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Evaluating the efficiency of ‘Waterwise’: A smart automated irrigation system for sustainable water management

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Abstract

Efficient irrigation is essential especially in the areas with limited water resources. However, cost-effective and the availability of automated solutions remain limited, especially for small-scale farmers. This study assesses Waterwise, an Arduino-based irrigation system aimed at optimizing water utilization, improved soil moisture management, and minimizing energy consumption. A true experimental design was employed and conducted in six (6) barangays in Malinao, Aklan, Philippines with thirty (30) farmers selected through accidental sampling. Key performance metrics included water use efficiency (WUE), soil moisture management, and energy use efficiency with findings showing high effectiveness across all areas. WUE recorded a mean score of 4.51, classified as very highly efficient, while soil moisture management obtained an average score of 4.38 and energy efficiency obtained 4.37 average score, both classified as highly efficient. These findings demonstrate the potential of low-cost, automated systems in improving agricultural sustainability. For further implementation, it should include structured user training to support scalability and renewable energy integration in agriculture.

Keywords: *efficient irrigation, Arduino, water efficiency, sustainability, cost-effective, energy efficiency*

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1. Introduction

Irrigating crops is a practice that can be traced way back thousands of years ago; it is a system that has benefited many people in the past and even in modern civilization. Irrigation, in agriculture, is the artificial application of water on land to hydrate plants. Some farmers, especially those who own wide fields, mostly use water irrigation for less manual work of watering the plants or use canals to provide the proper supply of water for their crops (Jones, 2025). Irrigation has been fundamental to agricultural development for millennia, serving as the backbone of food production systems worldwide. From the ancient civilizations of Egypt and Mesopotamia, where the first systematic irrigation networks emerged over 8,000 years ago, to contemporary precision agriculture, the artificial application of water to croplands has enabled societies to transcend the limitations of rainfall-dependent farming. Traditional irrigation methods have evolved from manual bucket systems to sophisticated canal networks, reservoirs, and motorized pumps, yet the fundamental challenge remains: delivering the right amount of water to crops efficiently while conserving increasingly scarce water resources.

In the modern agricultural landscape, this challenge has intensified due to global population growth, climate change, and competing demands for freshwater resources. Agriculture currently accounts for approximately 70% of global freshwater withdrawals, with irrigation being the largest consumer within this sector (FAO, 2020). Despite the rise of advanced technology over time, the basic purpose of irrigation is much the same: to provide and supplement water for crops in wide fields and gardens to improve their quality and health. It is believed that agriculture or civilization is not possible without some form of irrigation. Some of the first recorded forms of irrigation in the past involved people carrying buckets of water from wells or rivers to provide for their crops. Soon enough, with the world revolving and evolving, water irrigation was improved from buckets and canals to new technologies like reservoirs, tanks, and pumps to supply water to crops and fields (Hovey, 2020). With this being stated, it will sooner or later come to the world’s attention what else is there to be contributed in water irrigation systems to improve and make the process simple and easy to handle.

As water scarcity intensifies across regions, particularly in developing countries where smallholder farmers predominate, the imperative for water-efficient irrigation technologies has become critically urgent. The Food and Agriculture Organization projects that agricultural water demand will increase by 50% by 2050 to meet food security needs, while climate variability continues to exacerbate water availability uncertainties (FAO, 2020; Mukherjee et al., 2022). This convergence of rising demand and diminishing supply underscores the necessity for innovative irrigation solutions that maximize productivity while minimizing resource consumption. Modern-day civilization and technology will be a big help in taking a big step forward in discovering a new and an efficient way of handling our daily occurrences, such as a tool or a system needed for better plant growth that could benefit worldwide. Water scarcity is a pressing global issue that has significant implications for agriculture, farmers, and gardeners. The increasing water demand, associated with climate change and unsustainable practices, has led to a reduction in water availability in many regions with the consequences of reduced crop yields, increased food prices, and negative impacts on the environment.

The advent of smart agriculture technologies, particularly microcontroller-based automated irrigation systems, represents a transformative opportunity to address these challenges. Recent advances in sensor technology, wireless communication, and embedded computing have enabled the development of precision irrigation systems capable of real-time soil moisture monitoring, automated water delivery, and data-driven decision support. Arduino-based irrigation systems have emerged as particularly promising solutions due to their affordability, ease of customization, and capacity to integrate multiple sensors for environmental monitoring (Almalki et al., 2024). These systems utilize soil moisture sensors to continuously assess field conditions and trigger irrigation only when necessary, thereby eliminating water waste from over-irrigation while preventing crop stress from under-watering. Studies demonstrate that precision irrigation technologies can reduce water consumption by 20-40% compared to conventional methods while maintaining or improving crop yields (Alshawabkeh et al., 2024; Lakhiar et al., 2024). Beyond water conservation, automated irrigation systems offer additional benefits including reduced labor requirements, lower energy consumption through optimized pump operation, and enhanced soil health management by preventing waterlogging and erosion.

Despite these advantages, adoption rates among smallholder farmers in developing regions remain limited due to high initial costs, technological complexity, inadequate digital infrastructure, and insufficient training programs (Bwambale et al., 2023). The Philippines, an archipelagic nation where agriculture employs approximately 25% of the workforce and contributes significantly to rural livelihoods, faces acute irrigation challenges. The country experiences pronounced seasonal rainfall variability, with distinct wet and dry seasons that complicate agricultural water management. Smallholder farmers, who constitute the majority of agricultural producers, predominantly rely on manual irrigation methods or rain-fed agriculture, making them particularly vulnerable to climate-induced water stress.

In the Western Visayas region, including Aklan province, agricultural productivity is frequently constrained by inadequate irrigation infrastructure and limited access to water-efficient technologies. Local farmers encounter multiple obstacles including rising input costs for seeds, fertilizers, and fuel; unpredictable weather patterns that disrupt planting schedules; and restricted access to agricultural extension services and digital information systems (Philippine Statistics Authority, 2023). These challenges are compounded by limited financial resources and technical knowledge, which prevent farmers from adopting modern irrigation technologies that could enhance their productivity and resilience. The development of affordable, user-friendly automated irrigation systems tailored to the specific needs and constraints of smallholder farmers in developing countries thus represents a critical research priority with substantial implications for food security, rural development, and sustainable resource management.

This research addresses a critical gap in the existing literature on smart irrigation systems by evaluating the practical implementation and effectiveness of a low-cost, Arduino-based automated irrigation solution specifically designed for smallholder farmers in resource-constrained settings. While extensive research has documented the technical capabilities and potential benefits of automated irrigation systems, most studies focus on large-scale commercial agriculture or controlled experimental environments (Cui et al., 2025; Iqbal et al., 2024). Limited empirical evidence exists regarding how these systems perform when deployed among actual smallholder farmers who face real-world constraints including limited technical expertise, inadequate digital infrastructure, climate variability, and financial limitations. Furthermore, few studies comprehensively evaluate the integrated effects of water use efficiency, soil moisture management, and energy consumption within a single automated system accessible through mobile applications. This research fills these gaps by assessing *Waterwise*, an Arduino-based automated irrigation system implemented among thirty farmers across six barangays in Malinao, Aklan.

This study aims to evaluate the efficiency of *Waterwise* in optimizing resource utilization among farmers and gardeners in Malinao, Aklan. It specifically aims to assess the Water Use Efficiency (WUE) of the Waterwise automated irrigation system compared to conventional manual irrigation practices; evaluate its effectiveness in soil moisture management, including maintaining optimal moisture levels, preventing over-watering, and supporting sustainable soil health; determine the system's energy use efficiency in terms of electricity consumption and operational sustainability; identify the challenges faced by smallholder farmers in implementing automated irrigation technology, such as climate variability, high input costs, and limited access to digital infrastructure; and gather farmer recommendations for system improvements and scalability, particularly in relation to renewable energy integration and user training requirements.

The significance of this study extends beyond its immediate research context to address broader challenges in agricultural development and environmental sustainability. First, by demonstrating that low-cost automated irrigation can achieve high efficiency levels among smallholder farmers, this research provides a scalable model for technology diffusion in developing countries where the majority of agricultural production occurs on small farms. Second, the study contributes to the United Nations Sustainable Development Goals, particularly SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action), by promoting resource-efficient agricultural practices that enhance food security while conserving water and energy resources. Third, the research informs policy development by identifying specific barriers to technology adoption and user requirements for system design, thereby guiding future interventions to support agricultural modernization. Finally, by integrating theoretical frameworks from technology acceptance, innovation diffusion, and resource conservation, this study advances scholarly understanding of how sustainable agricultural technologies can be effectively introduced and sustained in developing agricultural communities.

2. Literature Review

2.1. Theoretical Framework

This study is anchored on three theoretical frameworks that collectively explain the adoption, efficiency, and sustainability of automated irrigation systems in resource-constrained agricultural settings.

The Technology Acceptance Model, developed by Davis (1989), serves as the primary framework for understanding user adoption of *Waterwise*. TAM posits that technology acceptance is primarily determined by two constructs: Perceived Usefulness (PU) and Perceived Ease of Use (PEOU). In the context of this study, PU refers to the degree to which farmers believe that *Waterwise* enhances their irrigation efficiency, water conservation, and crop productivity. PEOU addresses the system's user-friendliness through the custom mobile application interface. These constructs directly influence farmers' behavioral intention to adopt and continue using automated irrigation technology, which aligns with the study's objective of evaluating system effectiveness and user acceptance among smallholder farmers.

The Diffusion of Innovation Theory (DOI) provides the framework for understanding how *Waterwise* spreads within farming communities. DOI identifies five key attributes that determine innovation adoption: relative advantage (the system's superior water efficiency compared to traditional methods), compatibility (alignment with existing farming practices), complexity (ease of understanding and use), trialability (opportunity to test before full adoption), and observability (visible results in water savings and soil management) (Rogers, 2003). This theory explains the adoption barriers identified in the study including high input costs, climate variability, and limited technology access while providing a roadmap for scaling the innovation across similar agricultural contexts.

Grounded in sustainable development principles, the Resource Conservation Theory (Hobfoll, 1989, 2001) emphasizes the optimization of limited resources to achieve long-term sustainability. In agricultural systems, RCT focuses on maximizing resource use efficiency while minimizing waste and environmental degradation. This framework directly supports the study's evaluation metrics: WUE, Soil Moisture Management, and Energy Use Efficiency. By applying RCT, the study examines how *Waterwise* conserves critical resources water, energy, and soil quality thereby promoting agricultural sustainability in water-scarce environments. This theoretical lens validates the system's contribution to addressing global challenges such as climate change adaptation, food security, and sustainable resource management as outlined in the United Nations Sustainable Development Goals (SDGs 2, 6, 12, and 13).

The integration of these three frameworks provides a comprehensive theoretical foundation for the study. TAM explains *why* farmers adopt *Waterwise*, DOI clarifies *how* the innovation spreads within communities, and RCT demonstrates *what* sustainable outcomes are achieved. Together, they support the hypothesis that affordable, user-friendly automated irrigation systems can significantly improve water efficiency, soil management, and energy conservation while addressing the socio-economic and environmental challenges faced by smallholder farmers in developing regions.

2.2. Smart Irrigation Systems and Automation Technology

The integration of microcontroller-based systems in agriculture has revolutionized traditional irrigation practices. Recent studies have demonstrated the effectiveness of Arduino-based automated irrigation systems in optimizing water usage and improving crop management. These systems utilize soil moisture sensors to continuously monitor moisture levels and trigger automated watering when predetermined thresholds are reached, significantly reducing water waste and labor requirements (Almalki et al., 2024; Aarif, 2025). The advancement of smart sensor technologies has enabled real-time monitoring of environmental parameters, allowing farmers to adapt their practices to changing climate patterns and enhance agricultural resilience (Aarif, 2025).

The advancement of Internet of Things (IoT) technologies has further enhanced smart irrigation capabilities by enabling remote monitoring and control through mobile applications and web interfaces. IoT-enabled irrigation systems allow farmers to monitor field conditions in real-time, receive alerts about soil moisture levels, and adjust irrigation schedules from anywhere using smartphones or computers (Benyezza et al., 2021). This connectivity is particularly valuable for smallholder farmers who manage multiple plots or engage in off-farm employment, as it reduces the need for constant physical presence in fields. Research by Krishnan et al. (2020) demonstrated that IoT-based precision irrigation systems improved water use efficiency by 30% while reducing labor requirements by 50% in smallholder vegetable production systems.

Machine learning and artificial intelligence are increasingly being integrated into smart irrigation systems to enhance decision-making capabilities. These advanced systems analyze historical data, weather forecasts, crop growth stages, and soil characteristics to predict optimal irrigation schedules and water requirements (Nawandar & Satpute, 2019). A study by Vij et al. (2020) showed that machine learning-based irrigation systems achieved 35% water savings compared to conventional scheduled irrigation while improving crop quality and yield. However, the complexity and cost of AI-enabled systems may limit their accessibility to smallholder farmers, highlighting the continued relevance of simpler Arduino-based solutions that balance functionality with affordability. The scalability and adaptability of microcontroller-based irrigation systems make them particularly suitable for diverse agricultural contexts. These systems can be customized to accommodate different crop types, field sizes, and environmental conditions through software modifications and sensor configurations (Goyal & Sharma, 2023). Recent innovations include solar-powered autonomous systems that operate independently of grid electricity, making them viable for remote agricultural areas with limited infrastructure (Rayhana et al., 2020). The modular nature of Arduino-based systems also facilitates incremental adoption, allowing farmers to start with basic automation and gradually add functionality as they gain experience and resources.

2.3. Water Use Efficiency and Conservation

The WUE has become a critical factor in sustainable agriculture, particularly in water-scarce regions. WUE is defined as the amount of carbon assimilated as biomass or grain produced per unit of water consumed by crops, which represents the balance between carbon gain and water loss during photosynthesis (Dehghanpir et al., 2024). At the field level, WUE can also be expressed as crop yield per unit of irrigation water applied. This provides a practical metric for evaluating irrigation system performance.

Improving WUE is essential for maintaining agricultural productivity while conserving increasingly scarce freshwater resources, particularly in arid and semi-arid regions where agriculture accounts for over 80% of water consumption (Rosa et al., 2020). Recent research has focused on agricultural and technology-based strategies to improve WUE in arid and semiarid areas, in which optimized irrigation practices are essential for maintaining productivity under changing climate conditions. For example, Lakhiar et al. (2024) conducted a comprehensive review of precision irrigation water-saving technologies under changing climate, and emphasized their role in enhancing water use efficiency, crop yield, and reducing environmental footprints. Their findings support the implementation of automated systems that respond dynamically to environmental conditions, with documented water savings ranging from 20% to 50% depending on crop type, climate, and previous irrigation practices.

Variable rate irrigation systems, which adjust water application rates based on spatial variability in soil properties and crop water requirements, have shown particularly promising results in improving WUE while addressing within-field heterogeneity (Colaizzi et al., 2021). Furthermore, Alshawabkeh et al. (2024) stressed emerging technologies for efficient water use in agriculture, such as the precision irrigation systems incorporating real-time data monitoring that can reduce water consumption by up to 30% compared to conventional methods while maintaining or improving crop yields. This efficiency gain is attributed to several factors including elimination of over-irrigation, reduction of deep percolation losses, minimization of surface runoff, and optimization of irrigation timing to match crop development stages and evapotranspiration demands. Furthermore, deficit irrigation strategies control water stress at specific growth stages when implemented through precision systems can achieve WUE improvements of 15-25% without significant yield penalties for many crops (Fernández, 2017).

Studies have also revealed significant potential for water savings through technology adoption. Research on field-scale crop water consumption indicates that improved irrigation efficiency and strategic crop selection can reduce water consumption substantially, with northern regions showing lower irrigation efficiencies than southern regions (Thaler et al., 2024). Research in various agricultural systems has demonstrated that soil moisture sensor-based irrigation can reduce water applications by 25-45% compared to farmer-managed irrigation while maintaining crop productivity (Bwambale et al., 2022). The integration of weather data, crop coefficients, and soil moisture information enables more sophisticated scheduling algorithms that account for evapotranspiration dynamics and optimize irrigation timing and amount.

Climate-smart irrigation practices that enhance WUE are increasingly recognized as essential adaptation strategies for agricultural systems facing increased water scarcity and climate variability. These practices include mulching to reduce evaporation losses, conservation tillage to improve soil water retention, and crop rotation patterns that optimize water productivity across seasons (Frenken & Gillet, 2012). When combined with precision irrigation technologies, these complementary practices can achieve cumulative water savings of 40-60% while improving soil health and resilience to drought stress (Jägermeyr et al., 2016). The economic benefits of improved WUE extend beyond water conservation to include reduced energy costs for pumping, lower labor requirements, and often improved crop quality and marketability.

2.4. Soil Moisture Management

Advanced soil moisture sensors provide high-frequency, high-precision, and cost-effective monitoring of soil water storage, which is essential for efficient water resource utilization and crop health management (Cui et al., 2025). Recent technological advancements in soil moisture sensors have enabled on-the-go monitoring and provide recommendations for optimizing resource use and minimizing environmental impacts (Iqbal et al., 2024). Sensors integrated into irrigation systems facilitate more precise watering schedules than those based solely on historical data or weather forecasts (Gong et al., 2022). The spatial and temporal variability of soil moisture within agricultural fields necessitates strategic sensor placement and interpretation protocols to ensure representative measurements.

Research has shown that soil moisture varies considerably across field landscapes due to differences in soil texture, topography, drainage patterns, and crop water uptake, with coefficients of variation often exceeding 30% (Vereecken et al., 2014). Effective soil moisture management requires understanding of this variability and positioning sensors in locations that reflect average field conditions or critical management zones. Multi-sensor networks that capture spatial heterogeneity provide more robust data for irrigation decisions, particularly in larger fields or those with significant topographic variation (Hedley & Yule, 2009).

The economic viability of soil moisture sensor adoption depends on several factors including crop value, water costs, field size, and irrigation system type. Cost-benefit analyses have demonstrated positive returns on investment for soil moisture monitoring in high-value horticultural crops, where the combination of water savings, yield improvements, and quality enhancements typically justify sensor investment within one to three growing seasons (Thompson et al., 2007). For lower-value field crops or small farm operations, the economic case may be less compelling unless water is particularly scarce or expensive. However, as sensor costs continue to decline and farmers gain experience with sensor-based management, adoption rates are increasing across diverse agricultural contexts. Government subsidies and technical assistance programs in many regions further improve the economic attractiveness of precision irrigation technologies (Chukalla et al., 2015).

2.5. Energy Efficiency in Irrigation System

Energy consumption in irrigation systems represents a significant operational cost for farmers and makes energy efficiency a critical consideration in system design. Recent research has highlighted the potential of energy-efficient smart irrigation technologies as a pathway to both water and energy sustainability in agriculture. For example, Sattar et al. (2025) noted that conventional irrigation methods often involve substantial energy expenditure, whereas automated systems with optimized scheduling can reduce energy consumption while maintaining irrigation effectiveness. The integration of renewable energy sources, particularly solar power, with smart irrigation systems has emerged as a promising approach for sustainable agriculture. Solar-powered irrigation systems can operate independently of grid electricity, reducing operational costs and environmental impact while ensuring reliable water delivery in remote agricultural areas. This integration aligns with global trends toward circular resource use and sustainable agricultural practices.

2.6. Challenges in Agricultural Technology Adoption

Despite the demonstrated benefits of smart irrigation systems, several barriers to adoption persist, particularly among smallholder farmers in developing regions. Bwambale et al. (2023) identified key challenges including high initial investment costs, limited access to technical knowledge, and inadequate digital infrastructure. Climate variability poses additional challenges, with irregular rainfall patterns making it difficult for farmers to plan planting and harvesting schedules, increasing crop loss risks. The digital divide remains a significant obstacle to technology adoption in rural agricultural communities. Limited access to mobile devices, internet connectivity, and digital literacy programs constrains farmers' ability to fully utilize smart irrigation systems and access timely agricultural information.

Addressing the challenges requires comprehensive approaches that combine technology development with capacity-building initiatives, farmer training programs, and supportive policy frameworks. While existing literature extensively documents the technical capabilities of smart irrigation systems and their potential benefits, there is limited research on the practical implementation and effectiveness of low-cost, Arduino-based automated irrigation systems specifically designed for smallholder farmers in developing countries. Most studies focus on large-scale commercial agriculture or controlled experimental conditions, leaving a gap in understanding how these systems perform in real-world settings with resource-constrained farmers. Additionally, few studies comprehensively evaluate the combined effects of water use efficiency, soil moisture management, and energy efficiency in a single integrated system accessible through mobile applications. This study addresses these gaps by evaluating the *Waterwise* system's effectiveness among actual farmers in Malinao, Aklan, providing empirical evidence for the viability of affordable automated irrigation technology in promoting sustainable agriculture and empowering smallholder farmers.

The convergence of smart irrigation technology, water conservation imperatives, and sustainable agriculture practices forms the foundation for evaluating automated irrigation systems like Waterwise. Contemporary agricultural challenges particularly water scarcity, energy consumption, and climate variability demand innovative solutions that balance productivity with resource efficiency. The literature reveals that microcontroller-based irrigation systems, utilizing soil moisture sensors and automated controls, have demonstrated significant potential in optimizing water usage while reducing labor requirements and operational costs (Almalki et al., 2024; Aarif, 2025). These technological interventions address critical agricultural needs by enabling real-time environmental monitoring and dynamic response to changing conditions.

Water use efficiency emerges as a central concern in sustainable agriculture, representing the balance between crop productivity and water consumption. Research indicates that precision irrigation systems incorporating real-time data monitoring can reduce water consumption by up to 30% compared to conventional methods while maintaining or improving crop yields (Alshawabkeh et al., 2024). This efficiency gain is particularly crucial in water-scarce regions where optimized irrigation practices are essential for maintaining agricultural productivity under changing climate conditions (Dehghanpir et al., 2024). Advanced soil moisture sensors complement these systems by providing high-frequency, cost-effective monitoring that enables more precise watering schedules than traditional approaches based solely on historical data or weather forecasts (Cui et al., 2025; Gong et al., 2022).

Energy efficiency represents another critical dimension of sustainable irrigation, with conventional methods often involving substantial energy expenditure. The integration of renewable energy sources, particularly solar power, with smart irrigation systems has emerged as a viable pathway toward both water and energy sustainability in agriculture (Sattar et al., 2025). However, despite these technological advances, significant barriers to adoption persist, particularly among smallholder farmers in developing regions, including high initial costs, limited technical knowledge, inadequate digital infrastructure, and the digital divide (Bwambale et al., 2023).

3. Methodology

3.1. Research Design

This study employs experimental design to evaluate the efficiency of the Waterwise automated irrigation system among smallholder farmers in Malinao, Aklan. The research assesses the system's performance across three key metrics: WUE, soil moisture management, and energy use efficiency, comparing automated irrigation against conventional manual irrigation practices.

The independent variable is the irrigation method (Waterwise automated system vs. conventional manual irrigation), while the dependent variables are water consumption, soil moisture levels, energy consumption, and crop yield. The study also examines farmers' challenges in traditional irrigation practices and their experiences with the automated system through mixed-methods data collection.

3.2. Participants of the Study

The study involved 30 farmers and gardeners from six barangays in Malinao, Aklan: Kinalangay Nuevo (n=6), Kinalangay Viejo (n=6), Lilo-an (n=2), Malandayon (n=5), San Dimas (n=5), and San Roque (n=6). These barangays were purposively selected based on their extensive agricultural fields and gardens suitable for irrigation system implementation.

3.3. Instrumentation and Data Gathering Process

Data collection employed a structured survey questionnaire composed of three main sections. The first section assessed the level of efficiency using validated scales adapted from agricultural technology evaluation literature. Participants rated system performance across water use efficiency, soil moisture management, and energy use efficiency using a five-point Likert scale. The second section identified challenges farmers face in implementing automated irrigation technology. The third section gathered farmer recommendations for system improvements. Structured interviews were conducted with a subset of participants to gather rich qualitative data regarding their experiences. Technical measurements were collected using flow meters for water consumption, calibrated sensors for soil moisture levels, and electricity meters for energy consumption. Data gathering followed a systematic timeline including baseline data collection, system installation and training.

3.4. Data Analysis

Quantitative survey data were analyzed using descriptive statistics including means and standard deviations. Mean scores were calculated and interpreted using predetermined classification ranges. Technical measurement data were analyzed using paired t-tests to assess whether differences were statistically significant. Qualitative data from structured interviews and open-ended survey questions were analyzed using thematic analysis, following established procedures for identifying, analyzing, and reporting patterns within qualitative data.

3.5. Research Ethics

To ensure ethical conduct, the researchers obtained necessary approvals from relevant authorities. This included obtaining formal written consent from the school principal, the research adviser, the mayor, and the barangay captains in the areas where the research was conducted. These letters clearly outlined the research objectives, methodology, and measures in place to safeguard participant confidentiality and data privacy. Before any data collection, the researchers obtained informed consent from each participant. This involves illustrating the research purpose, procedures, potential risks, and benefits, and emphasizing the participant's right to withdraw from the study at any time. Participants are free to choose to take part without pressure and understand that their information will be kept confidential. This ensured that the interview process was conducted ethically, respecting the rights and well-being of those involved in maintaining the integrity of the research process.

4. Findings and Discussion

The flow chart in Figure 1 provides a visual explanation of the process involved in creating and operating an automated water irrigation system. On the other hand, Figure 2 shows the prototype of the developed irrigation system.

Figure 1

The operation of Waterwise

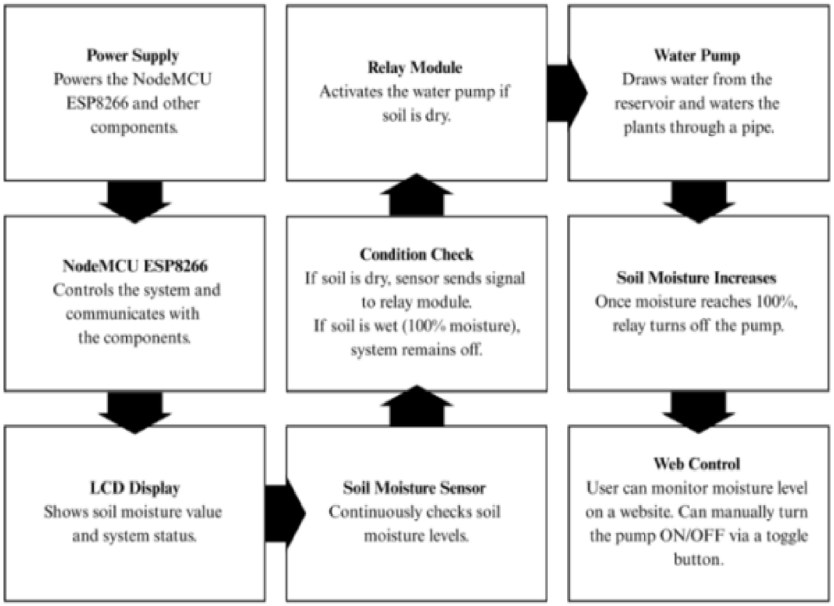

Figure 2

Prototype of the Waterwise

Table 1

The level of efficiency of water irrigation system with water irrigation application

Indicators	Mean	SD
Water Use Effieciency	4.51	0.58
Soil Moisture Management	4.38	0.65
Energy Use Effiency	4.37	0.67

Table 1 shows that the system performed very highly efficient in water use, with an overall mean score of 4.51 (SD = 0.58). It reveals that *Waterwise* is effective in maintaining water supply, reduces insufficiency, and develops innovative watering methods. However, some variability was observed by the respondents of how effectively the system minimized overall water waste, revealing room for improvement in monitoring and user-driven conservation practices. In terms of soil moisture management, the system performed high efficiency, with an overall mean score of 4.38 (SD = 0.65). It reveals that the system had successfully provided ground water recharge for long-term sustainability in maintaining optimal soil moisture levels, reduces soil erosion, prevents over watering, and contributes to sustainable soil management practices. In terms of energy use, results revealed that the system performed high efficiency, with an overall mean score of 4.37 (SD = 0.67). The system significantly reduces water consumption and unnecessary watering compared to traditional irrigation methods. The findings demonstrated *Waterwise* as a viable solution for improving agricultural sustainability and resource efficiency to the farmers and gardeners.

Through structured interviews, it revealed the challenges that farmers and gardeners encountered including climate variability. One respondent stated, *"Problema namon hay kung tig ueuean, ro sobrang tubi nga naga tugpa sa tanom hay maeaw-ay man dahil naga sanhi ra imaw it pagkamatay it mga tanom."* (One of our problems we are facing is when it is the rainy season, over watering can cause our plants to wither). Irregular rainfall patterns make it challenging for farmers to plan planting and harvesting schedules, increasing the risk of crop loss. Moreover, farmers face significant challenges due to high input costs, particularly the rising prices of essential resources such as seeds, fertilizers, pesticides, and fuel as stated by a respondent, *"Malisod makara ro pag taas it mga baeakeon maskapin ro binhi ag ro fertilizer. Kaya kun amat hay gina pili ko lang ro mga buebarato ugaling hay iba gid ro may manami nga kalidad."* (The high price of the seedling and fertilizer is hurting my wallet, that is why sometimes I choose to buy cheaper options but has better quality seedling and fertilizer is much better.)

The participants face several challenges related to access to technology and information due to a lack of digital infrastructure. These challenges limit their ability to improve productivity, adopt modern farming techniques, and compete in the agricultural market as stated by a respondent, *"Nalisdan kami nga makasagap it mga impormasyon nga mas makabulig kamon sa pag panami pagid sa among mga tanom, dahil ngani ra sa kakueangan it gamit parehas ro mga cellphone ngara."* (It is difficult for me to pick up information that can help me improve my farming skills, because I do not have a mobile phone.) For technologies to make a sustainable impact, they must be embedded within broader frameworks of capacity-building, farmer training, and policy support.

The improvements suggested by farmers align with global agricultural innovation trends, particularly the shift toward renewable energy (solar-powered irrigation), circular resource use (wastewater recycling), and integrated nutrient-water management. As stated by the respondent, *"Manami kunta kung butangan niyo it solar panel nga pwedeng maka pa gana sa inyong system para mas makatipid ag makabuhin sa paggamit it kuryente."* (It would be great if a solar panel could be installed that could work with the irrigation system to save more on electricity usage). *"Kung ga tipid ka sa paggamit it tubi pwede ka nga mag reuse it tubi nga halin sa inyong baeay pero kinahangean ra nga i-filter ag i-disinfect do tubi anay bago* *itao sa tanom."* (If you are saving water, you can reuse water from your home, but it must first be filtered and disinfected before being put into the plant).

The recommendations highlight the adaptability and scalability of *Waterwise*, which strengthens its potential as a model system for smallholder farming in developing countries. These findings demonstrate the potential of low-cost, automated systems in improving agricultural sustainability. For further implementation, it should include structured user training to support scalability and renewable energy integration in agriculture.

5. Conclusion

This study evaluated the efficiency of *Waterwise*, an Arduino-based automated water irrigation system designed to optimize water use, improve soil moisture management and minimize energy consumption among farmers and gardeners in Malinao, Aklan. The findings validated that *Waterwise* achieved high efficiency in water use, soil moisture management and energy use efficiency. These findings demonstrate its strong potential as a cost-effective, automated system in improving agricultural sustainability. Moreover, these results validate the main argument that affordable automation can significantly enhance water efficiency, soil moisture management, and energy conservation in local farming systems. This research underscores that low-cost, automated irrigation systems are viable tools for promoting sustainable agriculture, improving water resource management, and empowering smallholder farmers in developing regions.

Integrating smart irrigation systems like *Waterwise* can address critical challenges posed by climate variability, resource scarcity, and rising input costs. It is recommended that future implementations include structured user training, digital literacy programs, and renewable energy integration such as solar-powered irrigation in order to maximize system scalability and sustainability. Collaboration between policymakers, agricultural institutions, and technology developers is also crucial to support adoption at the community level.

Disclosure statement

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Institutional Review Board Statement

This study was conducted in accordance with the ethical guidelines set by the relevant institutional authorities. The conduct of this study has been approved and given relative clearances by the school principal, research adviser, municipal mayor of Malinao, and barangay captains in all participating barangays.

AI Declaration

The authors declare the use of Artificial Intelligence (AI) in writing this paper. In particular, the author used Grammarly in refining sentence structure, Quillbot in summarizing key points and paraphrasing ideas and Claud to refine the clarity of ideas, ensuring the author's originality of ideas. The authors take full responsibility in ensuring proper review and editing of contents generated using AI.

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