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Solar-Powered Filtration: An Investigation into Clean Water Treatment Performance

Firda Herlina[1*], Faisal Rahman[1], Ruliana F[1], Jainal Arifin[1], Agus Wiramsya[1], M.Suprapto[1], Ice Trianiza[1], Rendi[1], Ahmadil Amin[1], Mujiburahman[1], Dwiretnosari[1], Yuli Panca[2]

[1]Islamic University Kalimantan Muhammad Arsyad Al Banjari Banjarmasin Indonesia
[2]INTI International University, Faculty of Engineering and Quantity Surveying, Negeri Sembilan, Malaysia

***Email:** tanyafirda@gmail.com,

Abstract

Untreated wastewater significantly threatens both environmental health and human well-being, highlighting the importance of effective water treatment worldwide. This study evaluates a solar-powered filtration system as a practical alternative, especially for areas with limited infrastructure. The system uses solar panels to drive a water pump and filtration unit, with Powdered Activated Carbon (PAC) and aluminum sulfate serving as the primary filtration materials. Tests were carried out on samples from rivers and wells. Laboratory analysis showed that, after treatment, river water contained Fe = 0.81 mg/L, Mn = 0.08 mg/L, and hardness = 106.8 mg/L, while well water contained Fe = 0.26 mg/L, Mn = 0.04 mg/L, and hardness = 53.4 mg/L. These results indicate a substantial reduction in contaminants, bringing water quality close to clean water standards. Overall, the solar-powered system presents an effective, renewable, and eco-friendly method for producing safe water in remote or infrastructure-limited regions.

Keywords

Renewable energy, eco-friendly technology, clean water process, solar panels

Introduction

The global demand for clean water has never been greater. Population growth, rising pollution levels, and degradation of water sources have intensified the scarcity of safe water—especially in remote regions with limited infrastructure (UN-Water, 2024; UNESCO, 2023). Both groundwater and surface water supplies are declining due to deforestation, land-use change, over-extraction, and contamination (Global Water Institute, 2024; UN-Water, 2024).

Although Indonesia is an archipelagic country with abundant freshwater, many communities still face challenges in accessing safe water. Approximately 33.4 million people lack clean water, and 70 million do not have adequate sanitation, with only 24.3% of rural residents having access to safely managed drinking water in 2022 (DFAT). Factors such as pollution, deforestation, and land-use changes further affect water quality (Munfiah et al., 2013;

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Andriyanto, 2010; Juniarto et al., 2013). In villages like Anjir Muara Lama, rivers have shrunk, wells have dried up, and the remaining water is often discoloured and emits unpleasant odors, making it unsafe for consumption. These local conditions reflect broader global trends: 2.2 billion people worldwide still lack safely managed drinking water, and nearly half of the global population experiences severe water scarcity for at least one month each year (UNICEF/WHO, 2023; UN Water, 2024).

Several traditional filtration methods, such as cloth filtration, rapid sand filtration, and slow sand filtration, have been used to improve water quality. pH is a key parameter in water treatment, indicating a solution's acidity or alkalinity. It must be controlled during processes like disinfection, coagulation, softening, and corrosion prevention. Water is acidic below pH 7, neutral at 7, and alkaline above 7 (Effendi et al., 2003). While pH does not directly affect human health, water with pH < 6.5 can corrode pipes and release toxic metals, whereas pH > 8.5 may cause scaling in metal pipes.

Even though water pumps are now widely available and accessible, the limited availability of electricity in rural areas has become a major operational challenge, as many regions remain unconnected to the national power grid (Febrina et al., 2015). This limitation increases the cost and restricts the operation of conventional pumping systems. To address this issue, the utilization of solar energy has emerged as a promising, sustainable, and environmentally friendly solution. A solar-powered water pumping system converts sunlight into electrical energy through solar panels, which then operate water pumps, particularly during daylight hours when sunlight intensity is sufficient (Arifin et al, 2024).

Research methodology

This study investigates the effectiveness of a solar-powered water filtration system in providing safe and clean water for rural communities with limited electricity access. The research objectives are to design and build a filtration system powered by solar panels that functions independently of the main power grid, and to assess its performance in reducing contaminants, including iron (Fe), manganese (Mn), and overall water hardness. An experimental approach was used in Anjir Muara Lama Village, Anjir Muara District, Barito Kuala Regency, South Kalimantan.

The system consisted of a solar panel, DC water pump, and filtration unit utilizing Powdered Activated Carbon (PAC) and aluminum sulfate as filtration media (Zulfikar, 2014). Water samples were collected from river and well sources and filtered under natural sunlight conditions. Laboratory tests were conducted in Banjarmasin City to analyze pH, Fe, Mn, and hardness levels before and after filtration. The system's performance was assessed based on contaminant reduction, solar energy utilization, pump flow rate, and filtration efficiency over varying sunlight intensities. Figure 1 illustrates the framework and operational setup of the solar-powered water filtration system, consisting of a solar panel, DC pump, and filtration unit equipped with Powdered Activated Carbon (PAC) and aluminum sulfate as the main filtration media. Figure 1 is shown solar panel water filtration system framework used in the test.

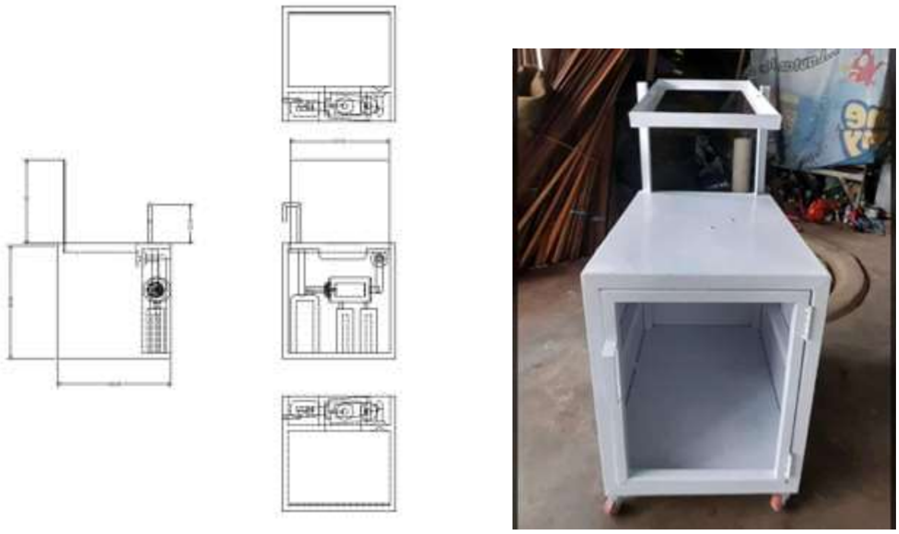

Figure 1. Solar panel water filtration system framework and setup.

Results and discussion

Water quality analysis before filtration

Laboratory test results for river and borewell water were compared against the Clean Water Quality Standards to assess the performance of the solar-powered filtration system, as outlined below.

- *River water sample*

The river water sample showed murky turbidity and noticeable color, indicating the presence of suspended solids and organic matter. The iron (Fe) concentration was 1.42 mg/L, slightly exceeding the clean water standard of 1.0 mg/L, while manganese (Mn) reached 8.55 mg/L, significantly higher than the permissible limit of 0.5 mg/L. The hardness value was 408 mg/L, still within the acceptable range of ≤500 mg/L. The pH level was 6.05, which is slightly acidic and below the acceptable range (6.5–9.0). These results indicate that the river water sample is not suitable for direct consumption without treatment due to excessive metal content and low pH.

- *Bore well water sample*

The bore well water sample appeared clear and slightly murky, showing a much better initial quality compared to river water. The iron (Fe) and manganese (Mn) concentrations were 0.04 mg/L and 0.05 mg/L, respectively — both well below the standard limits. The hardness value of 136.15 mg/L was within the acceptable limit of ≤500 mg/L, and the pH level of 6.88 fell within the ideal range (6.5–9.0). These results confirm that bore well water meets the clean water quality standards and is suitable for household use after minimal treatment.

- *Water quality after filtration*

After filtration using the solar-powered water purification system, the quality of both river (well) water and bore well water showed significant improvement across all measured parameters compared to pre-filtration values. Well (River) water sample post-filtration analysis indicated that the turbidity and color of the well (river) water became clear, demonstrating the effectiveness of the filtration process in removing suspended solids and organic impurities. The iron (Fe) concentration decreased to 0.81 mg/L, falling below the clean water standard of 1.0 mg/L, while manganese (Mn) was reduced to 0.08 mg/L, also well within the acceptable limit of 0.5 mg/L. The hardness value dropped to 106.8 mg/L, significantly below the standard limit (≤500 mg/L), indicating a softening effect of the filtration media. The pH value measured 6.03, which is slightly below the recommended range (6.5–9.0), suggesting a mildly acidic nature likely due to residual coagulants or dissolved carbon dioxide. Table 1 is presented comparison results of testing before and after filtration process using solar cell.

Table 1. Results of testing before and after filtration.

Sample	Test parameter	Before filtration (lab test results)	After filtration (lab test results)	Clean water standard
River water	Turbidity	Murky	Clear	–
	Color	Colored	Clear	–
	Iron (Fe) (mg/L)	1.42	0.81	1.0
	Manganese (Mn) (mg/L)	8.55	0.08	0.5
	Hardness (mg/L)	408	106.8	500
	Acidity (pH)	6.05	6.03	6.5 - 9.0
Bore well water	Turbidity	Slightly murky	Clear	–
	Color	Clear	Clear	–
	Iron (Fe) (mg/L)	0.04	0.26	1.0
	Manganese (Mn) (mg/L)	0.05	0.04	0.5
	Hardness (mg/L)	136.15	53.4	500
	Acidity (pH)	6.88	6.07	6.5 – 9.0

Bore well water sample

The bore well water sample also exhibited clear turbidity and color following filtration, reflecting efficient particulate removal. The iron (Fe) content decreased to 0.26 mg/L, and manganese (Mn) to 0.04 mg/L, both values well within the permissible limits. The hardness level was further reduced to 53.4 mg/L, and the pH value of 6.07 was close to the lower threshold of the acceptable range. These findings indicate that the bore well water already possessed good quality before treatment and achieved near-optimal clean water conditions after filtration.

The results of the post-filtration water analysis demonstrate that the solar-powered filtration system significantly improves water quality for both river (well) and bore well sources. The turbidity and color of both water samples were rendered clear, indicating the system’s ability to remove suspended solids and visible impurities. This confirms the efficiency of the filtration media, which combined Powdered Activated Carbon (PAC) for adsorption of organic contaminants and aluminum sulfate for coagulation of fine particles. For the well (river) water, iron (Fe) concentration decreased from 1.42 mg/L pre-filtration to 0.81 mg/L post-filtration, and manganese (Mn) from 8.55 mg/L to 0.08 mg/L. The substantial reduction in manganese demonstrates the system’s effectiveness against metals that are typically difficult to remove. Similarly, the hardness value decreased from 408 mg/L to 106.8 mg/L, reflecting the softening effect of the filtration system. Although the pH of 6.03 remained slightly below the recommended range (6.5–9.0), this is a minor limitation that can be addressed by post-treatment methods, such as lime addition or aeration.

The bore well water showed lower initial contamination, and the filtration process further improved quality, with iron and manganese well within standard limits and hardness reduced to 53.4 mg/L. The pH of 6.07, slightly acidic, also suggests the influence of dissolved CO_2 or residual coagulants. The solar-powered filtration system proved effective in reducing key contaminants such as iron, manganese, and hardness, thereby improving water clarity and quality. Both water sources met the Clean Water Standard (PerMenKes No. 32, 2017) for heavy metal and hardness parameters after treatment. However, a minor adjustment to neutralize the pH—for example, by adding limestone or aeration—may be required to fully comply with ideal drinking water pH levels. These results demonstrate that the solar filtration technology not only performs well in purifying water but also offers a sustainable and energy-efficient alternative for clean water provision in rural and electricity-limited areas.

Additionally, the system's design allows for scalability, making it suitable not only for single households but also for community-level water treatment, addressing broader public health concerns in regions with limited water infrastructure. Future work should investigate long-term performance, seasonal variations in water quality, and integration with additional treatment processes, such as UV disinfection or biofiltration, to further ensure water safety and compliance with drinking water standards.

Conclusion

The study demonstrates that the solar-powered water filtration system effectively improves water quality and meets the Clean Water Standard for key parameters such as iron (Fe), manganese (Mn), and hardness. The system successfully reduced metal concentrations and turbidity in both river (well) water and bore well water, producing clear water suitable for domestic use. Although the pH values of both water samples remained slightly below the ideal range (6.5–9.0), this minor deviation can be corrected through simple post-treatment methods such as aeration or pH adjustment using alkaline materials. The research confirms that utilizing solar energy as the power source for water filtration is a feasible, sustainable, and environmentally friendly solution—particularly for rural and off-grid communities where access to electricity and clean water is limited. Future studies are recommended to optimize the filtration media composition and system design to enhance pH balance and overall filtration efficiency under varying environmental conditions.

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