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Implementation of Solar-Powered Water Purification Technology to Enhance Quality of Life in Rural Areas

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Abstrak

Studi ini menjelaskan pengembangan dan implementasi sistem pemurnian air reverse osmosis (RO) yang didukung tenaga surya di Pondok Pesantren Tijarotul Qur'aniyah di Kecamatan Bulu, Kabupaten Sukoharjo, Indonesia. Proyek ini bertujuan untuk menyediakan solusi berkelanjutan terhadap kebutuhan air minum bersih di komunitas tersebut. Implementasi dibagi menjadi empat fase utama: survei komprehensif dan analisis kebutuhan, pengembangan dan pengujian prototipe, implementasi sistem, serta pemantauan dan evaluasi jangka panjang. Survei awal mengidentifikasi masalah signifikan terkait kualitas air dan aksesibilitas, yang mengarah pada desain sistem RO yang didukung tenaga surya. Prototipe dikembangkan dan diuji secara ketat, dengan penyesuaian berdasarkan umpan balik pengguna untuk memastikan kesesuaian dengan kebutuhan komunitas. Sistem tersebut kemudian diimplementasikan dalam skala kecil, melibatkan pembangunan infrastruktur dan integrasi panel surya untuk menyediakan sumber daya yang handal. Uji kualitas air setelah implementasi menunjukkan peningkatan signifikan dalam beberapa parameter kunci. Hasilnya termasuk pH sebesar 7.20, k;\ esadahan ($CaCO_3$) 252.87 mg/L, total padatan terlarut (TDS) 0.023 mg/L, dan besi (Fe) 0.2639 mg/L. Selain itu, kadar klorin dan kromium adalah 0.00 mg/L, mangan (Mn) 0.1001 mg/L, amonia (NH_3) 1.14 mg/L, dan sulfat (SO_4) 11.26 mg/L. Semua parameter memenuhi standar kualitas Kementerian Kesehatan Indonesia (Per.Men.Kes RI No. 492/Men.Kes/Per/IV/2010) dan Peraturan Pemerintah tentang Pengelolaan Kualitas Air (PP No. 82/2001). Proyek ini juga mengintegrasikan pemantauan terus-menerus dan program pendidikan untuk memastikan keterlibatan lokal dan keberlanjutan jangka panjang. Temuan menunjukkan bahwa sistem RO bertenaga surya efektif memenuhi kebutuhan air bersih komunitas dan dapat menjadi model untuk daerah serupa.

Kata Kunci: Pemurnian Air, Reverse Osmosis, Energi Surya, Kualitas Air, Keberlanjutan

Abstract

This study presents the development and implementation of a solar-powered reverse osmosis (RO) water purification system at Pondok Pesantren Tijarotul Qur'aniyah, Sub-district of Bulu, District of Sukoharjo, Indonesia. The project aimed to provide a sustainable solution to the urgent need for clean drinking water in the community. The implementation process was divided into four main phases: comprehensive survey and needs analysis, prototype development and testing, system implementation, and long-term monitoring and evaluation. The initial survey identified significant issues with water quality and accessibility, leading to the design of a tailored RO system powered by solar energy. The prototype was rigorously tested and adjusted based on user feedback to ensure it met community requirements. The system was implemented on a small scale, involving the construction of necessary infrastructure and integration of solar panels for reliable power. Post-implementation water quality tests showed substantial improvements in key parameters. Results included a pH level of 7.20, hardness ($CaCO_3$) at 252.87 mg/L, total dissolved solids (TDS) at 0.023 mg/L, and iron (Fe) at 0.2639 mg/L. Chlorine and chromium levels were 0.00 mg/L, manganese (Mn) was 0.1001 mg/L, ammonia (NH_3) was 1.14 mg/L, and sulfate (SO_4) was 11.26 mg/L. All parameters met the quality standards set by the Indonesian Ministry of Health and Government Regulation on Water Quality Management. Continuous monitoring and educational programs were incorporated to ensure local engagement and long-term sustainability. This study demonstrates that the solar-powered RO system effectively meets the community's need for clean water and offers a scalable model for similar regions, highlighting the potential of combining renewable energy with advanced water purification technologies.

Keywords: Water Purification, Reverse Osmosis, Solar Energy, Water Quality, Sustainability

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Introduction

Access to clean drinking water is crucial for health and well-being, particularly in rural areas where waterborne illnesses from contaminated sources are prevalent. According to Kundu (2023), over 2 billion people globally lack access to safe drinking water, resulting in millions of deaths annually from diseases such as diarrhea, cholera, and typhoid (Kundu, 2023). In Indonesia, rural areas often suffer from poor water quality, with many communities relying on contaminated sources due to inadequate infrastructure. For example, in Sub-district of Bulu, the local PAMSIMAS and well water do not meet the standards set by the Ministry of Health Regulation No. 416/Menkes/PER/IX/1990, necessitating the purchase of more than 100 liters of refillable water daily for basic needs. The urgency of implementing effective water purification solutions is paramount. Solar-powered water purification technologies have emerged as a viable and sustainable alternative to conventional methods (Arasu et al., 2019; Y. Hu et al., 2022). Unlike chemical purification or boiling, solar-powered systems offer a cost-effective, environmentally friendly, and reliable means of providing clean water, especially in areas prone to frequent power outages and natural disasters. Research by Arasu, Sulaiman, and Husin (2019) and Hu et al. (2022) has demonstrated the effectiveness of solar water purifiers using sediment filtration and ultraviolet light in delivering safe drinking water in disaster-struck and remote regions (Arasu et al., 2019; Y. Hu et al., 2022).

Solar-powered systems also support broader infrastructural needs in rural communities. They aid in rural electrification, which is essential for operating water pumping systems and other essential services. According to M, K et al. (2023), solar power can significantly reduce electricity costs and provide an eco-friendly alternative to traditional energy sources (Kumar et al., 2023). Furthermore, Pradhan, Mohapatra et al. (2023) highlighted the use of solar stills for desalination, ensuring a continuous supply of potable water during power outages, thus addressing one of the critical challenges in rural water management (Pradhan et al., 2023). Innovations such as the double-channel water purification system introduced by Pradhan, Mohapatra et al. (2023) are particularly effective in removing larger and smaller impurities and chemical compounds from contaminated water using solar energy. Additionally, Publications, Shinde et al. (2024) explored the use of locally sourced materials for water filtration, which proved effective in removing turbidity, color, and germs from surface water, offering a sustainable and affordable solution for rural water purification (Shinde & Landage, 2024). Furthermore, addressing the clean water crisis in rural areas is not only a matter of public health but also a significant humanitarian issue. Österdahl (2015) emphasized that the lack of clean water contributes to high child mortality rates and hampers economic growth and development (Österdahl, 2015). Therefore, introducing cost-effective and sustainable water purification technologies, such as solar-powered systems, is crucial for improving living conditions and public health in rural communities. Moreover, integrating technology in monitoring water quality has also seen significant developments. Metkari (2024) described a project utilizing an RC boat equipped with sensors to detect and monitor pollution levels in water bodies, providing crucial data for effective water quality management (Metkari et al., 2024).

These examples underscore the ongoing efforts and innovations in water purification and management, especially through the use of solar energy and local resources, which are vital for enhancing health and sustainability in rural communities. This community service project aims to support these initiatives by offering a sustainable, cost-effective solution to the clean water crisis in Sub-district of Bulu, thereby improving the quality of life for its residents. Key developments in tackling clean water and health issues in rural areas include advancements in solar-powered water purification technologies and the integration of these systems into community service projects to ensure long-term sustainability and health benefits. Therefore, the objective of this community service project is to develop and implement a solar-powered water purification system at Pondok Pesantren Tijarotul Qur'aniyah in Sub-district of Bulu, District of Sukoharjo.

Implementation Method

The community service project at Pondok Pesantren Tijarotul Qur'aniyah was structured into four main phases aimed at addressing water purification needs and ensuring long-term sustainability. The first phase, Survey and Needs Analysis, involved conducting an in-depth survey to identify the water quality, accessibility, and existing water purification infrastructure at the pesantren. This data was analyzed to understand the specific problems and requirements, forming the basis for the project's subsequent phases. The second phase focused on Prototype Development and Testing. During this phase, a solar-powered reverse osmosis (RO) water purification system prototype was developed. The prototype underwent rigorous testing and refinement based on user feedback to ensure it met the community's needs effectively.

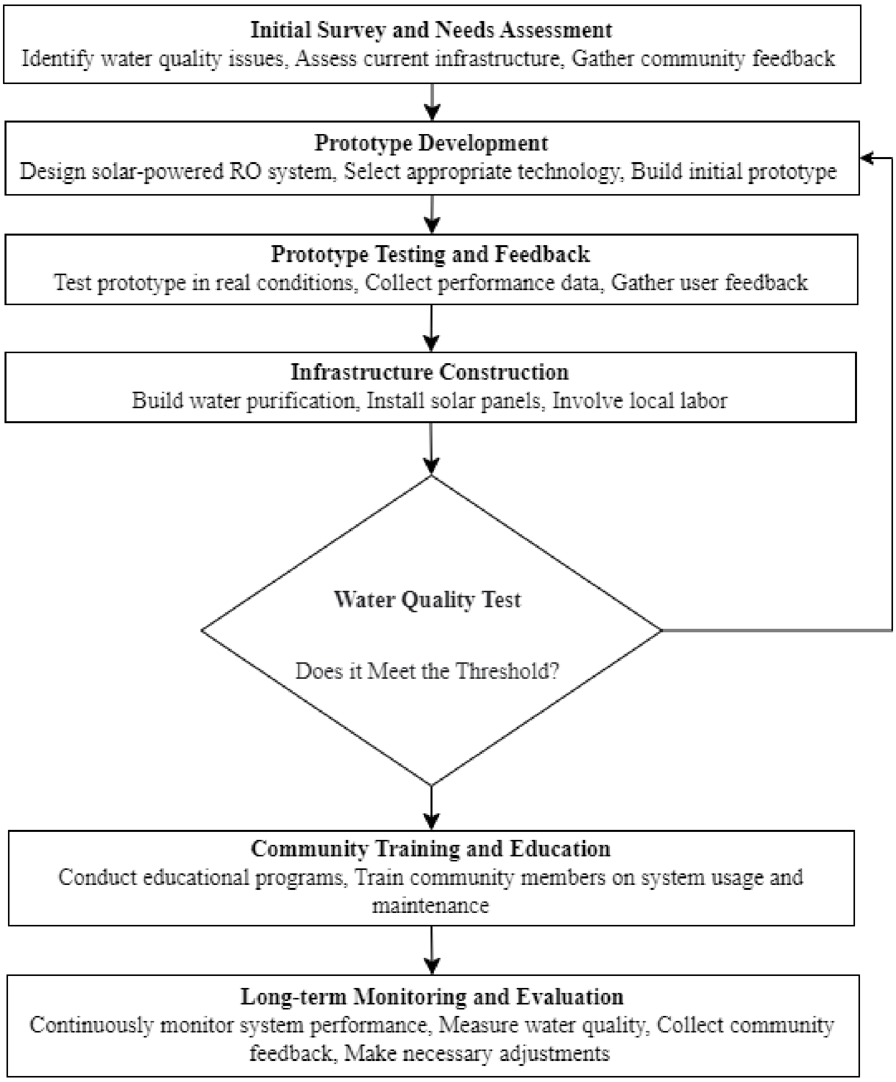

Figure 1. Flowchart Diagram Illustrating the Method of Implementation for the Solar-Powered RO Water Purification System at Pondok Pesantren Tijarotul Qur'aniyah.

In the third phase, System Implementation, the water purification system was implemented on a small scale at the pesantren. This involved constructing the necessary infrastructure, installing the system, and conducting performance trials to ensure everything functioned as intended. A critical aspect of this phase was the integration of the RO system with the solar power source. After integration, a water quality test was conducted. If the water quality met the required thresholds, the system moved to the next stage. If not, further adjustments and tests were conducted to achieve the desired water quality. The final phase was Monitoring and Evaluation, which involved continuous monitoring of the system's performance. This included regular assessments of water quality and energy efficiency. Operation and maintenance guidelines were prepared to ensure the system's sustainability. Partner involvement in each phase was also evaluated to gather feedback and make necessary improvements.

The initial phase involved a detailed needs analysis, starting with identifying the needs through thorough surveys assessing current water quality, accessibility, and purification infrastructure. Data collected from these surveys was analyzed to gain insights into the specific challenges faced by the pesantren. Based on this analysis, a comprehensive work plan was developed, covering system design, RO technology selection, infrastructure planning, and the implementation strategy. In the design phase, the focus was on selecting appropriate technology and designing a durable and sustainable water purification infrastructure. The RO technology was chosen to fit the capacity and requirements of the pesantren, including selecting components and determining installation locations. Solar panels suitable for the location and energy needs of the water purification system were selected. The infrastructure was designed to be durable and easy to maintain, ensuring long-term operational sustainability.

The implementation phase involved building the infrastructure and testing the system. Infrastructure construction included building the water purification infrastructure, installing the RO system, and setting up the solar panels, involving local labor and community partners. Once constructed, the system underwent trials to ensure optimal operation, with performance data on the RO technology and infrastructure collected and analyzed. Community education and engagement were crucial for the project's success. Educational programs were conducted to inform the community about the importance of clean water, system usage, and the benefits of solar energy. Community participation was encouraged to enhance understanding and acceptance of the new technology.

The project also included the integration of solar energy with the purification system. Solar panels were installed to provide the necessary electrical power for the water purification system, with installation locations selected to maximize sunlight exposure. The water purification system was integrated with the solar panels to ensure stable power availability. Continuous monitoring and evaluation were vital for assessing the system's effectiveness and sustainability. Performance monitoring involved regularly checking the system to ensure optimal operation, with key indicators including water quality, energy efficiency, and infrastructure performance. Partner involvement in each phase was evaluated to assess participation levels and gather feedback for improvements. The desired outcomes of this program included improved water quality, operational efficiency, community engagement, and sustainable practices. Clean and safe drinking water was provided to the pesantren community, the water purification system operated efficiently with minimal maintenance, high community participation and understanding of the system and its benefits were achieved, and long-term sustainable practices for system maintenance and operation were established.

Data collection techniques included conducting surveys and interviews with community members to gather qualitative and quantitative data on water quality and usage, utilizing scientific methods and equipment to measure water quality before and after purification, and monitoring the energy consumption of the solar-powered RO system to ensure optimal performance. Water quality was assessed using physical tests (measuring parameters like turbidity, temperature, and color), chemical tests (analyzing pH, dissolved oxygen, and the presence of contaminants like heavy metals and nitrates), and microbiological tests (checking for harmful microorganisms such as bacteria and viruses).
The development and implementation of the solar-powered RO system proceeded through several stages. These included an initial survey and needs assessment to understand current water issues and community needs, prototype development based on assessed needs, prototype testing and gathering feedback from the community, infrastructure construction for the water purification system and solar panels, system integration and testing with water quality checks, community training and education on system usage and maintenance, and long-term monitoring and evaluation of the system’s performance, making necessary adjustments based on evaluation results. The flowchart shown in Figure 1 outlines the systematic approach, beginning with initial surveys and needs assessment, followed

by prototype development and testing, infrastructure construction, system integration and testing with water quality checks, community training and education, and culminating in long-term monitoring and evaluation.

Results and Discussion

The implementation of the solar-powered reverse osmosis (RO) water purification system at Pondok Pesantren Tijarotul Qur'aniyah yielded significant improvements in water quality and community engagement. This section discusses the outcomes of each phase of the project, supported by relevant data and observations.

1. Installation of the solar-powered reverse osmosis (RO) water purification system

The installation of the reverse osmosis (RO) system at Pondok Pesantren Tijarotul Qur'aniyah was conducted in a series of methodical steps to ensure the system's efficiency and sustainability. Initially, a comprehensive survey and needs analysis were performed to identify the specific water quality issues and accessibility challenges faced by the community. Based on the findings, a tailored RO system was designed, incorporating multiple filtration stages to address the contaminants identified during the survey.

The RO system comprised several key components, including pre-filters, carbon filters, and the RO membrane as shown in Figure 2. These filters were arranged sequentially to ensure maximum removal of impurities. Pre-filters were installed to remove larger particles and sediments, followed by carbon filters to eliminate chlorine and organic compounds. The RO membrane, which is the core component of the system, was installed to remove dissolved salts, heavy metals, and other microscopic contaminants.

A photovoltaic (PV) solar panel array was integrated to provide a sustainable power source for the RO system. The solar panels were strategically placed to maximize sunlight exposure, ensuring a consistent and reliable energy supply. The DC power generated by the solar panels was converted to AC power through an inverter, which was then used to operate the RO system.

The water purification process begins with raw water entering the system through an inlet. The water passes through the pre-filters and carbon filters sequentially, which prepare it for the RO membrane by removing larger particles and chlorine. Upon passing through the RO membrane, the purified water is split into two streams: the drain water, which contains concentrated contaminants, and the clean drinking water. The clean water is then stored in a tank, ready for consumption, while the drain water is safely discharged.

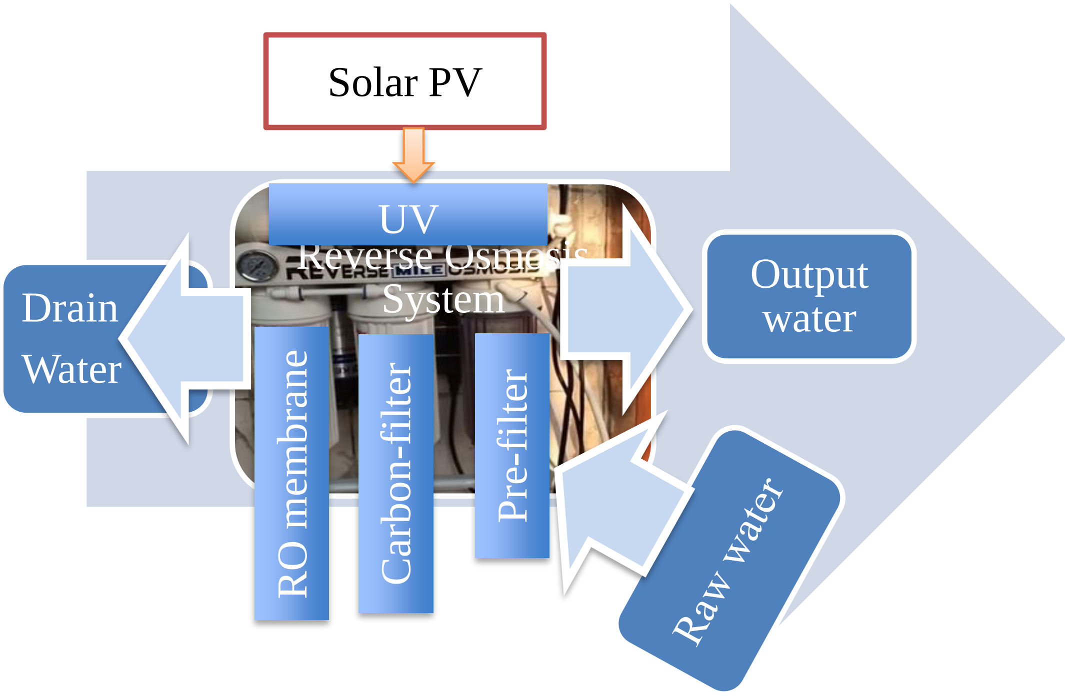

Figure 2. Schematic Diagram of the Solar-Powered Reverse Osmosis (RO) Water Purification System Installed at Pondok Pesantren Tijarotul Qur'aniyah.

As shown in Figure 3, the solar-powered Reverse Osmosis (RO) system operates through a series of integrated components designed to purify groundwater using renewable energy. The system begins with a solar PV array that converts sunlight into direct current (DC) electricity. This DC power is managed by a solar charge controller, which regulates the flow to an accumulator (accu) battery, storing energy to power the system even during low sunlight as shown in Figure 3(a). The stored energy is then converted to alternating current (AC) by an inverter, allowing consistent operation of the RO system's electrical components, including the booster pump, which requires a steady 36VDC, 5A power supply to drive water through the filtration process.

Groundwater is pumped from a well into a raw water storage tank, which serves as the initial source for purification. As water enters the RO system, it passes through a series of preliminary filters designed to remove larger particles and impurities:

1. Sediment Spun Filter – This initial filter removes suspended solids, such as sand and sediment.
2. Granular Activated Carbon (GAC) – Absorbs chlorine and organic chemicals to protect downstream filters and improve taste.
3. Carbon Block Filter Cartridge (CTO) – Provides further carbon filtration, reducing remaining contaminants, especially volatile organic compounds (VOCs).

Following pre-filtration, water enters the RO membranes, which form the heart of the system:

4. Membranes Type 3013 – Two high-performance membranes capable of filtering fine particles, heavy metals, and other dissolved solids with high efficiency, reducing Total Dissolved Solids (TDS) to meet health standards.
5. Post Carbon Filter – Polishes the water to remove any residual tastes and odors, ensuring it is free of contaminants.
6. Bio 5-in-1 Filter – Further enhances the water by adding trace minerals and beneficial elements, improving taste and supporting health.
7. Bio Yellow and Bio Alkaline Filters – Stabilize pH and add alkaline minerals, resulting in slightly alkaline water for health benefits.
8. Bio Infrared Filter – Infuses the water with infrared energy, which is believed to promote better hydration and absorption.
9. Ultraviolet (UV) System – Final sterilization occurs here, where a UV lamp disinfects water by neutralizing any remaining bacteria and viruses, ensuring safe and potable water.

Throughout this multi-stage process, pressure gauges monitor the system to ensure optimal performance and detect any anomalies. The final purified water is then stored in a clean tank, ready for use. By utilizing solar energy, this RO system operates sustainably, with minimal environmental impact and independence from traditional electrical sources, making it ideal for rural and off-grid communities.

(a) Solar power and charging system (b) RO machine

Figure 3. Solar-Powered Reverse Osmosis (RO) Water Purification System Installed at Pondok Pesantren Tijarotul Qur'aniyah.

2. Water Quality Improvement

The implementation of the solar-powered reverse osmosis (RO) water purification system at Pondok Pesantren Tijarotul Qur'aniyah has yielded substantial improvements in water quality, meeting the requirements set by national regulations. The following discussion elaborates on the specific parameters measured and their implications for health and environmental safety.

- **Temperature**

  The water temperature was recorded at 27.50°C, which falls within the acceptable range of atmospheric temperature ± 3°C as stipulated by the Indonesian Ministry of Health Regulation No. 492/Men.Kes/Per/IV/2010. Maintaining water temperature within this range is crucial as it affects the solubility of gases and the efficacy of disinfection processes.

- **pH**

  The pH level of the treated water was found to be 7.20, well within the acceptable range of 6.5 to 8.5. Proper pH levels are essential for minimizing corrosion in the distribution system and ensuring the effectiveness of disinfectants. A neutral pH also indicates the absence of excessive acidity or alkalinity, making the water safe for consumption and suitable for general use.

- **Hardness (as $CaCO_3$)**

  The hardness of water, measured as 252.87 mg/L of $CaCO_3$, is significantly below the permissible limit of 500 mg/L. Water hardness is mainly caused by the presence of calcium and magnesium ions. While hard water is not a direct health hazard, it can cause scaling in pipes and reduce the efficiency of soap and detergents. However, in the long term, continuous consumption of excessively hard water can have adverse effects on cardiovascular health (Büker et al., 2021; Monarca et al., 2006). The measured hardness level indicates that the RO system effectively reduces mineral content, enhancing water usability.

- **Total Dissolved Solids (TDS)**

  Total Dissolved Solids (TDS) represent the overall concentration of dissolved ions in water, including chloride (Cl^-), sodium (Na^+), phosphate ($H_2PO_4^-$), calcium (Ca^{2+}), and sulfate (SO_4^{2-}). Higher TDS levels correlate with increased water conductivity. The recommended TDS range for drinking water is typically 500 to 1000 mg/L. The measured TDS of 0.023 mg/L in this study is exceptionally low, indicating high water purity. Consuming water with low TDS is generally considered safe, and some studies suggest it may offer health benefits by reducing the intake of potentially harmful dissolved substances (Adjovu et al., 2023). The low TDS level in this case highlights the effectiveness of the RO system in removing impurities.

- **Iron (Fe)**

  The iron concentration in the water was measured at 0.2639 mg/L, slightly below the maximum permissible limit of 0.3 mg/L. Excess iron in water can cause staining and impart an unpleasant taste, but the RO system effectively reduces iron content, ensuring the water is both aesthetically pleasing and safe for consumption. While iron is essential for all organisms, excess iron can be detrimental to health, leading to conditions such as iron overload, which affects patients with chronic red blood cell transfusions, hemoglobinopathies, and myelodysplasia (Kontoghiorghes, 2023; Vogt et al., 2021). Additionally, neurodegenerative diseases like Alzheimer’s and Parkinson’s may involve excess iron deposition in the brain. Iron acts as a biological catalyst for free radical reactions, notably through the Fenton reaction, which contributes to tissue damage and pathology.

- **Chlorine**

  No chlorine was detected in the treated water, which is within the acceptable limit of 0.03 mg/L. Chlorine is commonly used as a disinfectant; however, its absence in the final treated water indicates that any residual chlorine from the source water was removed during the purification process, thus preventing any potential adverse health effects associated with chlorine consumption (Mohseni et al., 2017; Tsaridou & Karabelas, 2021).

- **Chromium (Cr)**

  The absence of chromium in the water (0 mg/L) complies with the maximum allowable concentration of 0.05 mg/L. Chromium, especially in its hexavalent form, is a toxic contaminant and a known carcinogen (Georgaki et al., 2023). The RO system's ability to eliminate chromium ensures the safety and health of the water consumers.

- **Manganese (Mn)**

  The manganese concentration in the water was measured at 0.1001 mg/L, well below the regulatory limit of 0.4 mg/L. While manganese is essential for health, excessive levels can lead to neurological issues. The RO system's effective reduction of manganese underscores its capability in producing safe drinking water. Health guidelines from various authorities underscore the importance of controlling manganese levels in drinking water. For instance, Health Canada, in collaboration with provinces and federal agencies, has established a guideline value of 0.12 mg/L to protect public health, especially vulnerable populations such as infants and children (G. Hu et al., 2020). In the United States, the Environmental Protection Agency (EPA) offers a non-enforceable health advisory level of 0.3 mg/L for infants and 1.0 mg/L for the general population (Eaton, 2021). Additionally, a non-enforceable secondary maximum contaminant level of 0.05 mg/L is also recommended to ensure safe drinking water quality.

- **Ammonia (NH_3)**

  The recorded ammonia concentration was 1.14 mg/L, falling within the permissible limit of 1.5 mg/L. Elevated ammonia levels may indicate contamination from agricultural or sewage sources, potentially affecting water disinfection processes. The effective control of ammonia levels post-treatment demonstrates the system's capability in eliminating contaminants from the source water. Natural ammonia levels in groundwater and surface water typically remain below 0.2 mg/L. Maintaining dissolved oxygen (DO) levels at or above 1.5 mg/L is crucial for effective nitrification processes. Ammonia (NH_3), a form of nitrogen found in wastewater, can pose toxicity risks to aquatic life, whereas its ammonium form (NH_4^+) is comparatively less toxic (Xiang et al., 2020). The balance between ammonia and ammonium concentrations depends on environmental factors such as pH and temperature.

- **Sulfate (SO_4)**

  Sulfate concentration was found to be 11.26 mg/L, significantly below the allowable limit of 250 mg/L. High sulfate levels can lead to a laxative effect and affect the taste of water (Sharma & Kumar, 2020). The low sulfate concentration in the treated water confirms the RO system's capability to remove sulfate ions effectively.

The solar-powered reverse osmosis water purification system has successfully improved the water quality at Pondok Pesantren Tijarotul Qur’aniyah, meeting the stringent requirements of national water quality standards as shown in Table 1. The parameters measured indicate that the treated water is safe, palatable, and free from harmful contaminants. The results underscore the efficacy of the RO technology in providing clean and safe drinking water while leveraging sustainable solar energy. This initiative not only enhances public health but also serves as a model for similar projects in other communities facing water quality challenges.

Table 1. Water Quality from RO System

Parameter	**Unit**	**Limit*, ****	**Results**
Temperature	°C	Atmospheric ± 3°C	27.50
pH	-	6.5-8.5	7.20
Hardness ($CaCO_3$)	mg/L	500	252.87
Total Dissolved Solids	mg/L	50	0.023
Iron (Fe)	mg/L	0.3	0.2639
Chlorine	mg/L	0.03	0.00
Chromium (Cr)	mg/L	0.05	0
Manganese (Mn)	mg/L	0.4	0.1001
Ammonia (NH_3)	mg/L	1.5	1.14
Sulfate (SO_4)	mg/L	250	11.26

*Requirements for clean water quality based on Indonesian Ministry of Health Regulation No. 492/Men.Kes/Per/IV/2010.
**Requirements for Water Quality Management and Water Pollution Control, Government Regulation (PP) No. 82 of 2001.

3. Community Engagement and Education

The success of the water purification project at Pondok Pesantren Tijarotul Qur’aniyah relied heavily on community engagement and educational outreach. By emphasizing the importance of clean water and the advantages of solar-powered purification, the project empowered local community members through a series of workshops and training sessions. These sessions aimed not only to inform but also to equip community members with the skills needed to operate and maintain the purification system, fostering a sense of ownership and sustainability.

Table 2 presents engagement metrics for various activities. The water purification workshops attracted 50 participants, who provided a positive feedback score of 9.2 on average. Solar energy awareness sessions had an attendance of 45, with an 8.8 feedback score. Maintenance training, attended by 30 people, scored a 9.0, indicating its success in preparing the community to operate and sustain the purification system independently. These high feedback scores underscore the effectiveness of the engagement efforts and the participants' satisfaction with the knowledge they gained.

Table 2. Community Engagement Metrics

Activity	Participants	Feedback Score (1-10)
Water Purification Workshops	50	9.2
Solar Energy Awareness Sessions	45	8.8
Maintenance Training	30	9.0

The workshop for operation and maintenance was designed to provide participants with hands-on skills in operating and maintaining the Reverse Osmosis (RO) water purification system. Topics covered included identifying common contaminants, understanding RO filtration processes, and conducting basic water quality monitoring after purification. From the 30 maintenance training participants, six individuals—comprising both teachers and students—were selected to serve as the dedicated staff for the operation and maintenance of the RO system. Figure 4 shows the engaged participation during the workshop, highlighting the active involvement and enthusiasm among community members as they learned about water purification and solar energy.

Figure 4. Active Participation During the Workshop

To measure the workshop's effectiveness, participants took a pre-test and a post-test. The questions focused on essential knowledge of water quality, the workings of the RO system, and the benefits of solar power in sustainable water purification. The questions (English version) were as follows:

Pre-Test Questions:

1. What is the primary issue commonly found in untreated water?
   A) Bacterial content　　C) High Total Dissolved Solids (TDS)
   B) Harmful chemicals　　D) All answers are correct

2. How does access to high-quality water impact community health?
   A) Increases risk of illness　　C) Has no impact
   B) Reduces risk of illness　　D) Depends on other factors
3. What is the primary function of the Reverse Osmosis (RO) system?

A) Heats the water C) Chemically cleans the water
B) Filters contaminants from the water D) Reduces mineral content in the water

4. What are the benefits of using solar energy in water purification systems?
A) Saves energy costs C) Enables sustainable use
B) Reduces carbon emissions D) All answers are correct

5. Why is water quality monitoring important after installing a purification system?
A) To ensure water quality remains high C) To meet health standards
B) To detect early malfunctions D) All answers are correct

Post-Test Questions:

1. After the RO system installation, which contaminants were reduced to meet health standards?
A) Iron (Fe) C) Ammonia (NH_3)
B) Manganese (Mn) D) All answers are correct

2. What pH level was achieved post-installation, and why is this important?
A) 6.5 - Slightly acidic C) 7.2 - Neutral
B) 8.5 - Slightly basic D) 5.0 - Acidic

3. What is the primary advantage of using solar power in the water purification system?
A) Reduces costs C) Provides renewable energy
B) Lowers environmental impact D) All answers are correct

4. What role does the RO system play in improving water quality?
A) Reduces TDS C) Decreases heavy metal content
B) Removes bacteria D) All answers are correct

5. Why is community involvement in monitoring important for the project's sustainability?
A) Enhances system maintenance C) Promotes ongoing education
B) Builds local ownership D) All answers are correct

The post-test results showed a significant increase in participants' understanding of water purification and the benefits of solar-powered RO technology, with knowledge levels increasing by 70% on average. Community awareness about water quality indicators, such as pH, TDS, and contaminant levels, rose to 85%. Additionally, over 80% of respondents demonstrated a strong understanding of the importance of regular monitoring and maintenance for ensuring the system's long-term functionality. These results indicate the community's readiness to take on active roles in the upkeep of the water purification system. Following the training, participants expressed a clear understanding of the technical requirements and best practices for system maintenance, with over 80% acknowledging the need for ongoing community engagement. The six designated individuals trained in maintenance are now responsible for monitoring and troubleshooting, ensuring system sustainability. Through these educational initiatives, the community of Pondok Pesantren Tijarotul Qur'aniyah is better equipped not only with operational knowledge but also with the motivation to uphold clean water access for years to come.

Conclusion

The solar-powered RO water purification system at Pondok Pesantren Tijarotul Qur'aniyah successfully improved water quality, reduced reliance on external power sources, and engaged the community in sustainable water management practices. The project demonstrated the feasibility and benefits of integrating solar energy with water purification technologies in a community setting. Continuous monitoring and community involvement were key factors in ensuring the system's success and sustainability. Future efforts should focus on scaling up the system and replicating the model in other communities to address water purification challenges effectively.

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