e-ISSN : 2597-6052
MPPKI MEDIA PUBLIKASI PROMOSI KESEHATAN INDONESIA
Research Articles Open Access

Community Based Biofiltration for Hard Water Treatment in Rural Indonesia: A Public Health Oriented Approach

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ARTICLE INFO

Manuscript Received: 25 Apr, 2025
Revised: 25 Jul, 2025
Accepted: 28 Jul, 2025
Date of Publication: 11 Sept, 2025
Volume: 8
Issue: 9
DOI: 10.56338/mppki.v8i9.7896

KEYWORDS

Biofiltration;
Hard Water Treatment;
Kesambi Wood;
Rice Husk Ash;
Rural Water Quality

ABSTRACT

Introduction: Clean water accessibility remains a persistent challenge in rural Indonesia, especially in regions with naturally hard groundwater. This study evaluated the effectiveness of a novel dual-media biofiltration system that integrates activated carbon from Schleichera oleosa (Kesambi wood) and rice husk ash two locally abundant materials to address hard water contamination in Lanca Village, South Sulawesi. This synergistic combination represents an innovative, low-cost approach with both environmental and public health benefits in rural water treatment.
Methods: Utilizing a quasi-experimental design, three water samples (n = 3) were tested for levels of $CaCO_3$, Ca^{2+}, Mg^{2+}, and Fe before and after filtration.
Results: The filtration system achieved substantial reductions: total hardness ($CaCO_3$) decreased by 55.78%, calcium by 65.99%, magnesium by 40.40%, and iron by 100%. Although these changes did not reach statistical significance ($p > 0.05$) due to the small sample size, the experimental filter outperformed a palm fiber-based control filter across all parameters.
Conclusion: The study highlights the biofilter's role not just as a technical solution, but as a promotive health technology leveraging local materials to meet national water standards while enhancing community resilience. The findings underscore its practical applicability in achieving SDG 6.1 and offer a scalable, sustainable solution for decentralized rural water treatment.

Publisher: Fakultas Kesehatan Masyarakat Universitas Muhammadiyah Palu

INTRODUCTION

Access to clean and safe water remains a fundamental pillar for public health and sustainable development. In rural Indonesia, particularly in areas with limestone geological formations, the challenge of hard water is both prevalent and persistent. Water hardness, characterized by elevated concentrations of calcium (Ca^{2+}), magnesium (Mg^{2+}), and other mineral ions, poses technical, environmental, and health challenges that disproportionately affect rural communities. The Indonesian Ministry of Health sets the maximum allowable limit for total hardness at 500 mg/L; however, many rural water sources exceed this standard (1). This situation is not only a matter of inconvenience but also a public health concern.

In practical household contexts, the use of hard water results in scaling in plumbing systems, reduced soap efficiency, and skin irritation. The excessive intake of mineral rich water has been linked to urolithiasis, impaired nutrient absorption, and gastrointestinal distress (2,3). Furthermore, recent studies suggest a complex relationship between water hardness and health, highlighting potential benefits such as improved bone health, but also risks including hypercalcemia and kidney dysfunction when mineral intake is unregulated (4,5). These health implications call for immediate and contextually appropriate interventions. One such solution is the use of community-based biofiltration systems utilizing locally sourced materials, such as activated carbon from *Schleichera oleosa* (Kesambi wood) and rice husk ash, which have shown potential in reducing water hardness effectively and affordably.

The geological makeup of Indonesia exacerbates the issue. Widespread limestone formations contribute to naturally high levels of calcium and magnesium in groundwater, particularly in unpiped rural areas (6,7). Satellite imagery and hydrogeological surveys confirm the correlation between such geological profiles and the elevated hardness of local water sources. This geological predisposition presents an enduring obstacle to safe water access, which remains an essential component of public sanitation and health efforts (8,9).

Public health strategies globally emphasize the importance of sustainable and community based interventions to address such environmental health challenges. In various low resource settings, measures such as rainwater harvesting, biosand filters, and decentralized filtration systems have been implemented to great effect (10). These strategies align with global frameworks such as the Sustainable Development Goals (SDGs), particularly SDG 6.1, which aims for universal and equitable access to safe and affordable drinking water. Promotive health technologies are integral to achieving this goal, emphasizing community participation, affordability, and adaptability (11).

Among these strategies, biofiltration has emerged as a practical and effective solution. Utilizing locally sourced and naturally abundant materials, biofilters offer a decentralized means of water purification. This study investigates a biofiltration system using activated carbon derived from Schleichera oleosa (Kesambi wood) and rice husk ash. These materials are selected for their high adsorption capacities and chemical properties conducive to removing hardness causing ions. Kesambi wood contains lignin and phenolic compounds that facilitate ion binding, while rice husk ash, rich in silica, enhances surface adsorption and ion exchange (12,13).

While individual studies have demonstrated the efficacy of either activated carbon or rice husk ash in improving water quality, research exploring the synergistic application of both materials remains limited. This study fills that gap by combining these two substances into a single filtration unit and assessing its effectiveness in reducing water hardness under real world conditions in a rural Indonesian village. By employing a quasi-experimental design with both control and experimental groups, the study provides comparative insights into the filtration efficiency and practical implementation of this biofilter technology.

Moreover, this study extends the evaluation of biofilters beyond technical metrics to their potential role in health promotion. Promotive health technologies are defined by their capacity to empower communities to proactively manage their environmental health risks. Through the use of low cost, replicable, and community adaptable filtration units, this intervention demonstrates the potential for public health integration in rural settings. It supports the decentralization of water treatment systems and fosters local ownership and sustainability in water management practices (14,15).

The 2018 Indonesian Basic Health Research (Riskesdas) survey revealed that 7.8% of primary household water sources contain elevated levels of heavy metals or minerals, posing serious health risks. Simultaneously, over 2 billion people globally still lack access to safely managed drinking water (16). This gap underscores the urgency for scalable and sustainable solutions tailored to specific local contexts. In Indonesia, compliance with national clean water standards, including the regulation of total hardness and metal ions, remains a significant challenge (17,18).

This research, therefore, sets out to evaluate the effectiveness of biofiltration using Kesambi wood based activated carbon and rice husk ash as a low cost, environmentally sustainable, and community driven solution to the hard water problem. It seeks to determine whether this filtration method can bring water quality within national standards and contribute to promotive health outcomes. The novelty of this study lies in its integrated approach, combining environmental engineering, public health promotion, and rural empowerment in one replicable model. It aims to provide evidence that such biofiltration technology is not only technically viable but also socially and environmentally beneficial, particularly in the context of Indonesia’s rural water security challenges.

METHOD

This study employs a clear and systematic approach to ensure the reliability and validity of the findings. Below are the components of the methodology:

Research Type

This study adopted a quasi-experimental, non-randomized pretest posttest control group design to evaluate the effectiveness of a locally constructed biofiltration system in reducing the hardness of groundwater in a rural setting. The experiment compared two filtration systems: an experimental filter utilizing activated carbon from *Schleichera oleosa* (Kesambi wood) and rice husk ash, and a control filter employing palm fiber. The primary aim was not only to assess water quality improvements, but also to examine the intervention's potential as a promotive health technology for underserved rural populations.

Populations and Sample

The population in this study consists of all hard water sources within Lanca Village, Tellu Siattinge District, Bone Regency. Sampling was conducted using an integrated approach, with three replicates (n = 3) of 1000 mL each, drawn from a single household where the biofilter unit was installed. This single-site selection was based on logistical feasibility, stable access to the same groundwater source, and controlled environmental exposure during the observation period. Although the design limits external validity, future studies will incorporate multi-site sampling across various households to enhance the generalizability and spatial representativeness of findings.

Research Location

The study was conducted in Lanca Village, Tellu Siattinge District, Bone, South Sulawesi and the sampled water was tested at the Makassar City Public Health Laboratory Center.

Instrumentation or Tools

Figure 1. Device For the Filtration of Hard Water
Source: Author, 2024

This study is an experimental study in which 2 groups of filtration media are compared. The first group is the experimental unit for the experiment (treatment) and the second group is the control group (comparison), then the difference between the measurements of the two is sought, and this difference is considered as the result of the treatment. In Figure 1, the experimental group uses rice husk ash and Kesambi charcoal as adsorbents, while the control group uses palm fiber. The Ca, Mg and Fe content was also measured to supplement the data. The filtration method was chosen because the equipment is simple, cost-effective, and can be easily constructed using local materials available in the community. The estimated cost of a single biofilter unit including PVC tubing, gravel, rice husk ash, and Kesambi wood charcoal is approximately Rp60.000–Rp90.000, which is significantly more affordable compared to biosand filters (Rp300.000–Rp450.000) or ceramic candle filters (Rp150.000–Rp225.000). This affordability supports scalability and adoption in resource limited rural settings.

When analyzing the water quality, the results are checked in the form of a reduction in the hard water content and other parameters. The duration of water treatment in this study is opening the tap for 1 minute, then closing the tap again for 5 minutes, then opening the tap again to take water samples from the treatment. In addition, the sampled water was tested at the Makassar City Public Health Laboratory Center.

Data Analysis

To assess the statistical significance of changes in water quality before and after treatment, the Wilcoxon signed rank test was applied. A threshold of $p < 0.05$ was used to determine statistical relevance. Although no behavioral or perceptional data were included, reductions in contaminant levels were interpreted in the context of public health promotion. Practical significance defined by descriptive reduction percentages was prioritized alongside statistical evaluation to understand the real world applicability of the intervention (19).

Ethical Approval

This study was approved by the Health Research Ethics Committee of Hasanuddin University (Approval Number: 2083/UN4.14.1/TP.01.02/2024). All participants, provided informed consent prior to participating in the study. The confidentiality of all participants was strictly maintained throughout the research process.

RESULTS

The study was conducted from August to September 2024. The analysis of the laboratory tests was carried out at the Makassar City Public Health Laboratory Center.

Baseline Water Quality

The water quality assessment conducted prior to the filtration process confirmed that the groundwater used by residents of Lanca Village exhibited levels of hardness and calcium significantly exceeding national clean water standards. Total hardness was measured at 615.11 mg/L $CaCO_3$, and calcium levels reached 396.41 mg/L, both surpassing the limits of 500 mg/L and 200 mg/L, respectively, as stipulated by the Indonesian Ministry of Health. Meanwhile, magnesium and iron levels 12.72 mg/L and 1.0 mg/L, respectively were within acceptable thresholds (Table 1).

These findings are consistent with existing literature noting that aquifers in limestone dominated geological areas often contain mineral concentrations exceeding safe thresholds (20,21). Households using such untreated hard water regularly encounter scaling, soap inefficiency, and health risks like kidney stones and digestive disturbances (4).

Table 1. Measurement Results for Hard Water Before the Use of Filter Media

Parameters	Results	Quality standard*
$CaCO_3$	615,11	≤500 mg/l
Ca	396,41	≤200 mg/l
Mg	12,72	≤15 mg/l
Fe	1,0	≤1 mg/l

Source: Primary Data, 2024

Effectiveness of Experimental Biofilter

After filtration using a system containing activated carbon from *Schleichera oleosa* and rice husk ash, water samples exhibited a considerable reduction across all parameters. The average concentrations post filtration were 261.12 mg/L for $CaCO_3$, 103.67 mg/L for Ca, 8.06 mg/L for Mg, and 0.00 mg/L for Fe, equating to respective reductions of 55.78%, 65.99%, 40.40%, and 100% (Table 2).

These values fell well within the Indonesian national clean water standards, demonstrating the biofilter's efficiency in removing contaminants of concern. The reference values for total hardness, calcium, magnesium, and iron are based on the Indonesian Ministry of Health Regulation No. 32 of 2017 concerning Environmental Health Quality Standards and Water Health Requirements**.** The high porosity and chemical adsorption capability of both filtration media explain these outcomes. Kesambi wood-based carbon is known for its strong affinity toward divalent ions due to its phenolic compounds and porous matrix (23,24). Rice husk ash contributes additional functionality through silica induced ion exchange (25,26)

Table 2. Measurement Results of Hard Water with Experimental Filter Media

Parameter	Measurement 1	Measurement 2	Measurement 3	Mean ± SD	Median	Min	Max	Quality Standard
$CaCO_3$ (mg/L)	271.99	256.08	255.30	261.12 ± 9.36	256.08	255.30	271.99	≤ 500 mg/L
Ca (mg/L)	134.80	89.93	86.29	103.67 ± 27.16	89.93	86.29	134.80	≤ 200 mg/L
Mg (mg/L)	7.58	8.34	8.25	8.06 ± 0.40	8.25	7.58	8.34	≤ 15 mg/L
Fe (mg/L)	0.00	0.00	0.00	0.00 ± 0.00	0.00	0.00	0.00	≤ 1 mg/L

Source: Primary Data, 2024

Comparison with Control Filter

The control filtration unit, which used palm fiber as its primary medium, also reduced contaminant levels but with slightly less efficacy than the experimental setup. Post treatment concentrations averaged 280.52 mg/L ($CaCO_3$), 115.32 mg/L (Ca), 8.09 mg/L (Mg), and 0.00 mg/L (Fe), resulting in respective reductions of 54.33%, 62.44%, 32.00%, and 100% (Table 3).

Palm fiber demonstrated effective physical filtration and minor chemical interactions. However, its lower adsorptive surface area and absence of specialized chemical binding functionalities make it less efficient in reducing mineral ions when compared to the synergistic Kesambi–rice husk combination (27,28).

Table 3. Measurement Results for Hard Water with Control Filter Media

Parameter	Measurement 1	Measurement 2	Measurement 3	Mean ± SD	Median	Min	Max	Quality Standard
$CaCO_3$ (mg/L)	280.91	280.14	280.52	280.52 ± 0.38	280.52	280.14	280.91	≤ 500 mg/L
Ca (mg/L)	148.89	99.82	97.25	115.32 ± 29.21	99.82	97.25	148.89	≤ 200 mg/L

Parameter	Measurement 1	Measurement 2	Measurement 3	Mean ± SD	Median	Min	Max	Quality Standard
Mg (mg/L)	8.65	7.84	7.77	8.09 ± 0.47	7.84	7.77	8.65	≤ 15 mg/L
Fe (mg/L)	0.00	0.00	0.00	0.00 ± 0.00	0.00	0.00	0.00	≤ 1 mg/L

Source: Primary Data, 2024

Statistical Analysis

Statistical analysis using the Wilcoxon signed rank test was conducted to evaluate the significance of reductions in all four parameters ($CaCO_3$, Ca, Mg, Fe). As shown in Tables 4 and 5, none of the measured differences reached statistical significance ($p > 0.05$), with p values ranging from 0.083 to 0.109.

Despite these findings, which can be attributed to the limited sample size ($n = 3$) and low variance, the descriptive statistics suggest meaningful improvements in water quality. The replicates were taken from a single filtration system under identical operational conditions to evaluate consistency in treatment performance. While generalizability is limited, similar community-based water treatment interventions have demonstrated strong outcomes in rural settings (29), reinforcing the practical relevance of our findings despite the small sample . The lack of statistical significance does not negate the practical utility of the biofilter, as supported by recent literature advocating for broader metrics like effect size and predictive impact in small sample public health experiments (30,31). This view is echoed in Hartgerink's (2016) reanalysis of prior experimental findings, which illustrates that statistical non-significance especially in underpowered designs can obscure practically relevant effects that deserve interpretive attention (4).

Table 4. Result of the Wilcoxon Test Calculation Experiment Filter Media

Parameters	Measurement Time	Mean ± SD	Median	Minimum	Maximum	Sig
Caco3	Before Filtration	615.11 ± 0.00	615.11	615.11	615.11	.109
	After Filtration	256.46 ± 1.38	256.08	255.30	257.99	
Ca	Before Filtration	396.41 ± 0.00	396.41	396.41	396.41	.109
	After Filtration	88.81 ± 2.19	89.93	86.29	90.22	
Mg	Before Filtration	12.72 ± 0.00	12.72	12.72	12.72	.109
	After Filtration	8.41 ± 0.21	8.34	8.25	8.65	
Fe	Before Filtration	1.00 ± 0.00	1.00	1.00	1.00	.083
	After Filtration	0.00 ± 0.00	0.00	0.00	0.00	

Source: Primary Data, 2024

The results of Table 4 showed that the parameters $CaCO_3$, Ca, Mg and Fe for the concentration of the water samples in the filtration device using the experimental filter media combination of Kesambi wood activated carbon and rice husk ash have no effect or no significant difference in the quality of the parameters tested. This is evident from the significant value (sig), which has a value > 0.05.

Table 5. Result of The Wilcoxon Test Calculation Control Filter Media

Parameters	Measurement Time	Mean ± SD	Median	Minimum	Maximum	Sig
Caco3	Before Filtration	615.11 ± 0.00	615.11	615.11	615.11	.109
	After Filtration	280.5 ± 0.39	280.52	280.14	280.91	
Ca	Before Filtration	396.41 ± 0.00	396.41	396.41	396.41	.109
	After Filtration	99.11 ± 1.62	99.82	97.25	100.25	
Mg	Before Filtration	12.72 ± 0.00	12.72	12.72	12.72	.109
	After Filtration	7.85 ± 0.09	7.84	7.77	7.94	
Fe	Before Filtration	1.00 ± 0.00	1.00	1.00	1.00	.083
	After Filtration	0.00 ± 0.00	0.00	0.00	0.00	

Source: Primary Data, 2024

The results of Table 5 showed that the parameters $CaCO_3$, Ca, Mg and Fe for the concentration of the water samples in the filtration device using control filter media have no influence or no significant difference in the quality of the tested parameters. This can be seen from the significant value (sig), which has a value > 0.05.

DISCUSSION

Interpretation of Key Findings

The findings of this study provide compelling evidence for the effectiveness and promotive health potential of low cost biofiltration systems in treating hard water in rural settings. The combination of *Schleichera oleosa* (Kesambi wood) activated carbon and rice husk ash yielded substantial reductions in key water quality parameters $CaCO_3$, Ca, Mg, and Fe placing post filtration values well within Indonesian national standards. Although Wilcoxon test results indicated no statistically significant differences due to the small sample size, the descriptive reductions and practical implications remain noteworthy.

The biofilter's notable performance, especially in reducing calcium (by 65.99%) and eliminating iron entirely, aligns with findings from previous studies that support the effectiveness of rice husk ash and activated carbon in water purification applications (12,13). This synergy of materials is rooted in their respective chemical and structural properties: the high lignin and phenolic compound content of Kesambi wood allows for effective ion adsorption, while the silica rich rice husk ash offers robust ion exchange and surface interaction capabilities. These mechanisms explain the substantial improvements observed in the study's post treatment results.

The relevance of this study extends beyond technical efficacy to its position within the broader scope of public health promotion. In rural Indonesia, and globally in similar contexts, water hardness presents not just an infrastructural challenge but a public health risk. Conditions such as urolithiasis, dermatological irritation, and digestive issues have all been linked to prolonged consumption of mineral rich water (2,3). By substantially lowering these contaminants using local, affordable materials, the biofilter presents a practical solution that aligns with the principles of promotive health technologies.

Promotive health strategies emphasize the empowerment of communities to proactively manage their health environments. In this light, the biofilter is more than a tool for water purification it is a vehicle for public health education, community participation, and local innovation. To ensure long-term effectiveness, future implementations should include standardized metrics such as turbidity increase rates, ion breakthrough curves (e.g., for Ca^{2+} and Mg^{2+}), pressure drop over time, and periodic household surveys on filter usage, maintenance behavior, and user satisfaction. These indicators can help track filter degradation and user compliance to inform program sustainability and targeted technical support. Its affordability, replicability, and compatibility with household scale infrastructure make it a feasible addition to Indonesia's existing public health framework, such as the STBM (Sanitasi Total Berbasis Masyarakat) approach. Moreover, its alignment with SDG Target 6.1 underscores its relevance in the international agenda for equitable and sustainable access to clean water (11,32).

From a public policy perspective, the integration of biofiltration systems into rural health promotion programs offers several advantages. These include cost savings from reduced disease burden, increased resilience of communities to environmental health risks, and opportunities for local economic engagement through the sourcing and production of filter materials (33,34). Furthermore, the empowerment of communities to take control of their water management practices builds long term sustainability into public health interventions.

Despite these strengths, several limitations warrant discussion. The lack of statistically significant outcomes limits the strength of inferential claims. However, as argued by Greenland et al. (2016) and Imbens (2021), p values alone are not definitive indicators of practical importance (30,35). Especially in environmental health studies with small sample sizes, researchers are encouraged to consider effect sizes and real world relevance alongside statistical results (25,31). In this study, the substantial descriptive improvements in water quality clearly indicate practical utility, even in the absence of $p < 0.05$.

Further challenges include material variability and environmental dependencies. While rice husk ash and Kesambi wood are locally abundant in many parts of Indonesia, regional differences in ash composition or wood porosity could affect filtration outcomes. Future research should explore longitudinal performance, seasonal variability, and adaptation of the filter design to other community contexts (36). The limited sample size in this study was primarily due to logistical and infrastructural constraints, including restricted access to multiple rural households with similar hard water profiles and controlled settings for experimental installation. In addition, while this study focused solely on physicochemical outcomes, future studies may incorporate microbial assessments to evaluate broader water safety profiles.

The discussion must also acknowledge the potential for broader community empowerment through such technologies. As local stakeholders engage in building, maintaining, and possibly modifying filtration systems, they contribute not only to their own health outcomes but also to local innovation ecosystems. Evidence from community driven development projects shows that participatory approaches increase the sustainability and effectiveness of health interventions (37,38).

In conclusion, the biofilter evaluated in this study is an example of contextually appropriate health technology that bridges environmental engineering and public health. It demonstrates that significant improvements in water quality are achievable through the integration of local materials and community based methods. Compared to other decentralized water treatment models such as biosand filters, ceramic candle filters, and household chlorination this system offers advantages in terms of simplicity, material accessibility, and cultural acceptance in rural Indonesian contexts. While chlorination may offer effective microbial control, it lacks mineral removal capacity; biosand filters require larger volumes and periodic maintenance. The rice husk Kesambi combination biofilter thus provides a locally tailored solution with complementary health and environmental benefits.

Comparison with Previous Studies

The findings of this study reinforce existing evidence on the capacity of natural biofilters to reduce water hardness effectively. Prior studies by Budiman and Mentarianata (2015) demonstrated that rice husk ash media alone could reduce total hardness by up to 68%, while Sarifudin (2022) showed that activated carbon derived from Kesambi wood significantly decreased calcium and magnesium concentrations. By integrating both filtration media, our study achieved a 65.99% reduction in calcium and a 100% removal of iron, surpassing the results of single media filtration in both selectivity and removal rate (12,13).

Nurullita et al. (2014) investigated the role of contact time in optimizing $CaCO_3$ reduction using activated carbon, showing that extended exposure to the medium enhances the filtration outcome (3). While our experiment applied a fixed contact time, the resulting 55.78% reduction in $CaCO_3$ still parallels the efficacy reported in controlled laboratory settings. This consistency underscores the inherent efficiency of the combined media, even when applied under simplified, real world conditions relevant to rural water treatment.

Yoshimoto et al. (2024) and other public health focused studies have emphasized the health risks associated with prolonged consumption of mineral rich or hard water, linking it to urolithiasis and gastrointestinal disturbances (2). Our findings confirm the potential of household scale filtration systems in reducing these risks, particularly through the complete removal of iron a contaminant known for both aesthetic and health concerns. By achieving these outcomes using affordable and sustainable materials, the filtration method presented here supports both environmental and health objectives.

Unlike many previous studies that primarily focus on technical parameters or controlled environments, this research frames biofiltration as a promotive public health technology. Its alignment with community health strategies and rural environmental management makes it especially relevant for areas lacking centralized water infrastructure. The adaptability and simplicity of the filter design allow for community driven implementation, thereby supporting broader goals such as SDG 6.1 and Indonesia's STBM program in promoting universal access to safe drinking water.

Implications for Public Health and Rural Environments

The data indicate that both filter systems effectively reduced water hardness and iron content to meet national standards. However, the experimental filter consistently outperformed the control across all parameters. In real world terms, this means rural households using the Kesambi wood and rice husk ash biofilter can significantly reduce their exposure to mineral related health risks such as urolithiasis, dry skin, and gastrointestinal issues (39,40).

Furthermore, the intervention's low cost and use of local materials support its scalability and sustainability in under resourced communities. As a promotive health technology, the biofilter aligns with SDG Target 6.1 and can serve as a practical model for decentralized water treatment in similar rural settings across Indonesia and beyond.

In summary, although statistical significance was not achieved, the practical effectiveness of the biofiltration device is clear. Its replicability, affordability, and environmental relevance make it a compelling candidate for broader adoption in community level water safety initiatives.

Limitations and Cautions

This study has several limitations that may influence the interpretation and generalizability of the findings. The research was conducted using a laboratory-scale prototype with a limited sample size and without variation in operational conditions such as flow rate, temperature, or long-term use cycles. As such, the filtration performance reported may not fully represent its efficacy under diverse, real-world rural household scenarios. Additionally, the analysis was limited to physicochemical parameters (calcium, $CaCO_3$, and iron), without including microbiological assessments or user behavior factors. This narrows the scope of health risk mitigation evaluated in the study. Future studies should address these aspects to ensure a more holistic understanding of the biofilter's potential for rural health promotion.

Recommendations for Future Research

Future research should examine the long-term performance of biofilters under actual household conditions, including variable flow rates, maintenance behavior, and seasonal water quality changes. Testing the filtration media across different geographical areas and water sources will help determine the adaptability and resilience of the system beyond controlled settings. Incorporating evaluations of microbiological contaminants such as *E. coli* or protozoa would also provide a more comprehensive assessment of health risks and benefits. Moreover, socio-economic aspects such as user acceptability, willingness to maintain the system, and cost-effectiveness should be investigated to support community-level implementation. Interdisciplinary studies that integrate technical performance with behavioral and economic analyses are recommended to inform scalable models of water treatment that align with rural health promotion goals and national public health strategies.

CONCLUSION

This study has demonstrated that biofiltration using a combination of *Schleichera oleosa* (Kesambi wood) activated carbon and rice husk ash effectively reduces hardness parameters $CaCO_3$, Ca^{2+}, Mg^{2+}, and Fe in groundwater exceeding national quality standards. Although the statistical significance was not established due to a limited sample size, descriptive data confirmed meaningful reductions, particularly in calcium (65.99%) and iron (100%). The small sample size was primarily due to logistical and infrastructural limitations, including restricted access to multiple rural households with comparable water profiles, and the need to maintain experimental consistency within a controlled setting. Nevertheless, the filtration outcomes support the suitability of this technology for rural Indonesian settings, where technical infrastructure is limited and households remain exposed to high mineral content in untreated water.

The use of locally available agricultural and forestry by products offers an environmentally sustainable solution that aligns with national health strategies and SDG 6.1. Moreover, this intervention represents a promotive health technology that encourages community empowerment through low cost, replicable, and user friendly systems. Its integration into rural health education, public sanitation programs, or community led water safety planning has the potential to enhance water access equity and improve environmental health outcomes in low resource settings.

AUTHOR'S CONTRIBUTION STATEMENT

For research articles with multiple authors, a brief paragraph mentioning the contribution of each author can be provided. Researchers in the field of environmental health technology contribute greatly to creating innovative solutions to improve environmental quality to support public health. This research develops technology with environmentally friendly and efficient water disinfection methods. In addition, the development of environmental quality, accelerates the detection of environmental problems that could potentially threaten health. This contribution not only reduces the burden of environment-related diseases, but also supports the achievement of sustainable development goals in the global health sector.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

The use of generative artificial intelligence (AI) tools or AI-supported technologies—such as Grammarly and DeepL—during the drafting of this research paper.

SOURCE OF FUNDING STATEMENTS

The funding agency was not involved in the design, implementation, analysis, interpretation, or writing of this research paper.

ACKNOWLEDGMENTS

The researcher would like to thank the Head of Lanca Village, Bone Regency and Public Health Laboratory Center, Makassar City for their support and assistance in receiving permission and water measurements.

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