Dimas : Jurnal Pemikiran Agama untuk Pemberdayaan
Volume 25 No. 2, Oktober 2025
DOI: 10.21580/dms.v25i2.29198

Integration of Smart Rainwater Harvesting and Islamic Ecological Ethics: IoT-Based Community Empowerment in a Coastal Area of Demak

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Abstract

The northern coastal area of Demak, particularly Timbulsloko Hamlet, faces a severe clean water crisis due to tidal flooding, seawater intrusion, and land subsidence. Conventional rainwater harvesting (RWH) efforts initiated by residents have been unable to sustainably meet household needs because of limited capacity and the absence of adequate filtration systems. This community service program aims to develop an IoT-based Smart Rainwater Harvesting (Smart-RWH) system as an adaptive, affordable, and community-driven solution. The implementation methods included community outreach, training on RWH management and maintenance, the installation of a Smart-RWH system equipped with water quality sensors, and a trial of a simple Android-based monitoring application. The results indicate the successful installation of a 6,000-litre Smart-RWH unit equipped with pH and volume sensors, the development of an operational manual, and an improvement in community capacity for managing clean water using technology. The implications extend beyond increased access to safe water, as the program also strengthens socio-ecological resilience through local institutional empowerment and collective action. The Smart-RWH model offers significant potential for replication in other coastal areas facing similar challenges.

Keywords: *clean water, coastal community, community resilience, IoT, rainwater harvesting (RWH)*

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Introduction

Coastal communities in northern Demak are currently experiencing an accelerating socio-ecological crisis. This context is essential to frame the urgency of the present initiative. The northern coastal area of Demak Regency is facing an increasingly complex socio-ecological crisis due to tidal flooding, seawater intrusion, coastal erosion, and land subsidence. Timbulsloko Hamlet is one of the most severely affected areas, with homes inundated with saltwater almost year-round. This situation disrupts socio-economic activities and reduces the community's quality of life. One fundamental issue that arises is limited access to clean water. Community efforts to build conventional Rainwater Harvesting (RWH) systems can only meet a small portion of household water needs and lack filtration and water quality monitoring systems.

Meanwhile, technological developments are creating opportunities to rethink community-based water solutions. Developments in electrical technology and the Internet of Things (IoT) are opening up opportunities for more adaptive innovations to address this issue. Smart Rainwater Harvesting (Smart-RWH) is a rainwater management system equipped with digital sensors that monitor water volume and quality in real-time. It is connected to an Android-based application to facilitate recording and distribution. This concept aligns with the global trend of utilizing IoT for water resource management, which improves efficiency, data accuracy, and transparency in water management (Faishol, Ismail, & Hapsari, 2022; Lakshmikantha et al., 2021).

The urgency of implementing IoT-based Smart-RWH in coastal areas stems from two key factors. First, as the price of bottled water for locals is rising, there is an urgent need for a safe and reasonably priced source of clean water. Second, a technical innovation paradigm that can be applied to other communities dealing with comparable issues is required. International studies indicate that IoT-based systems, when combined with community-based water solutions, can enhance socio-ecological resilience, particularly in areas vulnerable to climate change (Shammin, Haque, & Faisal, 2021).

In addition to technological innovation, the development of renewable resources in rural areas must also involve local participation. Participatory mapping and utilization of natural potential, as demonstrated by Nugraha (2022), emphasize the importance of community-based approaches in identifying and managing village assets for long-term sustainability. This perspective strengthens the foundation of Smart-RWH as a model that integrates community empowerment with technological innovation.

By involving universities as partners, this activity also supports the achievement of the Sustainable Development Goals (SDG 6 – Clean Water and Sanitation, SDG 8 – Decent Work and Economic Growth, SDG 11 – Sustainable Cities and Communities, and SDG 13 – Climate Action) and university Key Performance Indicators (KPIs), particularly in the utilization of research findings and student learning experiences outside the campus.

Although existing studies demonstrate progress in IoT-based water monitoring and conventional RWH, a clear research gap remains: neither approach integrates technological innovation with community-based management and Islamic ecological ethics.

This Smart-RWH system is designed to collect, process, store, and distribute rainwater more effectively in accordance with community needs. Through this model, rainwater is collected, and its quality and volume are monitored using simple digital sensors. Field observation confirms that the standard RWHs were still susceptible to pollution and could not fulfill the long-term water demand of the coastal household (Huwaina, Hasibuan, & Fatimah, 2022; Lubis, 2024; Raru & Mawardin, 2024; Siki, Loden, & Making, 2024). Therefore, developing an Internet of Things (IoT)-based Smart Rainwater Harvesting (RWH) system is proposed as an innovative solution that integrates electrical engineering with local social practices. The innovation of this community service activity is the introduction of a monitoring system for both quantity and quality, which is accessible to residents through a simple application. On the other hand, it empowers local organizations to manage clean water. This model is geared toward social adaptation and environmental sustainability, enabling communities not only as beneficiaries but also as key actors in technology management. To date, no existing studies have examined RWH as a socio-technical system that integrates engineering innovation, local ecological practices, and Islamic ethical reasoning. Previous literature highlights either the technical dimension of IoT or the sociocultural dimension of community participation—but not both in a unified resilience model.

Previous studies have demonstrated that adaptive technological approaches incorporating community participation can enhance community resilience in the context of climate change (Batubara, Bosman, & Wagner, 2020; Karmilah & Madrah, 2024; Madrah, 2024). Based on this foundation, this community service activity is designed to integrate IoT-based technological innovation with the empowerment of coastal communities. The primary objective of this program is to establish Smart-RWH in Timbulsloko Hamlet, enhancing the household's clean water resilience and developing a local organization for long-term system management. This approach enhances social adaptation and environmental sustainability, enabling communities to emerge as beneficiaries and key actors in technology management.

Several regional studies have also found that community-based RWH has effectively increased residents' self-reliance (Kim, Han, Kabubi, Sohn, & Nguyen, 2016; Suprapti, Kusuma, Kardhana, Cahyono, & Juliana, 2025; Vadikar, 2024). This comparison shows that community involvement in designing, monitoring, and maintaining RWH systems determines their performance. The same principle applies in this activity—making communities the subjects of innovation, rather than merely its beneficiaries.

Based on this identified gap, the present program aims to provide an integrated model that enhances both technological effectiveness and community participation. This approach also aligns with Islamic values regarding human responsibility as *khalifah fil-ardh* (custodian of the earth). From a *fiqh bi'ah* perspective, efforts to conserve water are part of *imaratul-ardh*—sustainably prospering the earth. The Qur'an states that "everything living is made of water" (Qur'an, Al-Anbiya' [21]:30), implying the sanctity of water as the life-giving stream that needs to be preserved. Hence, the Smart-RWH is not only a technological innovation but also one way of putting the value of social worship (*ibadah ghairu mahdhah*) into practice in preserving environmental trust.

From a sociological perspective, the scarcity of clean water in coastal areas is not only a technical issue but also a reflection of broader, unequal relations between the center and the periphery. Coastal regions are often overlooked in development plans, leaving rural communities without access to basic infrastructure, such as clean water, sanitation, and effective environmental management. At the same time, towns and cities continue to advance. This spatial inequality has implications for systemic socio-ecological vulnerability: poor communities in disaster-prone areas experience a double economic and health burden. In this context, technological innovations like Smart-RWH demonstrate a form of sociotechnical adaptation. That is, the integration of technological solutions with social practices that emerge from the local experiences of residents (Batubara et al., 2020).

The urgency of implementing Smart-RWH in coastal areas stems from two key factors. First, there is an urgent need for a safe and affordable source of clean water, given the rising cost of purchasing water in gallons for residents. Second, there is a need for a model of technological innovation that can be replicated in other communities facing similar challenges. This approach is consistent with the community resilience hypothesis, which emphasizes the role of adaptive and social capability in reacting to environmental change (Pratama, Rohmansyah, Puntodewo, & Aulia, 2025). This program, which combines technological, social, and Islamic ecological spiritual dimensions, aims to develop a comprehensive model of resilience grounded in faith and social solidarity.

By involving universities as partners, this activity also supports the achievement of the Sustainable Development Goals (SDG 6 – Clean Water and Sanitation, SDG 8 – Decent Work and Economic Growth, SDG 11 – Sustainable Cities and Communities, and SDG 13 – Climate Action) as well as the Key Performance Indicators (KPI) of Higher Education, especially in the aspect of utilizing research results and student learning experiences outside the campus. Smart-RWH aims to be a community service model that combines technological innovation, theological reflection, and social empowerment into a unified approach to scientific practice.

Methods

This community service project focused on planning and implementing Smart Rainwater Harvesting (Smart-RWH), an Internet of Things (IoT)-based system in Timbulsloko Hamlet, Demak Regency. The lead partner, Timbulsloko Bangkit Community, had once employed a conventional RWH system confined to a cistern without filtration or water quality monitoring. Therefore, the implementation method focuses on transferring simple and affordable electrical and digital technologies so that the local community can operate effectively.

The initial phase involved socializing technology with residents about the Smart-RWH concept, including its fundamental differences from conventional RWH systems. The team then conducted the system's technical design, which included a 2,000-litre storage tank for wastewater equipped with a water level sensor (float sensor) and a 600-litre storage tank for clean water, both equipped with pH and Total Dissolved Solids (TDS) sensors to ensure the quality of the clean water. These sensors were connected to an ESP32-based microcontroller equipped with a Wi-Fi module, allowing them to transmit data to a monitoring application. Residents can use a simple application on their smartphones to monitor the Smart-RWH system via the Blynk platform.

The next stage involved installing the device in the field. This process included sensor installation, cable integration, calibration of all sensors (Float, pH, and TDS), and verification of the overall system performance. The system automatically recorded water volume and quality in real-time, displaying the data directly to residents through the application. In addition to technical aspects, the program also included community training on how to read sensor data, reset the system during disruptions, perform equipment maintenance, and maintain filters. This approach ensured technology transfer paralleled community capacity building.

The final stage involved mentoring and evaluation. Residents engaged in usage simulations and discussion panels to test the system's feasibility. The evaluation assessed the accuracy of sensor signal stability, volume, and pH information, as well as the community's reaction to the monitoring application. The results of this reflection served as a basis for system refinement, while also strengthening local institutions by establishing an RWH Team as its management team.

This implementation method demonstrated the contextual adaptability of electrical and IoT technology innovations in coastal communities. A simple technical approach and social mentoring made this program a technological application and a means of empowerment based on residents' real needs.

In addition to technology transfer, this activity also instilled Islamic ecological awareness values through spiritual and social approaches. Residents were urged to comprehend that safeguarding water was in the public interest and their moral obligation to Allah SWT. In the dialogue between the residents, "water as trust" was introduced, and awareness was raised that every drop of water has religious value when consumed efficiently and fairly. During the implementation process, students from three study programs—Electrical Engineering, Urban and Regional Planning, and the Magister of Islamic Education—collaborated in an interdisciplinary manner. Electrical

Engineering students were involved in sensor installation and calibration. Urban and Regional Planning students conducted spatial planning observations and assessed coastal settlement conditions. Magister of Islamic Education students developed educational modules on Islamic ecological ethics. This interdisciplinary collaboration improved students' technical skills and enriched their community-based learning experiences.

During the mentoring process, eco-literacy workshops were also conducted to instill ecological spiritual values. In this session, residents were encouraged to understand the principles of Islamic *fiqh* (*fiqh bi'ah*) regarding the mandate to safeguard water and the prohibition of excessive use (*israf*). This process provided space for contemplation among the residents and the campus team, illustrating that Smart-RWH technology was not just a water management instrument, but a means to construct a belief in the environment and social duty towards it.

*Picture 1. Socialization of the Smart-*RWH *working mechanism*

Results

1. Technical outputs

This community service program produced a tool previously designed and tested in the laboratory. The entire system performed well during the laboratory testing phase without significant problems. This condition indicated that the initial design was technically feasible for field application. However, while installing the system on the partner's premises, the team met with a few technical problems, especially signal stability, and a few instruments received in the open air. The local climate and quality of the network influenced the tool's performance. Therefore, the team added several supporting instruments to ensure the system continued operating as intended. These adjustments also provided the team with valuable experience in adapting the laboratory design to real-world conditions in the community. A diagram of the tool design used is shown in Figure 1.

Figure 1. Smart-RWH tool design

The results of this community service demonstrated that the program's success depended on the validity of the laboratory's technical design and its adaptability to real-world situations. Thus, this activity produced a functional prototype and enriched the team and partners' knowledge of the challenges of implementing simple technology in the community. To better understand how Smart-RWH works, the results analysis of this activity was from three main aspects: technical, social, and ecological. This section will first explain the core technical aspects of IoT-based system design.

The Smart-RWH design is visualized as a flowchart to support understanding of the system's working mechanism. This flowchart shows the stages in the wastewater and clean water tanks. Figure 2 shows the system's performance flow in the wastewater tank. The stages begin with program initialization, followed by checking the internet connection, and then proceed with water level measurement using a float sensor. When the reservoir is empty, the well pump and solenoid valve are turned on until the water reaches level 1. This process provides space in case rainwater refills at any time. The goal of this wastewater system is to ensure that the tank is consistently filled with wastewater for processing when needed.

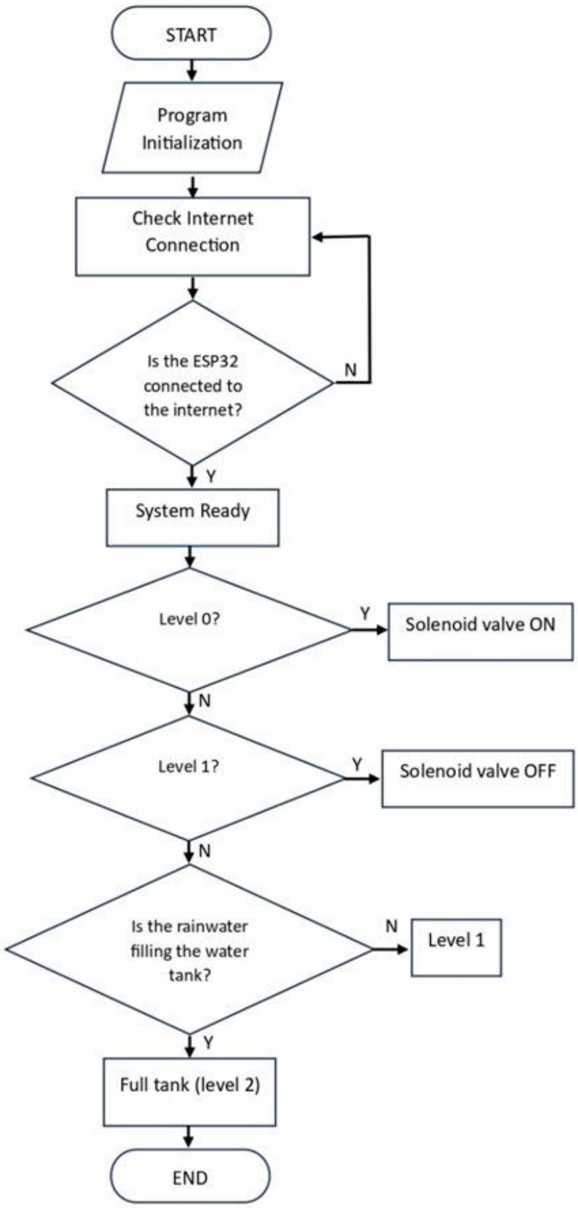

Figure 2. Flowchart of wastewater tank system

Figure 3 shows the workflow of the clean water tank system. Ensuring the system is online and the sensors are functioning correctly is the first step, which is the same as for the wastewater tank system. In the clean water system, when the clean water tank is empty (level 0), the system turns on the pump and Reverse Osmosis (RO) unit, allowing clean water to fill the tank to level 1. The clean water tank also has pH and TDS sensors. If the pH and TDS values do not meet the specified values, the pump and RO unit will be turned off. Staff will replace the filter/ membrane in the RO system to achieve the appropriate pH and TDS. This step is essential to maintain water quality and the availability of clean water.

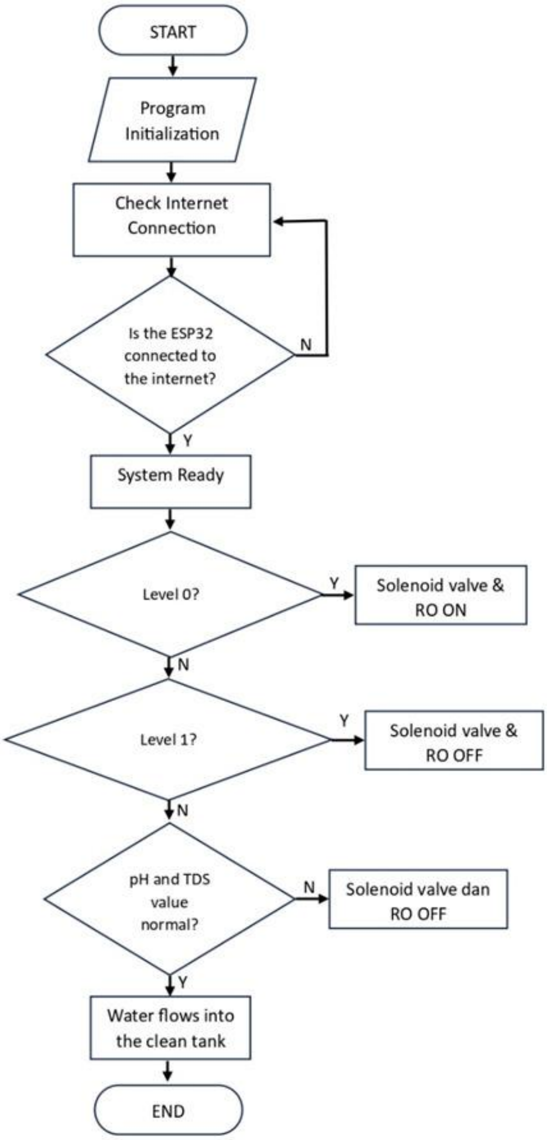

Figure 3. Flowchart of clean water tank system

Implementing this automation system is a key advantage of Smart-RWH compared to conventional RWHs. However, conventional RWHs require residents to manually pump, monitor, and regulate the flow of water, and the whole process is automated with Smart-RWH based on sensor signals. This system reduces the amount of work the community requires to sustain water availability while improving the quality of water data (volume and quality). Moreover, because the IoT-based system also enables residents to check the status of the reservoirs via the Blynk smartphone application, it increases transparency and control in water distribution. This system is consistent with finding of Faishol et al. (2022), indicating that IoT applications in water resource management lead to increased technical efficiency and more transparent and participatory management. Table 1 shows a comparison of conventional RWH and Smart-RWH systems.

Table 1. RWH system comparison

Aspects	Conventional RWH	Smart-RWH IoT-based
Filling System	Conventional, rely on gravity flow or a simple pump	Automatic with ESP32 sensor-controlled pump
Water Monitoring	None, quality and volume are not measurable	Real-time, using pH and water level sensors
Capacity and Efficiency	Limited, often insufficient for household needs	600-litre capacity, more efficient and measurable distribution
Water Quality	Prone to contamination due to lack of digital filter	More guaranteed, equipped with pH and TDS sensors
Data Access	Not available, based on residents' estimations	Monitoring with Blynk application on smartphone
Community Roles	Passive, only limited as a user	Active as team members (in RWH Team) and data monitor
Sustainability	Less adaptive to climate change	More adaptive, supporting socio-ecological resilience

2. Operational Performance

In implementing Smart-RWH, technical aspects are the backbone of the system's success. A clear design of the hardware specifications, controlling architecture, and protection mechanisms is necessary to ensure the solution works reliably in the laboratory and the field, especially in coastal environments susceptible to corrosion, electrical fluctuations, and poor internet connectivity. Therefore, the following technical description outlines the components used and the safety logic, connectivity, and maintenance plans to ensure the sustainability and long-term performance of Smart-RWH. Table 2 shows the technical specifications of Smart-RWH. Meanwhile, Picture 2 shows students installing the RO device.

The introduction of renewable energy-based technologies for social benefit has been effectively implemented in various contexts, such as the use of solar power plants (PLTS) in educational institutions. Kusmantoro & Farikhah, (2022) demonstrate that community service activities that integrate solar PV technology and environmental education significantly enhance public awareness and technical capacity in managing renewable resources. This finding resonates with the Smart-RWH model, which combines clean water technology with social and ecological literacy.

Overall, the field implementation demonstrated that Smart-RWH operated reliably under coastal conditions, ensuring water quality and usability for household needs

Discussion

The Smart-RWH prototype achieved an operational uptime of >90%, supplying clean water to 30 registered households during the pilot period. Water quality improved from an average of pH 6.1 (initial) to pH 6.9–7.2 after filtration, and TDS levels were reduced from approximately 230–250 ppm to 55–70 ppm. The system enabled an estimated 40–50% reduction in monthly household water expenditure (from IDR 80,000–100,000 to 40,000–50,000), representing a potential collective annual saving of approximately IDR 15–18 million for the participating community.

The implementation outcomes also reveal broader social and ecological implications, particularly in shaping community behavior and Islamic environmental ethics. Regarding social and religious implications, the program's success also reflects the growth of ecological piety at the level of society. The community is familiar with the technology and instills Islamic ethics in water management, such as prohibiting *israf* (excessive water use) and promoting *tahdzibul isti'mal* (wise use). These values strengthen social cohesion and foster *ukhuwah insaniyah*—collaboration among human beings in preserving God's creation. Thus, Smart-RWH functions as a concrete means of ecological *da'wah* (*da'wah bi al-hal*) to strengthen the Islamic awareness of coastal residents.

Table 2. Smart-RWH technical specifications

Components	Minimum Specification	Operational Notes
Main tank	600 L, food grade	Overflow + ventilation
Well pump	≥250 W, head ≥20 m	Dry-run protection
Sensor level	Float sensor	+ float switch failsafe
Sensor	pH and TDS	Regular calibration
Filter	Sediment–Carbon–RO–Post	Working pressure & service life
Control	ESP32, relay solid state	Watchdog, fail-safe
Power	Solar power plant (PLTS)	Surge & grounding
Connectivity	Wi-Fi (Blynk), offline log	RTC + SD card

Picture 2. RO installation

This result compares favorably with findings from other studies on IoT-based water monitoring (Ismail, Dawoud, Ismail, Marsh, & Alshami, 2022; Lakshmikantha et al., 2021). This design is also simpler and more cost-effective, making it easier to replicate at the community level. Filter maintenance and corrosion in coastal environments are the principal limitations that further protective constructions and a routine maintenance program have overcome. The potential long-term impact of Smart-RWH implementation is to decrease dependence on bottled water, realize household cost savings of as much as 40%, and give communities greater capacity to manage this and other adaptive technologies. Thus, Smart-RWH addresses technical clean water challenges and strengthens the socio-ecological resilience of coastal communities, which can be replicated in other areas with similar conditions.

Similarly, international studies indicate that IoT-based water systems contribute not only to technical efficiency but also to community resilience when governance and participation are embedded in the model. For example,Fijar, Kartika, Ningsih, Aditya, & Saputra, (2023) demonstrated the feasibility of an IoT-based rainwater harvesting system capable of monitoring pH, TDS, turbidity, and temperature in real time to ensure potability. While their model successfully improved water quality and demonstrated the reliability of sensor-based monitoring at prototype scale, the application remained primarily technical and laboratory-focused. In contrast, the Smart-RWH model in this study extends beyond system validation by embedding community governance, cost-benefit implementation, and value-based environmental ethics grounded in Islamic principles. This distinction highlights that the present study not only confirms the technical feasibility of IoT-enhanced filtration systems but also advances a socially integrated and ethically informed model of resilience in coastal communities. Meanwhile,Perumal, Sulaiman, & CY, (2018) found that transparency enabled by IoT monitoring improved trust, equity in distribution, and long-term system sustainability. Compared to these studies, the Smart-RWH model in this research adds a distinctive contribution by integrating Islamic ecological ethics as a behavioural framework, positioning resilience not only as a technical outcome but as a moral and communal practice grounded in religious values.

Socially, the implementation of Smart-RWH in Timbulsloko Hamlet demonstrated a significant shift in community interaction patterns with water resources. Residents bought bottled water or waited for clean water delivery outside the community before the program, which saw water as a precious resource acquired through market mechanisms. Following Smart-RWH's implementation, water was seen as common goods that must be handled collectively. This improvement reflected residents' increased readiness to collaborate on cleaning tanks, changing filters, and logging sensor data. Once technical activities emerged as new social spaces where residents talk, learn, and develop a sense of ownership over technology that they manage. Within the framework of community resilience theory, this represents the formation of adaptive capacity, the community's ability to learn, adapt, and build solidarity through collective experiences in the face of environmental change (Pratama et al., 2025).

In addition to fostering new solidarity, Smart-RWH also impacted on the division of gender roles at the household level. Informal interviews indicated that women, who had traditionally been responsible for household water needs, were the ones who benefited most. They no longer had to wait for water deliveries from outside or spent additional costs to buy gallons. Time typically spent queuing or drawing water can now be diverted to productive activities such as home businesses or *pengajian* (religious study). Certain women are active members of the Smart-RWH Team, mostly in documenting water quality and reporting tank status. This phenomenon illustrates women's ecological agency — that is, women taking an active role in the handling of natural resources through their religious practices and social responsibility (Anugraha, Karmilah, & Rahmana, 2022).

Economically, Smart-RWH has a substantial effect on household expenses. By our rudimentary calculations, each family spent approximately Rp 80.000–100.000 a month on water gallons. After using Smart-RWH, the cost came down to Rp 40.000–50.000 a month, mainly because of electricity bills for running pumps and maintaining the filter. This results in monthly savings of between 40-50% of clean water expenses. If this value is multiplied by 30 user families, Smart-RWH contributes to collective savings of over 15 million rupiahs in one year. These savings have social as well as economic value because they use some of the money left over for group social gatherings (*arisan*), collaboration (gotong royong), and religious gatherings (*tahlilan*). Thus, Smart-RWH is a technological tool and a medium for redistributing social benefits at the community level.

Smart-RWH also serves as a living laboratory for students across disciplines. Electrical Engineering students learn to design and maintain sensors, and Urban and Regional Planning students identify spatial patterns and environmental carrying capacity. Meanwhile, Magister of Islamic Education students develop an ecological *da'wah* module based on Islamic *fikih* (*fiqh bi'ah*). This cross-disciplinary collaboration fosters a holistic understanding that water issues are not merely technical issues, but interconnected social, ecological, and spiritual issues. On several occasions, residents also speak at thematic lectures on campus, demonstrating the practical application of the *Kampus Merdek*a concept—the knowledge exchange between academics and the community.

From an ecological sustainability perspective, Smart-RWH reduces pressure on shallow groundwater sources. Before the program, some residents dug new wells to avoid seawater intrusion, which exacerbated land subsidence. After Smart-RWH was implemented, active wells decreased because rainwater supplies were sufficient to meet basic needs. This technology reduces the overexploitation of groundwater and suppresses land subsidence. In the future, the success of this model can help mitigate environmental risks, such as land subsidence and the expansion of tidal flooding. Maintaining the balance of nature manifests the values of *ihya'ul-ardh* (giving life to the earth) and *tadbir al-ni'mah* (managing blessings), emphasized in Islamic ethics.

Ultimately, the results of the community's joint reflections demonstrate that technological innovation does not always require extensive infrastructure or high costs. The importance of technology for society was the determinant of success. The community embraced Smart-RWH not for its complexity but for its ability to meet real needs that resonated with their values. In this sense, community service became a place for co-creation—a space where science, religion, and indigenous knowledge intersect to create a resilient, just, and sustainable community.

Conclusion and Suggestion

Laboratory and field-testing results show that Smart-RWH can operate steadily with sufficient sensor accuracy and pump/ filtration system reliability. Adding corrosion protection, a fail-safe mechanism, and offline communication options enhance the system's robustness in a coastal area. Technical issues, including periodic filter maintenance and potential interruptions to internet connectivity, have solutions in the form of routine maintenance regimens and the potential installation of Wi-Fi. Together, these results suggest that Smart-RWH is a promising technology-based approach for sustainable clean water supply in coastal communities and provides avenues for scale-up. Theologically, this activity also embodies the principle of *rahmatan lil 'alamin* (mercy for the universe) in the context of natural resource management. Technology is an instrument of collective worship that connects faith, knowledge, and good deeds in addressing coastal areas' water crisis and climate change challenges. Smart-RWH aims to be a model for continuous learning between campuses and the community. This system can be enhanced with independent energy sources through solar panels and integration with digital village applications for regular water data monitoring.

Replication in Bogorame Village will be the next step in building a coastal innovation network based on Islamic ecological ethics. Therefore, Smart-RWH is both a technological solution and a socio-religious practice that cultivates ecological consciousness, self-reliance, and cooperation in the coastal communities confronted with the water crisis and climate change.

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