolite (third layer), Bio Ball (fourth layer), and Mineral Sand (fifth layer). However, after testing, the study replaced Zeolites with Ion Resin, Bioballs with Energy Beads, and Mineral Sand with Mineral Beads to prevent turbidity and discoloration while maintaining filtration efficiency. This modified arrangement ensured effective impurity removal and improved overall system performance.

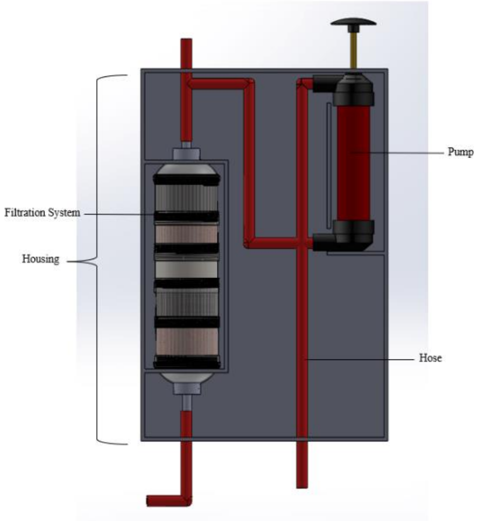

Figure 2.3D Model of Portable Filtration System

3.5. Prototyping the Model

Figure 3.Assembled Portable Filtration System

This study developed its prototype as shown in figure 3 based on 3D modeling, utilizing commercially accessible components for the system's hardware, filtration materials, and a detachable manually operated pump. The filtration materials included activated carbon, silica sand, zeolites, bio balls, and mineral sand, ensuring effective water purification. A clear container served as the system's main body, allowing visual monitoring of the filtration process, while plastic tubes were used for the inlet and outlet suction, and mesh was integrated into the lid for added filtration support. By incorporating these components, the study successfully constructed a Portable Water Filtration System that was both functional and accessible for household use.

3.6. Testing Water Sample

Figure 4.Unfiltered and Filtered Water Samples

The pre- and post-filtration water samples were tested using specified methods of analysis to evaluate the system's effectiveness. The water samples underwent two test parameters, focusing on physical properties, specifically color, turbidity, and pH. For pH analysis, the Electrometric method was used, while Color determination was conducted through visual comparison, and Turbidity was measured using Nephelometric analysis. Once the water filtration system prototype was completed, water samples were collected from a selected household in St. Peter Marlane, Minuyan, Norzagaray, Bulacan, where residents naturally experienced turbid water. Two samples were gathered: one was stored directly in an appropriate container, while the other underwent the filtration process before being stored. Both samples were kept in regular clear plastic containers for consistency. After collection, the water samples were transported to the ELARSI, Inc. testing facility for further analysis to determine the system's efficiency in improving water quality.

4. Findings

After the laboratory testing, the results of the unfiltered and filtered water samples were compared and evaluated based on the standard parameters for color, turbidity, and pH, as outlined in the Philippine National Standards for Drinking Water (PNSDW, 2017). The test results showed that the color of both filtered and unfiltered water remained the same at 5 TCU, which is within the safe-to-use limit of less than 50 TCU. However, turbidity significantly decreased from 326 NTU (unfiltered) to 28.4 NTU (filtered), indicating an improvement in water clarity, though it still exceeded the maximum standard value of 5 NTU. For pH levels, the filtered water measured 7.32, slightly more alkaline than the 7.05 pH of unfiltered water, showing a minor adjustment but remaining within an acceptable range. These findings indicate that while the filtration system helped reduce turbidity, further modifications may be necessary to meet the recommended standards.

Table 3: Comparison of Filtered and Unfiltered Water Samples based on Color, Turbidity and pH

Categories	Standard Values for Physical Qualities and Bacteriological Quality	Filtered Water	Unfiltered Water
Color	50 TCU - Maximum Value <50 TCU -Safe to use >50 TCU - Not recommended (TCU - True Colour Unit)	5 TCU	5 TCU
Turbidity	5 NTU - Maximum Value <5 NTU - High Water Clarity >5 NTU - Low Water Clarity (NTU - Nephelometric Turbidity Unit)	28.4 NTU	326 NTU
pH	7 - Neutral <7 - increasing acidity >7 - increasing alkalinity	7.32	7.05

5. Conclusions

The findings of this study reveal that a portable filtration system made from locally sourced materials can significantly enhance access to clean (non-potable) water for households. The post-testing results demonstrated visibly cleaner water, with favorable outcomes in terms of the tested water quality parameters, indicating the effectiveness of the proposed filtration mediums in improving water quality.

This study modifies three filter mediums from the study of Mohanad El-Harbawi et al., replacing Bioball with Energy Beads, Zeolites with Ion Resin, and Mineral Sand with Mineral Beads. The original filter mediums resulted in increased turbidity during initial filtration, whereas the new materials are more readily available in the market while maintaining similar filtration functions. Laboratory test results showed that the filtered water met the Philippine National Standards for Drinking Water (PNSDW) of 2017 in terms of color and pH level. The pH level of the filtered water was recorded at 7.32, while its color was measured at 5 true color units (TCU). Although the turbidity did not fully meet PNSDW standards, it improved significantly from 326 to 28.4 nephelometric turbidity units (NTU), indicating enhanced water clarity.

In conclusion, this research provides valuable insights into the development of sustainable water filtration systems that are both affordable and effective. The adapted and modified portable water filtration system can improve the physical properties of water for household washing. The system’s modular design allows for easy replacement of filtration mediums including Energy Beads, Ion Resins, Activated Carbon, Silica Sand, and Mineral Beads enhancing accessibility and usability. Additionally, its portable structure enables transport to different locations, making it suitable for outdoor settings with open water sources that are distant from industrial contamination. A detachable pump can also be utilized when faucets are unavailable.

By utilizing locally available filtration materials, this study presents a cost-effective alternative to conventional filtration systems, supporting sustainable water management. Ultimately, this initiative provides a practical and sustainable solution for communities facing water scarcity, both in everyday life and during disaster recovery. This approach aligns with the United Nations Sustainable Development Goal (UNSDG) 6 for 2030, promoting clean water access and responsible consumption.

Based on the findings and observations of this study, the following recommendations are proposed for future research and practical applications:

- Check Valve Addition: To address the issue of excessive water pressure from a faucet, it is recommended to incorporate an additional check valve. This measure will prevent water backflow to the faucet, thereby maintaining the integrity and functionality of the filtration system.
- Multiple Filtration Testing: Conducting multiple water filtrations using the prototype before laboratory testing is highly recommended. By filtering the water sample more than once, researchers can achieve a more comprehensive analysis and comparison of the laboratory results, leading to more accurate assessments of the filtration system's performance.
- Use of Flexible Pipes: Adapting the usage of flexible pipes is suggested for a more compact and portable outdoor packing of the filtration system. Flexible pipes will facilitate smooth water gathering and enhance the system's usability in various environments.
- 3D Printing of Filter Media Compartments: To ensure no leakages and improve the structural integrity of the filtration system, it is recommended to use 3D printing technology for the filter media compartments. Increasing the number of threading with rubber gasket placeholders will enhance the seal and prevent leaks. This approach will also eliminate the need for Teflon tape, which is typically used for leak prevention.

By implementing these recommendations, future research can build upon the findings of this study and further optimize the design and functionality of portable water filtration systems. These enhancements will contribute to the development of more efficient, accessible, and sustainable solutions for clean water access, aligning with global sustainability goals.

Acknowledgements

The study extends its heartfelt gratitude to all the authors, researchers, and individuals whose works and publications have provided the foundation for this project. Their pioneering ideas and contributions have been instrumental in advancing the field and shaping the direction of this research.

Additionally, the study acknowledges and appreciates all those who have supported it in various ways, even if not explicitly mentioned. Your collective efforts have played a crucial role in making this project a reality, and the study is sincerely grateful for your invaluable contributions. Together, we continue to push the boundaries of knowledge.

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