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Implementation of an IoT-Based Smart Irrigation System for Highland Horticultural Farming Communities.

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Abstract

Horticultural farming in the highlands of Nagari Alahan Panjang is generally still managed traditionally with manual watering that takes 3 to 4 hours per day. This results in limited productivity at the partner (Palanta Hasna) and farmers are vulnerable to weather uncertainty. This community service activity focuses on the implementation of Internet of Things (IoT)-based automatic irrigation technology on Palanta Hasna partner land to empower the farming community. The activity implementation is designed using a participatory approach that includes stages of socialization, mobile application technical training, hardware installation implementation, and ongoing mentoring and evaluation. The results of the activity show a real transformation of work patterns, where the burden of manual watering that takes 3 to 4 hours per day has been completely reduced to an automated system. In terms of human resource capacity, the evaluation results show an increase in participants' digital literacy by 45.7 points (from a score of 42.5 to 88.2). Agronomically and economically, the system's ability to maintain soil moisture has successfully boosted carrot harvest productivity by 20%, namely from 167.09 kg to 200.51 kg. This program proves that IoT technology interventions are effective in increasing land efficiency as well as the capacity of farming communities, with recommendations for sustainable development using hybrid energy and LoRa networks.

Keywords: Smart Farming, Internet of Things, Farmer Empowerment, Automatic Irrigation, Digital Literacy.

1. Introduction

Nagari Alahan Panjang, located in Lembah Gumanti District, Solok Regency, is geographically one of the most strategic horticultural production centers in the Bukit Barisan highlands. Situated at an altitude of 1,458 to 1,680 meters above sea level with a cultivated area of 782 hectares, this area is blessed with very specific agro-climatic conditions. Average daily temperatures ranging from 18°C to 26°C with monthly rainfall reaching 277 mm make this land an ideal habitat for various commodities of high economic value, such as red chilies, onions, cauliflower, carrots, leeks, and tomatoes. The agricultural sector in this region is not just a marginal economic activity, but the backbone of the livelihoods of the majority of the local population, contributing directly to regional food security and the welfare of farming families [1].

This vast agroclimatic potential faces the paradox of water resource management and increasingly unpredictable climate anomalies.[2] The essential problem faced by local farmer groups, particularly those partnering with the Palanta Hasna Farmers Group, is the high productivity vulnerability resulting from highly conventional cultivation methods. Farmers have relied entirely on natural rainfall (rain-fed) and manual irrigation systems for their harvests[3]. The lack of comprehensive water management infrastructure forces farmers to water their crops manually using buckets and conventional hoses pulled across the hilly terrain. This manual irrigation activity takes up a significant amount of time, approximately three to four hours per day, and drastically drains farmers' physical energy[4]. This excessive physical workload, in turn, reduces farmers' capacity to undertake other agricultural managerial activities, such as integrated pest control, precision fertilization, and exploring market access. Recent empirical studies on rural workflows emphasize that alleviating this localized "time poverty" through automation is a fundamental prerequisite for moving smallholders up the agricultural value chain [13].

In addition to the physical workload, conventional irrigation methods pose a significant risk of agronomic uncertainty. During the dry season, crops are susceptible to drought (water stress), while during the high-intensity rainy season, the lack of a measured drainage and irrigation system can lead to overwatering [5]. Uncontrolled waterlogging in highland horticultural crops is a major trigger for root rot and the proliferation of pathogenic fungi, leading to massive crop failure. Recent data-driven literature in high-altitude environments confirms that automated macro-climate adaptation networks are vital to mitigating these precise fungal and structural yield losses [14]. In this context of vulnerability, farmers in Palanta Hasna are in a passive position to weather dynamics. They need technological and managerial interventions capable of shifting the paradigm from "instinctive farming" to "precision and data-based farming.".

The farming practices at the partner location (Palanta Hasna) are still managed in a traditional way, using manual watering with buckets. This takes 3 to 4 hours per day, making farmers very vulnerable to weather uncertainty and operational inefficiencies, as shown in Figure 1.

Figure 1. Agricultural Land, Alahan Panjang

The transformation towards precision agriculture absolutely requires the integration of smart technology, one of which is through the Smart Farming approach based on the Internet of Things (IoT) [6]. The use of IoT-based smart irrigation systems offers a comparative advantage in automatically maintaining soil microclimate balance through real-time sensor monitoring [7],[8]. Contemporary smart farming reviews highlight that embedding automated cloud platforms and sensory feedback into irrigation valves drastically reduces environmental runoff while conserving critical resource bases [15]. However, from a community service perspective, the introduction of advanced technology to rural areas is not a linear process without obstacles. There is a significant gap between the readiness of technological infrastructure and the digital literacy capacity of farming communities [9].

Various literature on rural community empowerment confirms that the level of agricultural technology adoption is greatly influenced by digital literacy factors, implementation costs, risk perception, and the presence or absence of ongoing mentoring [10]. Within the context of Indonesian smallholder architecture, recent structural equation modeling shows that innovation attributes and intensive on-site learning networks are the prime exogenous determinants behind sustainable smart farming integration [16]. Furthermore, participatory extension frameworks developed show that structured, iterative co-learning cycles are essential to transition farmers safely from technological exposure to long-term experimentation [17]. The absence of intensive mentoring often leads to adoption failure, where modern tools end up as scrap metal because farmers feel technologically illiterate or afraid of damaging existing instruments.

The urgency of this community service activity lies not solely in the installation of smart irrigation system hardware, but rather in the empowerment and social engineering process of the Palanta Hasna farming community. The interventions designed focus on knowledge transfer, skills improvement (digital literacy), and changes in land management behavior. Automatic irrigation technology based on microcontrollers and soil moisture sensors is positioned as "tools," while the main subject of this activity is the farmer group itself [11]. This approach is in line with the basic principle of community service, namely building partner independence in solving their own problems sustainably [12].

This community service activity has three main objectives. First, to increase the digital capacity and skills of the Palanta Hasna farmer group through training and technical assistance in operating an IoT-based irrigation system, thereby growing their confidence in utilizing smartphone technology for agricultural activities. Second, to transform farmers' work patterns from previously relying on physical labor (manual watering for hours) to land management based on remote monitoring, in order to improve work time efficiency and farmers' physical well-being. Third, to reduce the risk of crop failure due to extreme weather anomalies through precise automation of plant water supply, thereby consistently increasing horticultural productivity.

To ensure this technology isn't just a one-time project, the project is designed with a sustainability analysis framework. Active involvement of farmer group members, from problem identification through joint installation, to post-activity device maintenance commitments, is a key pillar of sustainability. Through the implementation of this IoT-based automated irrigation system, it is hoped that the Palanta Hasna Farmers Group will not only be able to escape the shackles of climate uncertainty and manual labor inefficiencies, but also transform into a pioneering community (role model) for the implementation of independent, adaptive, and competitive smart farming in the highlands of West Sumatra.

2. Methods

This community service activity was implemented using a Participatory Action Research (PAR) approach. This approach was chosen because it philosophically positions the target partners—in this case, the Palanta Hasna Farmers Group—not merely as objects receiving technological assistance, but as active subjects directly involved in the process of problem identification, planning, implementation, and evaluation. This series of activities was systematically designed and implemented over three months, from November to January, taking place on the partner's plantation land in Nagari Alahan Panjang.

Table 1. Teknologi dan transformasi perilaku berjalan efektif.

Timeline	Main Stages	Key Activities	Achievement Indicators / Outputs
Month 1	Observation & Socialization	Focus Group Discussion (FGD) regarding manual irrigation constraints. Socialization of the smart farming (IoT) concept. Mapping of land issues.	Common perceptions and readiness of partners.
Month 2	Installation and Training	Participatory hardware installation (sensors and pumps). Mobile application operational training for 21 farmer members.	The IoT system is installed and fully operational. Farmers can monitor their fields via mobile phones.
Month 3	Evaluation and Sustainability	Daily mentoring. Pre-test and post-test evaluation of digital literacy. Formulation of equipment maintenance SOPs.	Improved digital literacy scores. Irrigation time has been drastically reduced (efficiency). Sustainability commitments (SOPs) are in place.
Final Stage	Dissemination and Publication	Evaluation data analysis (technical & partner). Writing and submission of article manuscripts.	Manuscripts published in Sinta 4 accredited community service journals.

To ensure effective technology transfer and behavioral transformation, the implementation phases are divided into four main stages:

Stage 1: Observation, Community Approach, and Socialization

Figure 2. Socialization about System IoT with the head of the Farmer Group

In the first activity, the community service team conducted a family-oriented and cultural approach (pendekatan kekeluargaan) with landowners and members of the Palanta Hasna Farmers Group to dismantle historical skepticism toward digital interventions. This community gathering was attended by all 21 active members of the farmer group, alongside local community leaders, ensuring broad institutional support at the grass-roots level. The main activities in this phase were Focus Group Discussions (FGDs) and program outreach. During these interactive FGD sessions, the team deployed unstructured diagnostic interviews to map localized Agro-climatic challenges and quantify the precise physical and economic burdens of their baseline irrigation practices.

Furthermore, this initial stage served as the baseline checkpoint where the pre-test questionnaire instruments were formally administered to the participants. By embedding the introduction of the IoT-based smart farming framework within the farmers' familiar social environment, the session successfully aligned perceptions, built trust, and cultivated the psychological readiness necessary for the subsequent participatory hardware installation. Ultimately, this comprehensive outreach raised partners' awareness regarding the urgency of transitioning from conventional, labor-intensive methods toward digital literacy-based land management**.**

Stage 2: Installation and Integrative Training

Figure 3. Installation of Irrigation Pipes, Soil Moisture Sensor

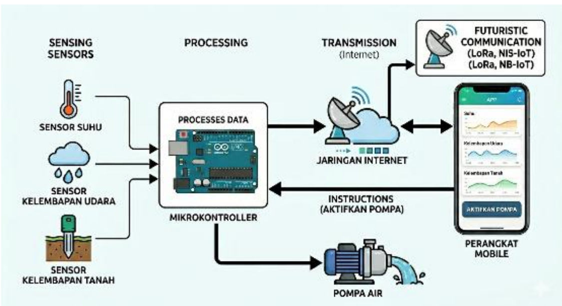

Figure 4. Implemented Technology Scheme

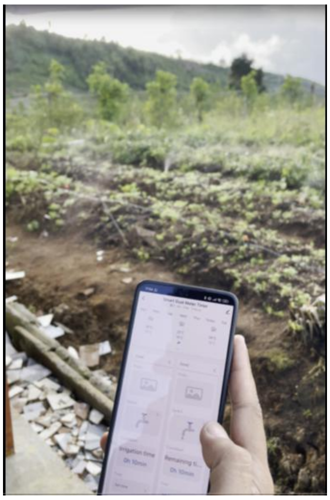

Figure 5. Training and assistance in using IoT

Entering the second month, activities focused on physical interventions and human resource capacity building. The IoT hardware installation process (microcontrollers, soil moisture sensors, temperature sensors, and automatic pump systems) on pilot plots was carried out in a participatory manner, directly involving landowners. This involvement aimed to ensure partners understood the basic structure of the devices and how to physically maintain them. After installation was complete, the next crucial stage was intensive training. Unlike traditional technical training, this training focused on improving partners' digital literacy. The service team assisted 21 individual farmers in installing, understanding the user interface, and operating the real-time land monitoring application via their respective smartphones.

Stage 3: Mentoring, Evaluation, and Sustainability Strategy

The third month was dedicated to ensuring successful technology adoption through ongoing mentoring and comprehensive program evaluation. The community service team monitored the transition of farmers' work patterns, as they began to reduce the frequency of manual watering. At this stage, evaluations were conducted using two main instruments:

1. **Technical and Agronomic Evaluation:** Measuring the reliability of the IoT system in maintaining soil moisture during weather anomalies, the efficiency of farmers' daily work time, and its impact on the growth of horticultural crops.
2. **Human Resource Capacity Measurement:** To quantitatively validate the impact of the mentoring program on human resource capacity building, a comprehensive cognitive and behavioral evaluation was conducted using a

pre-test and post-test design. This evaluation specifically measured three core dimensions: partner farmers' digital literacy, operational understanding of the system, and psychological readiness to adopt the technology. Data collection utilized a structured questionnaire instrument developed on a 5-point Likert scale, ranging from 1 (strongly disagree/lowest) to 5 (strongly agree/highest). The research instrument was purposively distributed to 21 active members of the farmer group who served as respondents. Assessments were administered immediately prior to the implementation of the mentoring period (pre-test) and upon its completion (post-test), enabling a robust statistical comparison to assess shifts in technological literacy and behavioral adoption readiness.

As a final step in the field, the team and partners developed a Sustainability Plan. This strategy included the creation of simple, local-language Standard Operating Procedures (SOPs) for equipment maintenance, as well as the establishment of a self-sufficient group maintenance scheme to ensure the technology remains operational even after the university's community service program has concluded.

Stage 4: Dissemination and Publication of Outputs

Primary data obtained from pre-test and post-test evaluations, sensor data recordings, and participatory field observations were then analyzed descriptively using qualitative and quantitative methods. The results of this comprehensive analysis, which measured the effectiveness of the technology and the success rate of community empowerment, were then compiled into a scientific paper. As a form of academic accountability and broad-based dissemination of knowledge, the final results of this community service activity are targeted for publication in an accredited national scientific journal on community service.

3. Results and Discussions

3.1 IoT System Implementation and Transformation of Farmers' Work Patterns

Community service activities at Palanta Hasna's farm in Nagari Alahan Panjang began with the participatory installation of an Internet of Things (IoT)-based smart irrigation system. This system integrates a microcontroller with temperature, humidity, and soil moisture sensors to respond precisely to weather dynamics. The key achievement of this implementation is not simply the functionality of the hardware, but rather the transformation of the culture and work patterns of farmers

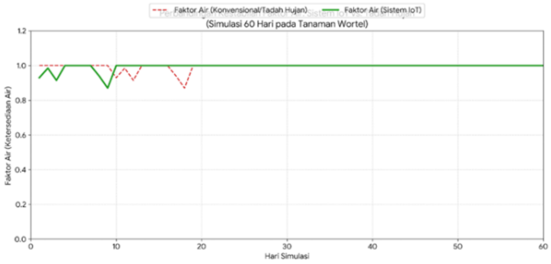

Figure 6. Comparison of Water Factor Stability on Conventional Land and IoT Systems

Before the introduction of technology, land monitoring was carried out entirely through visual estimation (0% accuracy) and a physically demanding manual watering process, taking up to 3–4 hours daily. Post-implementation, these manual interventions were drastically reduced to an automated system requiring only about 10 minutes of monitoring time per day via a smartphone app interface. This time and energy efficiency has had a direct impact on partners, whereby the time previously spent on watering can now be diverted by the farmers to other productive land management activities, such as weeding, follow-up fertilization, or resting to restore their physical fitness.

3.2 Digital Literacy Evaluation and Partner Capacity Building

To measure the impact of community service on improving community capacity, the service team conducted a cognitive evaluation using pre- and post-test instruments on 21 farmer group members. This instrument was designed to measure basic IoT understanding, application operational skills, and mental readiness to adopt new technology. The evaluation results are presented in Table 2.

Table 2. Improving Partners' Knowledge and Technology Adoption Readiness

Aspect	Before Community Service	After Community Service	Analysis/impact
Land Monitoring accuracy	0% (Only Visual / Manual estimate)	100% (Real-time 24 hours via application	Farmer no longer need to guess soil moisture and rainfall conditions
Lowest Soil Moisture	64.80% (high risk of drooping)	70% (Quaranteed stable, the pump will turn on automaticallya if drops)	Smart system prevents the soil from drying out to the plan strees threshold
Average water availability.	Depands on natural rainfall.	Maintained constant automatically by sensor and microcontrollers.	Water supply for plants is always close to optimal.
Irrication Volume.	Unmeasured (Tend to overwatering).	Irrigation pump is automatically deactivated if overwatering occurs.	Savings on irrigation water usage by 100% during periodes of high rainfall, with optimal soil moisture.
Estimated watering time	3-4 hours depending on the situation and conditions at the time.	10 minutes every day (via the system automatically)	Labor efficiency and operational time are significantly reduced
Accumulation of harvest results	167,09 Kg	Increased by 33.42 kg	20% increase proves that IoT is able to increase crop yields.

Table 2 shows a significant increase in understanding for the "Basic Understanding of IoT" indicator, which rose by 45.7 points (from 42.5 to 88.2). This increase demonstrates that the hands-on training method has successfully dismantled the stigma that IoT technology is complicated and only for academics. Furthermore, the "Application Operational Skills" indicator increased by 49.8 points. This is supported by the application's user interface design, which is very simple and uses terms that are easily understood by local farmers.

The most crucial impact was seen in the "Readiness for Technology Adoption" score, which reached 90.0 post-training. The partner satisfaction rate, which reached 80% (out of 21 respondents), confirmed that the farming community is actually very open to agricultural modernization, provided the technology transfer process is carried out gradually, is applicable, and is accompanied by intensive support.

3.3 Climate Risk Mitigation and the Impact of Increasing Productivity

Agroclimatically, the Alahan Panjang region experiences fluctuating and high-intensity rainfall patterns. The implemented IoT system was tested for its capabilities over a 60-day planting period. Field sensor data demonstrated the system's adaptive intelligence, maintaining stable soil moisture content at an average of 99% of the targeted optimum. During heavy rainfall events, the microcontroller automatically shut off the pump to prevent waterlogging.

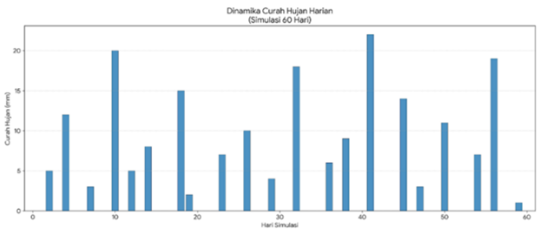

Figure 7. Daily Monthly Rainfall During the Planting Cycle

For farmer groups, this adaptive performance serves as "agroclimate insurance." This system effectively mitigates the risk of overwatering, which triggers root rot and the spread of pathogenic fungi—a classic problem that often leads to crop failure of horticultural commodities in highland areas.

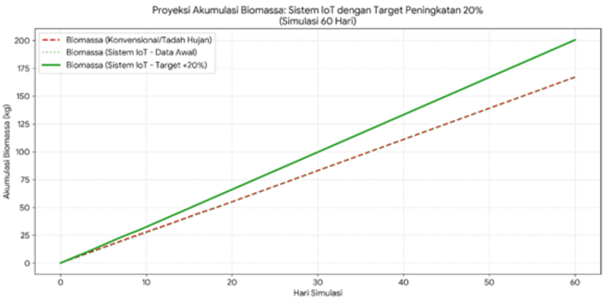

Figure 8. Comparison of Biomass Growth Accumulation Over 60 Days

The technological transformation of the irrigation system has generated profound socio-economic implications for partner farmers, extending far beyond raw agronomic improvements. Economically, this systemic shift fosters substantial cost optimization by drastically reducing daily operational expenditures while simultaneously enhancing crop productivity through microclimate preservation. For instance, field evaluations at the end of a 60-day planting cycle revealed that the IoT system successfully boosted carrot yields by 20%—from a baseline of 167.09 kg to 200.51 kg. This economic viability is further supported by minimized reliance on hired daily labor for irrigation maintenance, which significantly lowers total production costs and expands profit margins.

From a social perspective, the enhanced operational efficiency has dramatically restructured traditional farming labor dynamics. The transition from labor-intensive manual watering—which previously consumed 3 to 4 hours daily—to a streamlined 10-minute metric evaluation has effectively mitigated time poverty among farmers. This newly acquired time surplus enables a strategic shift from routine physical labor toward comprehensive land management. Consequently, farmers can now reallocate their labor capacity to other high-value, productive on-farm activities, including rigorous weeding, intercropping diversification, and meticulous post-harvest management. Ultimately, the synergy between these economic gains and social behavioral shifts establishes a more sustainable and resilient agricultural livelihood for the farming community.

3.4 Program Sustainability Analysis

The biggest challenge in the technology outreach program is ensuring the equipment remains operational and usable after the academic team leaves the site. To address this, the outreach team and its partners formulated four strategies for program sustainability:

1. **Technical Support and Self-Reliance (SOP)**: The team developed a Standard Operating Procedure (SOP) in the local language that is easy to understand, which includes simple

troubleshooting steps, such as how to reset the microcontroller if a network error occurs or how to clean the soil moisture sensor probe to maintain its accuracy.

2. **Financial Capacity for Maintenance**: The Palanta Hasna Farmers Group is encouraged to set aside a small portion of the increased harvest (20%) into the group's cash fund. This cash fund is specifically allocated for independent maintenance costs, such as replacing worn-out sensors or repairing pipe installations.
3. **Long-Term Infrastructure Development**: Given the limited internet coverage and unstable electricity supply in the highland plantation areas, the community service team recommended and planned a second phase of system development. This development plan includes the integration of solar panels as a self-sufficient hybrid energy source, as well as the use of a Long Range (LoRa) network topology to address internet connectivity gaps in the mountains. This strategy ensures that farmer groups can continue to evolve toward a fully digitalized agriculture.
4. **Post-Program Monitoring and Mutual Commitment**: implementation of SOPs and the allocation of maintenance funds, the program's sustainability is firmly secured through a structured post-program monitoring mechanism. The community service team and the partners have established an agreement to conduct virtual operational monitoring on a monthly basis, complemented by quarterly on-site field visits (ground checks). This mechanism is formally reinforced by the signing of a mutual commitment with the farmer group to independently maintain and safeguard the granted IoT infrastructure.

4. Conclusions

The community service program at the Palanta Hasna farm in Nagari Alahan Panjang has successfully implemented an IoT-based smart irrigation system, effectively transforming the farmers' operational work patterns. This initiative significantly enhanced the digital literacy of 21 farmer group members, evidenced by a surge in their basic IoT understanding scores from 42.5 to 88.2. From economic and climate resilience perspectives, the watering automation maximized daily labor efficiency and boosted harvest productivity by 20%. To ensure post-program sustainability, partner independence was strengthened through the establishment of technical SOPs, self-reliant funding schemes, and periodic monitoring commitments. Looking ahead, the integration of hybrid infrastructure using solar panels and a LoRa network is highly recommended to realize a fully autonomous digitalized highland agriculture in terms of energy and connectivity.

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Author Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	W
Okta Andrica Putra	✓	✓	✓	✓	✓	✓			
Hadi Syahputra		✓				✓			✓
Hasri Awal	✓		✓	✓			✓		

C: Conceptualization
M: Methodology
So: Software
Va: Validation
Fo: Formal analysis
I: Investigation
R: Resources
D: Data Curation
W: Writing-Review

Conflict of Interest Statement

Authors state no conflict of interest.

Data Availability

The data generated and analyzed during this community service activity are available from the corresponding author upon reasonable request.

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