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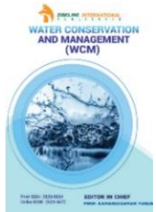

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RESEARCH ARTICLE

DEVELOPMENT AND EVALUATION OF A PORTABLE MULTI-FILTER WATER PURIFICATION DEVICE FOR LOW-INCOME REGIONS

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ABSTRACT

This study presents the development and evaluation of a portable multi-filter water filtration device tailored for low-income regions. The objective was to design a cost-effective solution to address water quality challenges by effectively removing contaminants and ensuring safe drinking water access. Using Autodesk Inventor, key components such as filter housing, caps, bracket, lithium-ion battery, water pump, and switch were integrated into the device. The methodology involved systematic filter selection based on effectiveness, cost, and usability, followed by experimental testing with municipal tap water and river water samples. Results showed significant reductions in metals, particulates, and impurities, enhancing water clarity and quality. While limitations in microscopic analysis were noted, future efforts should focus on advanced imaging equipment and broader field trials to refine the device and address specific community needs. Overall, this study contributes to the advancement of portable and affordable water filtration solutions for underserved populations.

KEYWORDS

Portable Multi-Filter, pH, Water Purification Device, Reverse osmosis, Activated carbon

1. INTRODUCTION

Water, an essential yet often taken-for-granted resource, is the backbone of life on Earth and fundamental to human activity. Covering about 71% of the Earth's surface, it plays a crucial role in domestic use, manufacturing, and agriculture. Despite its abundance, access to clean, potable water remains a critical challenge across the globe due to scarcity, pollution, and the impacts of climate change. These factors contribute to a complex crisis, highlighting the urgent need for sustainable water management and conservation efforts to ensure equitable access for all.

Access to safe drinking water is a fundamental human right and a critical determinant of public health (WHO and UNICEF, 2021). However, millions of people globally, particularly in low-income regions, lack this basic necessity (SDG, 2020). Contaminated water sources contribute significantly to the spread of waterborne diseases, causing immense health burdens and hindering development (Prüss-Ustün et al., 2014). Developing portable and efficient water purification devices specifically designed for low-resource settings offers a promising solution to address this global challenge (Clasen et al., 2007). These devices should be affordable, easy to operate, and capable of removing a broad spectrum of contaminants from various water sources (Yang et al., 2020).

Over half a billion people in rural areas of low-income countries lack access to clean drinking water, facing obstacles such as dispersed housing, inadequate infrastructure, sporadic public water supply, and the high cost of purification technologies. Consequently, many are forced to consume untreated water, exposing them to harmful contaminants including pathogens, trace organic compounds, and heavy metals like copper, zinc, chromium, and arsenic (Mahlangu et al., 2023). Water filters emerge as essential tools in combating these risks, effectively removing pollutants such as bacteria, viruses, and toxic metals. The critical importance of water filters lies in their ability to safeguard against health-threatening impurities, often invisible to the naked eye and stemming from various sources like agricultural runoff and industrial waste, ensuring the consumption of safe, clean water.

A portable multi-filter water purification device is a compact and efficient solution for ensuring clean drinking water. Such devices typically consist of multiple filtration stages to remove impurities effectively. They often include components like filter elements, activated carbon layers, and sterilizing pieces to enhance water quality (Yeongsu et al., 2019; Haoming et al., 2019; Jiang, 2019). These devices are designed for ease of use and transportation, making them suitable for various settings, including remote areas and emergency situations (Xiaoguang et al., 2018). By incorporating innovative features like compressible cylinders, filter membranes, and vacuumized negative-pressure environments, these devices can quickly and conveniently purify water from turbid to clear liquid, meeting drinking water standards (Xiaoguang et al., 2018). Overall, portable multi-filter water purification devices offer a practical and reliable solution for accessing safe drinking water on the go.

A variety of portable water purification devices have been developed to address water contamination issues in low-income regions. These devices incorporate different filtration methods to remove impurities such as pathogens, heavy metals, and volatile organic compounds (Xaba et al., 2022; . Designs include activated carbon and ceramic candle filtration, UV irradiation, and multi-stage filtration systems (Singh et al., 2022; Yusuf et al., 2020). Materials like stainless steel, clay, and activated carbon are utilized for their effectiveness in water purification (Yusuf and Murtala,2020). The devices are designed to be portable, modular, low-cost, and power-efficient, making them suitable for use in underdeveloped areas. Performance evaluations have shown successful removal of contaminants, improvement in water quality, and compliance with international standards for safe drinking water. These innovative solutions offer promising prospects for providing clean and safe drinking

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water to communities in need.

In a study on household water treatment systems, various commercial cartridge filters were assessed for turbidity removal (Afkhami et al., 2021). Testing filters with micron ratings of 10, 5, and 1 in large volume pilot trials revealed that pleated filters could be effectively cleaned and reused, unlike spun and wound filters which were discarded after single use. Additionally, it was demonstrated that pleated filters in series could filter up to 6m^3 of turbid water and be regenerated for three filtration cycles, highlighting their efficiency and durability. A household water purification system was developed utilizing cartridge filtration, UVC disinfection, and chlorination to treat turbid raw water (Maciel et al., 2021). Testing with high turbidity water demonstrated substantial reductions in turbidity, Escherichia coli, and total coliforms. Through a multi-phase approach involving various filtration steps and manual chlorination, water quality for domestic use in rural communities was effectively enhanced. Development of an advanced multifunctional portable water purifier using composite membranes and laccase immobilization for efficient water purification. The developed portable water purifier showed efficient removal rates of micropollutants, microorganisms, and turbidity in less than 5 minutes (Taheran et al., 2019). Research findings reveal the effectiveness of electrospun nanofibers in eliminating water bacteria and viruses, offering a promising avenue for water purification solutions (HMTShirazi et al., 2022; Fahimirad et al., 2021). With demonstrated high removal efficiency for both contaminants, the application of electrospun nanofibers in water treatment emerges as a practical approach for enhancing purification systems.

In response to the critical need for safe drinking water in low-income regions, this study introduces the development and evaluation of a portable multi-filter water purification device. Addressing design considerations, filtration stages, and material selection, this paper aims to elucidate the methodology behind the device's creation and performance assessment. By presenting an innovative solution, the study seeks to contribute to the provision of clean water solutions for underserved communities, thereby advancing global public health initiatives. This study provides a comprehensive overview of the design process and experimental procedures employed, offering insights into filter selection, design considerations, and performance evaluation methodologies.

2. Experimental Design of Water Treatment Device

2.1 Filter Design

The detailed design of the filter device using Autodesk Inventor software, examining each component's functionality and contribution to efficient water filtration. Through visualization and analysis, the design ensures optimization for performance, durability, and ease of assembly.

2.2 Filter Housing

The filter housing design takes center stage in the filtration system, providing a secure enclosure for the GAC and PP cotton filters. Its robust construction ensures proper alignment and positioning, preventing water bypass and maintaining filtration integrity. User-friendly features allow for easy filter replacement and maintenance. Utilizing Autodesk Inventor, the housing undergoes thorough visualization and optimization, enhancing overall performance and usability as shown in Figure 1.

Figure 1: Filter Housing with PP cotton filter inside.

2.3 Filter Caps

The filter caps are vital components of the filtration system, ensuring its functionality and performance. Engineered to securely fit onto the filter housing, they seal and enclose the filters, preventing water leakage or bypass. Equipped with coupling mechanisms, the caps facilitate pipe connection for smooth water flow, ensuring efficient filtration. Meticulously designed and optimized, the caps enhance the system's effectiveness and reliability depicted in Figure 2.

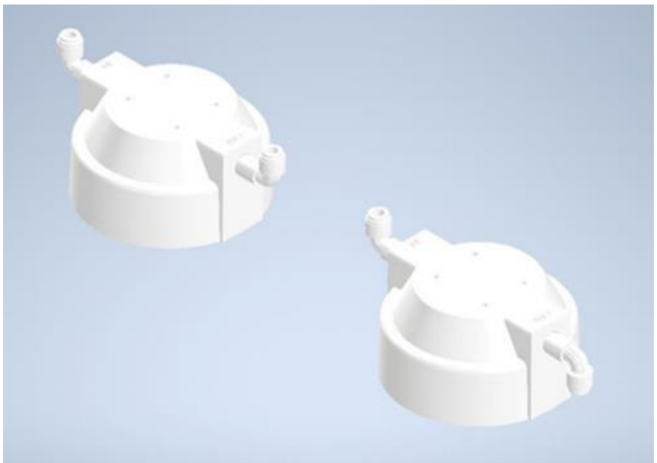


Figure 2: Filter Caps.

2.4 Holding Bracket

The holding bracket is a crucial component of the filtration system, providing structural support and stability to the filter assembly as illustrated in Figure 3. Designed with versatility in mind, it allows for the attachment of a pump and battery, enhancing portability. With strategic mounting points and secure fastening mechanisms, the bracket ensures the pump and battery remain firmly in place during operation and transportation. This portable design enables easy deployment in diverse settings, including rural areas or locations with limited clean water access. The thoughtful engineering behind the holding bracket not only enhances the system's functionality and durability but also improves its practicality and user-friendliness.

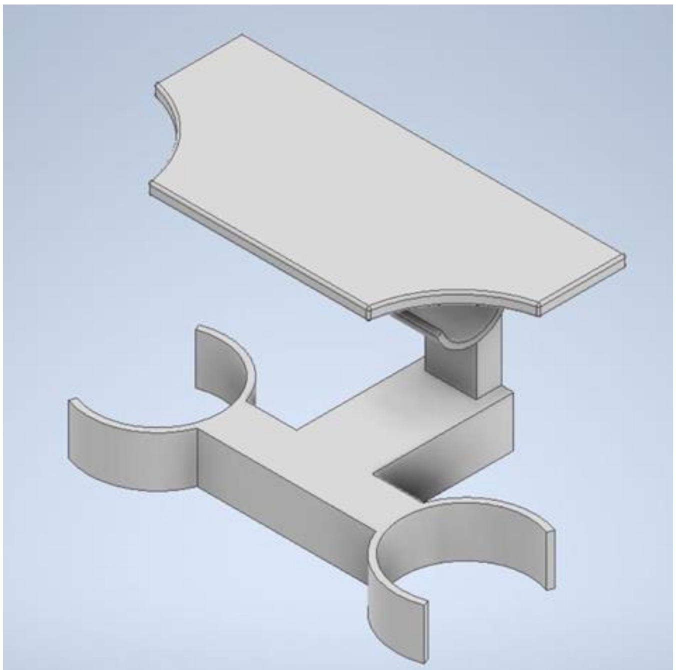


Figure 3: Holding Bracket.

To enhance usability, a Li-ion Battery and water pump are integrated into the filter design, working together for efficient water filtration as shown in Figures 4 and 5. Leveraging the high energy density and rechargeable capabilities of lithium-ion batteries, coupled with the pump's suction power, ensures effective filtration. This combination makes the filter suitable for diverse environments, including remote and off-grid locations.

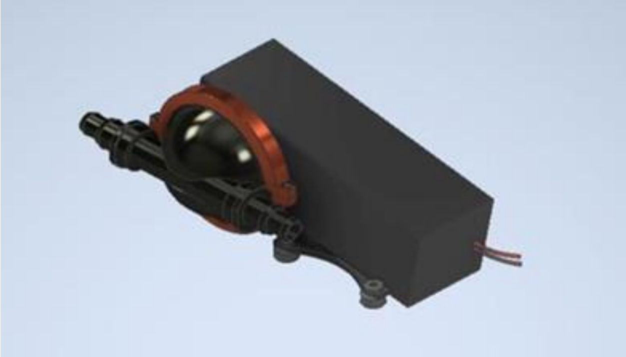


Figure 4. Water Pump.

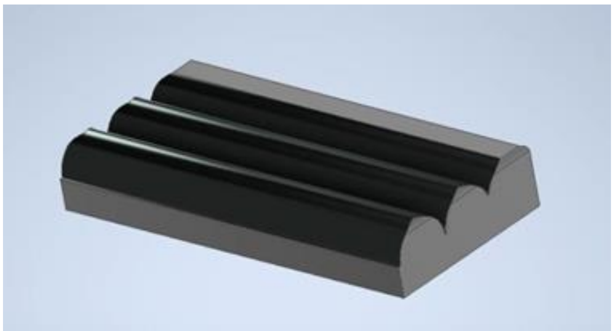


Figure 5. Li-Ion Battery.

Figures 6 and 7 showcase the fully assembled device, complete with a water tank representing the water source for the device, presented in both isometric and side views respectively.

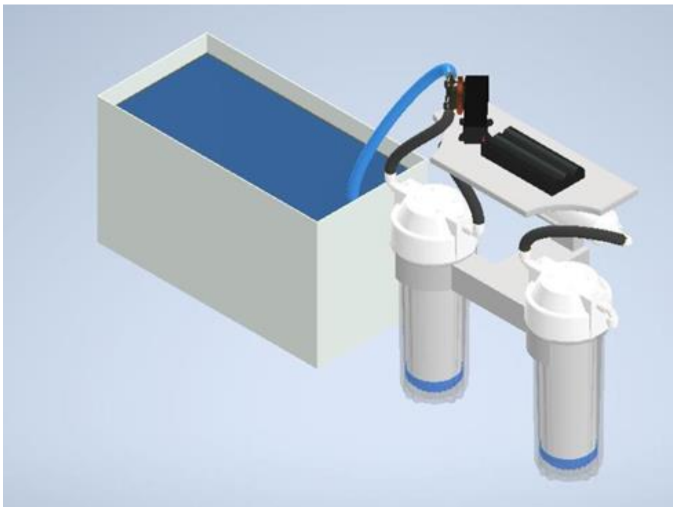


Figure 6: Isometric view of Assembled device.

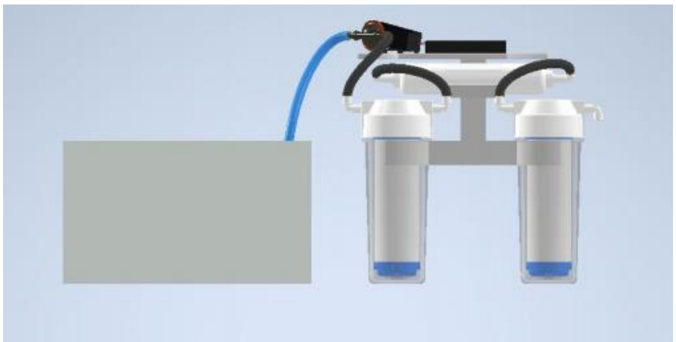


Figure 7: Side view of Assembled device.

2.5 Additional Parts

To enhance mobility and usability, additional components are integrated into the water filtration system, catering to rural settings. A vacuum pump plays a pivotal role, facilitating water suction from the source and forcing it through the filter system, simplifying the process of acquiring clean water. The inclusion of a lithium-ion battery powers the motor, offering a reliable and rechargeable energy source, eliminating the need for constant external power. Furthermore, a switch provides users with effortless control over the motor, enabling quick activation or deactivation as required. These additions enhance the device's mobility, usability, and suitability for deployment in rural areas with limited access to dependable power sources.

3. Methodology

The aim of this experiment is to evaluate the filtration system's efficacy by comparing water quality before and after filtration. Municipal tap water, river water, and bottled mineral water are examined under an optical microscope, with pH measurements taken using pH paper. Bottled mineral water serves as a reference for comparison. The experimental flowchart is depicted in Figure 8.

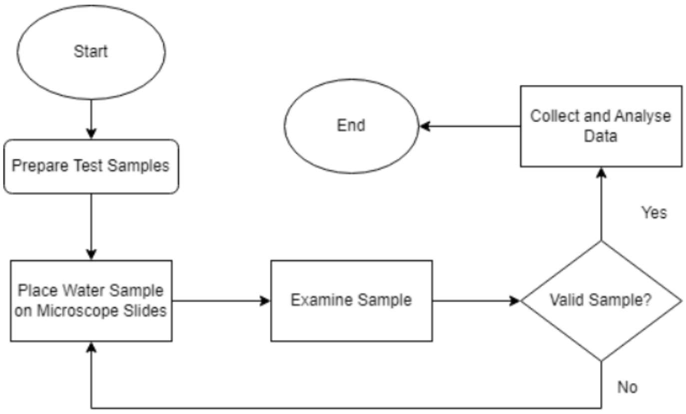


Figure 8: Experimental Flowchart

Sample collection involves obtaining municipal tap water, river water, and bottled mineral water. Each sample is meticulously labeled and placed in plastic cups for consistency. Cups 1 and 2 contain tap water and mineral water, while Cups 3, 4, and 5 hold river water, purified river water, and purified tap water respectively. Microscope slides are prepared by placing a small drop of each water sample on separate slides and covering them with coverslips to create sealed slides. Using an optical microscope, observations are made for visible particles, sediment, or microorganisms present in each sample. pH testing is conducted by dipping pH paper into each sample and comparing the color shift with a pH color chart. Results and discussions will evaluate microscope findings and pH readings for each sample, assessing changes in particle presence and pH levels before and after filtration. Additionally, any alterations in water color will be considered. The filtration system's effectiveness in eliminating impurities and enhancing water quality will be determined through data analysis and interpretation.

4. Results and Discussion

4.1 pH Testing

That pH testing is a crucial method for gauging the acidity or alkalinity of a solution. Ranging from 0 to 14, with 7 indicating neutrality, pH below 7 signifies acidity, while above 7 indicates alkalinity. In our experiment, pH testing was conducted using pH test strips to determine the acidity or alkalinity of water samples before and after filtration by the device. Pure water, considered neutral, should have a pH of 7. The results of pH testing are summarized in Table 4.1.

Table1: pH Test Results

Sample	pH
Municipal Tap water	6
Mineral Water	7
River Water	7
Purified River Water	7
Purified Tap water	7

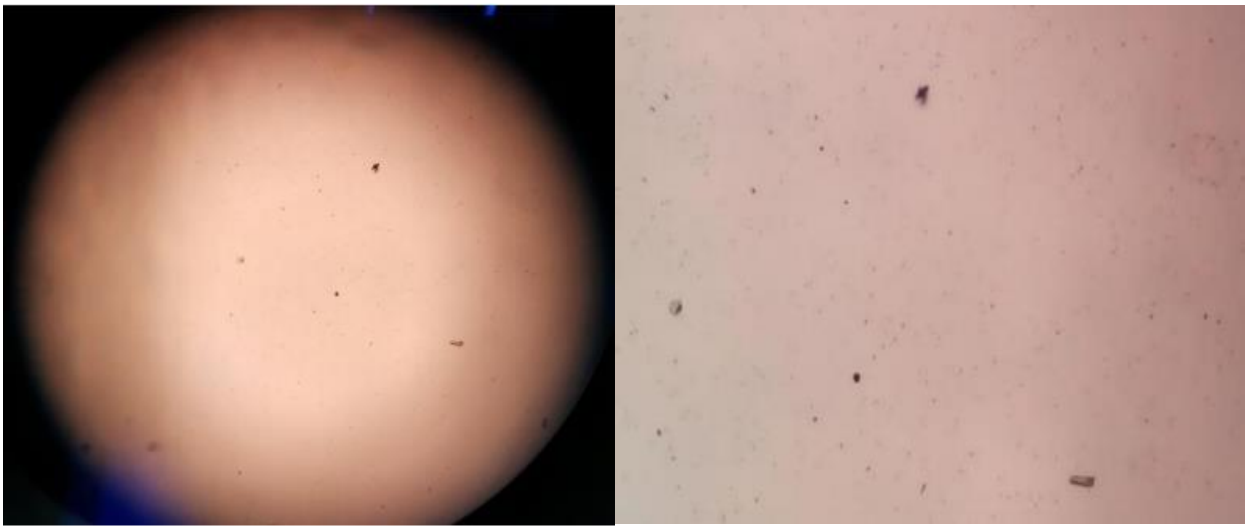
The pH test results reveal that municipal tap water in Malaysia tends to be slightly acidic, consistent with previous studies (Anual, 2020). This acidity can be attributed to factors such as industrial pollution, inefficiencies in the water treatment system, and inadequate training of personnel involved in the treatment process. Interestingly, the device effectively neutralized the water's pH from a slightly acidic 6 to a neutral 7, largely owing to the reverse osmosis (RO) filter. RO filtration involves passing water through a semi-permeable membrane to remove impurities and minerals, which often results in a reduction of both acidic and alkaline substances. However, the extent of pH alteration by a RO filter depends on the water's initial pH and mineral content. Other water samples, including dirty river water, maintained an ideal pH of 7 before and after filtration. This stability in river water pH can be attributed to natural buffers or minerals present in the environment, which help maintain consistent pH levels. However, it's essential to consider the precision and accuracy of pH measurements. Factors such as pH test strip calibration and sensitivity can influence results. To ensure accurate readings, more advanced pH meters should be employed, especially if minor pH changes need to be detected.

4.2 Microscope Results

The experiment utilized a microscope to evaluate the water filtering system's effectiveness, enabling detailed examination and characterization of filtered water samples. This essential scientific tool allowed for the identification and assessment of any remaining particles, microbes, or detritus in the filtered water, showcasing the filtration procedure's efficacy in eliminating impurities.

Comparing filtered water samples from various sources, such as river water and municipal tap water, provided further insight into the system's performance. The microscopic study was instrumental in thoroughly assessing the filtration system and providing tangible evidence of its ability to produce cleaner, clearer water. Under the compound microscope used in the experiment, water samples were examined with objective lenses magnifying at 4x and 10x, alongside a fixed 10x eyepiece lens. Combined, these lenses provided magnifications of 40x and 100x, respectively, allowing for detailed examination and analysis of microscopic particles or microbes present in the samples. A total of five samples were tested, including mineral water as a reference, municipal tap water, river water, and purified tap and river water filtered by the device.

Figures 9(a) and (b) present magnified views of mineral water samples under a microscope, with magnifications of 40x and 100x, respectively. Upon closer inspection, observable traces of elements, potentially including metals or other particles, become apparent. This magnification enables a clearer visualization of the microscopic composition of mineral water, which typically contains various minerals and trace elements naturally present in the water source. These images serve as a reference to compare and assess the appearance of other samples.

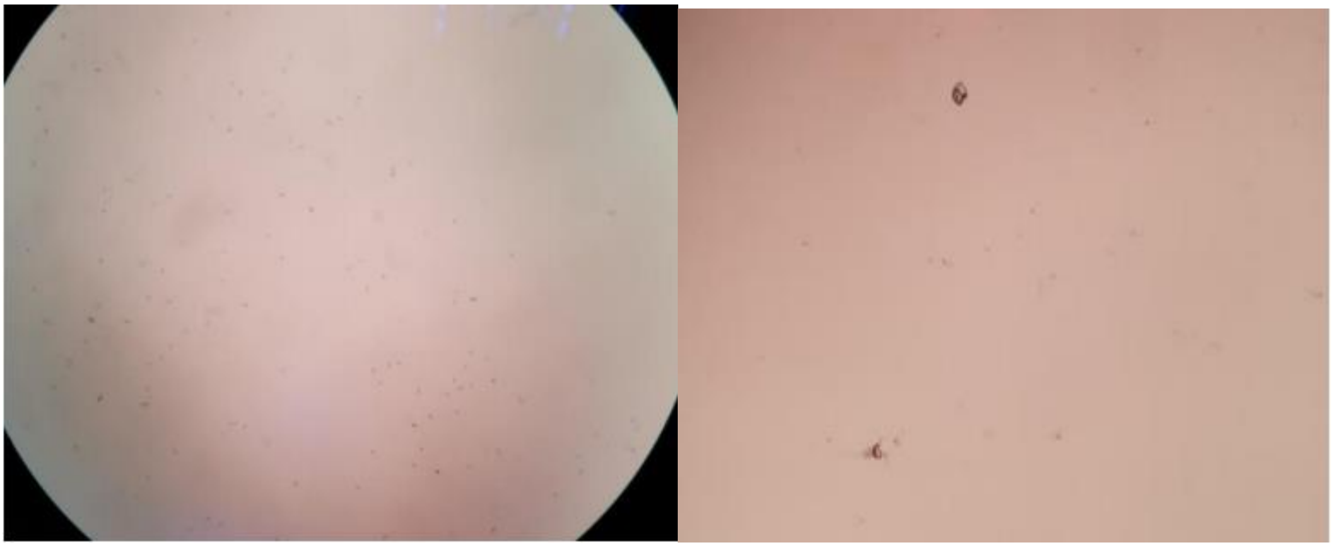


(a) **(b)**

Figure 9: (a) 40x Magnification view of mineral Water (b) 100x Magnification view of mineral Water.

The Figures 10(a) and (b) comparing municipal tap water samples under magnification highlight a greater presence of metals compared to mineral water samples. Several factors contribute to this disparity. Firstly, tap water is sourced from diverse bodies of water, like rivers, lakes, or underground aquifers, which may naturally harbor higher concentrations of metals due to geological influences.

Furthermore, industrial operations, urban runoff, and aging infrastructure can introduce additional metals into the water supply through contamination. These metals may include lead, copper, zinc, cadmium, among others. Additionally, potentially biological material was also observed under the 100x magnification.



(a) **(b)**

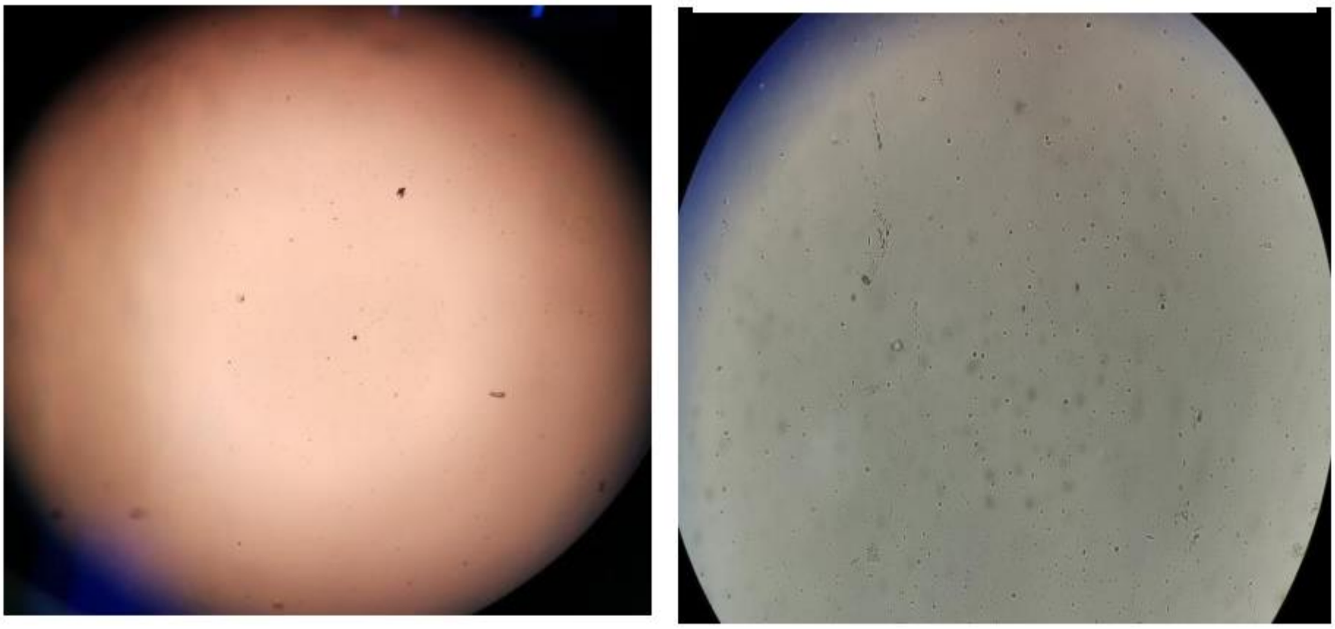
Figure 10: (a) 40x Magnification view of Municipal Tap Water (b) 100x Magnification view of Municipal Tap Water

The magnified images of purified tap water samples depicted in Figures in 11(a) and (b) markedly diminished levels of metals, indicating successful filtration of particulates. The employed filtration process efficiently eliminates a substantial portion of metals and other impurities present in the source water. Utilizing filter media such as activated carbon and reverse osmosis membranes facilitates the removal of microscopic particles and dissolved metals through adsorption, sieving, and ion exchange mechanisms. The meticulous design and optimization of the filtration system ensure proper capture and retention of particulates, resulting in purified tap water containing trace amounts of metals well within safe limits for human consumption. These images offer visual confirmation of the device's efficacy in improving tap water quality by significantly reducing metal concentrations and eliminating particulate impurities.

(a) **(b)**

Figure 11: (a) 40x Magnification view of Purified Tap Water (b) 100x Magnification view of Purified Tap Water.

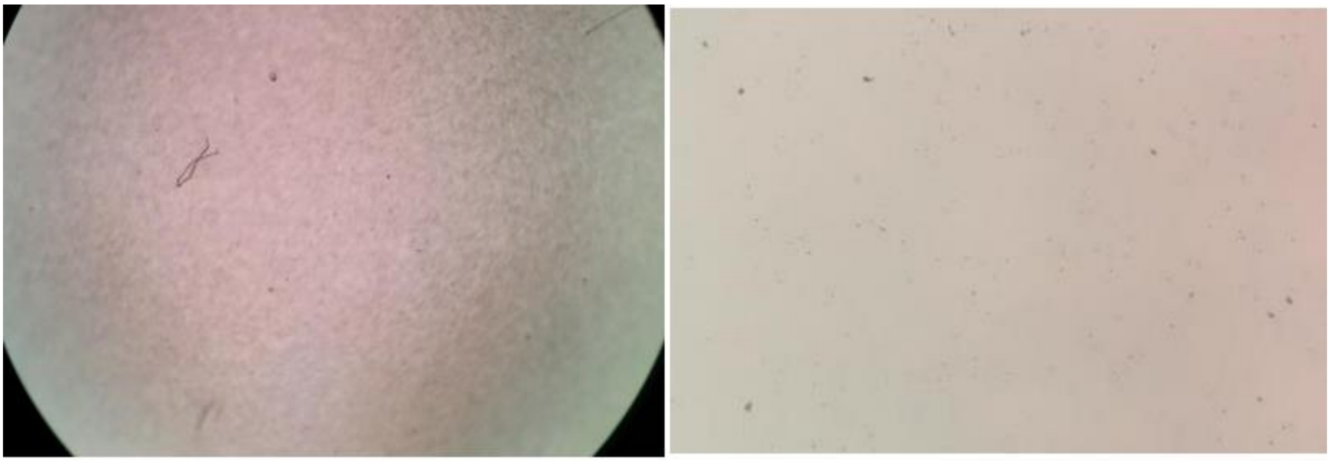
Figures 12(a) and (b) depict the river water sample, showcasing a notable presence of particulates and discoloration, suggestive of various impurities and suspended matter within the water. These observed particulates may stem from natural origins like soil erosion, organic matter, algae, and sedimentation. Moreover, human activities such as industrial discharge, agricultural runoff, and urban pollution can introduce pollutants and debris into rivers, exacerbating the accumulation of particulate matter.



(a) **(b)**

Figure 12: (a) 40x Magnification view of River Water (b) 100x Magnification view of River Water

Figures 13(a) and (b) illustrate the filtered river water obtained through the water filtration device, showcasing a marked enhancement in cleanliness and discoloration removal.Although residual particulates remain, it's clear that the filtration process has effectively diminished the concentration of impurities and suspended matter compared to the original river water sample. The device's integration of multiple filters, including the PP cotton, GAC, and reverse osmosis filters, efficiently captures and eliminates a significant portion of particulate matter, sediment, and dissolved contaminants.



(a) (b)

Figure 13 : (a) 40x Magnification view of Purified River Water (b) 100x Magnification view of Purified River Water

As a result, the filtered river water demonstrates improved clarity and reduced discoloration, indicating a substantial enhancement in water quality. Although it is advisable to conduct comprehensive water quality testing to ensure the safety of the filtered water for human consumption, the significant improvement observed in the filtered river water suggests that it is likely much cleaner and potentially suitable for use after filtration using the device.

5. Conclusion

This study successfully developed a portable and cost-effective water filtration device to address water quality issues in low-income areas. Through meticulous filter selection and design using Autodesk Inventor, the device effectively removed contaminants and improved water clarity. The device's diverse filtration methods, including mechanical, activated carbon, and reverse osmosis, proved effective. Experimental testing with municipal tap water and river water samples revealed successful reduction of metals, particulates, and impurities, enhancing water clarity and quality, although challenges in microscopic analysis highlight the need for advanced imaging equipment. Future efforts should focus on broader field trials and community engagement to refine the device and address specific needs, ultimately advancing access to clean drinking water in underserved communities.

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References

(SDG, 2020). The World Bank, "Sustainable Development Goal 6: Ensure access to water and sanitation for all."

(WHO) World Health Organization and UNICEF, 2021. Joint Monitoring Programme (JMP) for Water Supply, Sanitation and Hygiene.

Afkhami, A., Marotta, M., Dixon, D., Ternan, N. G., Montoya-Jaramillo, L. J., Hincapie, M., Dunlop, P. S., 2021. Assessment of low-cost cartridge filters for implementation in household drinking water treatment systems, Journal of Water Process Engineering, vol. 39, p. 101710, Feb. 2021, doi: 10.1016/j.jwpe.2020.101710.

Anual, Z. F., 2020. Drinking Water Quality in Malaysia: A Review on Its Current Status," International Journal of Environmental Sciences & Natural Resources, vol. 24, no. 2, Apr. 2020, doi: 10.19080/ijesnr.2020.24.556132.

Clasen, T., W. P. Schmidt, T. Rabie, I. Roberts, and Cairncross, S., 2007. Interventions to improve water quality for preventing diarrhoea: Systematic review and meta-analysis, Br Med J, vol. 334, no. 7597, pp. 782–785, Apr. 2007, doi: 10.1136/bmj.39118.489931.BE.

Fahimirad, S., Fahimirad, Z., Sillanpää, M., 2021. Efficient removal of water bacteria and viruses using electrospun nanofibers," Science of the Total Environment, vol. 751. Elsevier B.V., Jan. 10, 2021. doi: 10.1016/j.scitotenv.2020.141673.

Haoming, Haoyan, X., Hang, L., Xu, K., Huanqing, X., Jiashen, W., Du., 2019. Portable water purifier.

HMTShirazi, R., Mohammadi, T., Asadi, A. A., and Tofighy, M. A., 2022. Electrospun nanofiber affinity membranes for water treatment applications: A review, Journal of Water Process Engineering, vol. 47, Pp. 102795, Jun. 2022, doi: 10.1016/j.jwpe.2022.102795.

Jiang, P., 2019. Multi-stage filter element water purifying device.

Maciel, P. M. F., Fava, N. D. M. N., Lamon, A. W., Fernandez-Ibañez, P., Byrne, J. A., and Sabogal-Paz, L. P., 2021. Household water purification system comprising cartridge filtration, UVC disinfection and chlorination to treat turbid raw water, Journal of Water Process Engineering, vol. 43, Pp. 102203, Oct. 2021, doi: 10.1016/j.jwpe.2021.102203.

Mahlangu, O. T., Mubiayi, M. P., and Mamba, B. B., 2023. A facile approach for the synthesis of ceramic filters for methyl orange, chromium and lead removal from water," Physics and Chemistry of the Earth, Parts A/B/C, vol. 129, Pp. 103368, Feb. 2023, doi: 10.1016/j.pce.2023.103368.

Prüss-Ustün, A., Bartram, J., Clasen, T., Colford Jr, J. M., Cumming, O., Curtis, V., Cairncross, S., 2014 .Burden of disease from inadequate water, sanitation and hygiene in low- and middle-income settings: A retrospective analysis of data from 145 countries," Tropical Medicine and International Health, vol. 19, no. 8, pp. 894–905, 2014, doi: 10.1111/tmi.12329.

Shull, A., 2012.The Design and Creation of a Portable Water Purification System, doi: 10.32597/honors/39/https.

Singh, P., Andrabi, S. M., Raina, D. B., and Kumar, A., 2022. Three staged integrated community-based water filter system for potable water by effective removal of contaminants from ground water, Journal of Water Process Engineering, vol. 49, p. 103044, Oct. 2022, doi: 10.1016/j.jwpe.2022.103044.

Taheran, M., Kumar, P., Naghdi, M., Brar, S. K., Knystautas, E. J., Verma, M., and Surampalli, R. Y., 2019. Development of an advanced multifunctional portable water purifier, Nanotechnology for Environmental Engineering, vol. 4, no. 1, Dec. 2019, doi: 10.1007/s41204-019-0054-6.

Xaba, S. G., Tartibu, L. K., and Mashinini, P. M., 2022. Development of a Water Purification Device, in 2022 IEEE 13th International Conference on Mechanical and Intelligent Manufacturing Technologies, ICMIMT 2022, Institute of Electrical and Electronics Engineers Inc., 2022, Pp. 65–71. doi: 10.1109/ICMIMT55556.2022.9845284.

Xiaoguang. , B. Xi. , Z. Ying. , S. Jiawen. , J. Xu. , W. Xiaolin. , Z. Gaoting. , G. Tiancheng. , G. Bin. , L. Lei. , F. Chenglian. , Q. Cong. Meng, "Portable water purification device.," 2018

Xingxing, Rongmao, L., Zhaosheng, Z., Zhenhua, H., Jingbo, C., Yue, W., Qicun, P., Chen, 2019. Portable water sample filtering device.

Yang, H., Xu, S., Chitwood, D. E., and Wang, Y., 2020. Ceramic water filter for point-of-use water treatment in developing countries: Principles, challenges and opportunities, Frontiers of Environmental Science and Engineering, vol. 14, no. 5. Higher Education Press, Oct. 01, 2020. doi: 10.1007/s11783-020-1254-9.

Yeongsu, K., Gangmin, S., Kim, K., 2019. Multi-stage water purification filter. 2019

Yusuf, K. O., and Murtala, M. O., 2020. Development and performance evaluation of a portable household ceramic water filter with activated carbon and magnetic treatment unit, International Journal of Environmental Science and Technology, vol. 17, no. 9, Pp. 4009–4018, Sep. 2020, doi: 10.1007/s13762-020-02747-4.