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Community-Based Implementation of a Waterwheel-Based Micro-Hydro Power System through Civil Water Intake Construction in Rural Agam, Indonesia

Faisal Ashar[1*], Yaumal Arbi[2], Ricky Maulana[3], Risma Apdeni[4]
[1245] Civil Engineering, Faculty of Engineering, Universitas Negeri Padang, Indonesia
[3] Electrical Engineering, Faculty of Engineering, Universitas Negeri Padang, Indonesia
*Corresponding Author, e-mail: faisalashar@ft.unp.ac.id

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ABSTRACT

This article reports on a community service program to implement a waterwheel-based micro-hydro power system by constructing a civil water intake in Nagari Kamang Hilia, Agam Regency, West Sumatra. The program aimed to provide renewable electricity for rice milling and community street lighting, while strengthening local capacity for operations and maintenance. The implementation consisted of stakeholder coordination, field surveys, drone-based mapping, preparation of Detailed Engineering Design, civil intake construction, electrical integration, commissioning, and community training. The constructed components included an intake structure, a guide channel, a sluice gate, a trash rack, inlet and outlet channels, and a waterwheel chamber. These components were designed to regulate water flow, minimize disturbance from sediment and debris, and support stable waterwheel operation under low-head conditions. Field measurements indicated an average flow velocity of approximately 2 m/s, supporting an initial system capacity of about 5 kW. The system provides renewable electricity for productive use and street lighting, reducing dependence on costly diesel fuel and improving local energy resilience. The training activities also improved community knowledge of intake cleaning, sediment control, waterwheel inspection, and basic electrical safety. The program demonstrates that integrating civil engineering infrastructure, renewable energy technologies, and community participation can serve as a practical model for sustainable rural development.

Keywords: *Civil Water Intake; Community Empowerment; Micro-Hydro Power; Renewable Energy; Rice Milling.*

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INTRODUCTION

Access to reliable and affordable energy is essential to strengthening rural agricultural economies. In rural areas, electricity is needed not only for household activities but also for productive uses such as irrigation management, crop processing, rice milling, lighting, and small-scale community enterprises [1]. Renewable energy systems based on locally available resources have been widely promoted as practical solutions to improve rural energy access while reducing dependence on fossil fuels and on unstable grid supply [2]. In Indonesia, micro-hydro power has become one of the most relevant renewable energy options for rural communities because it can use rivers, irrigation channels, and low-head water resources to generate decentralized electricity [3].

Micro-hydro power systems are generally suitable for areas with continuous water flow and existing agricultural water infrastructure. Compared with large hydropower projects, micro-hydro systems require smaller civil works, can be developed at a community scale, and are more adaptable to local needs and site conditions [4]. Their technical performance is influenced by water discharge, hydraulic head, turbine or waterwheel characteristics, generator efficiency, and the reliability of the supporting civil infrastructure [5]. Therefore, proper planning of the intake structure, guide channel, trash rack, forebay, and flow-control system is essential to ensure that water is captured, directed, and continuously supplied to the energy conversion unit [6].

For low-head hydropower applications, waterwheel-based systems offer a practical alternative, as they can operate with relatively small elevation differences and moderate flow rates. Gravity waterwheels and other low-head hydropower devices have been reported as technically suitable for microscale energy generation, especially in rural areas where simple construction, easy maintenance, and local adaptability are important considerations [7]. In such systems, the civil water intake structure plays a key role by regulating flow stability, reducing hydraulic losses, preventing debris from entering the system, and protecting mechanical components from operational disturbances [8]. Debris accumulation at hydropower intake screens or trash racks can reduce flow efficiency and cause measurable operational losses, making intake design and maintenance critical for long-term performance [9].

In agricultural villages, access to productive energy is closely linked to post-harvest efficiency. Rice milling facilities require a stable power supply to maintain production continuity, reduce operating costs, and increase the added value of agricultural products. When electricity supply is limited, or diesel engines are used as backup power, production costs increase, and local farmers may become less competitive. Previous studies have shown that micro-hydro implementation can improve rural livelihoods when technical feasibility is combined with social acceptance, local participation, and clear institutional arrangements [10].

Nagari Kamang Hilia, located in Agam Regency, West Sumatra, is an agricultural area with strong potential for rice production and other farming activities. The village has extensive paddy fields, irrigation channels, and local rice milling, which support household income and food supply. However, the continuity of electricity supply remains a challenge, particularly for productive activities such as rice milling and public facilities such as street lighting. These conditions indicate the need for a locally available renewable energy system that can support agricultural productivity and improve rural energy resilience [11].

Figure 1: Farm Area

The community service program discussed in this article was designed to address these local needs by implementing a waterwheel-based micro-hydro power system and constructing a civil water intake. The program was not limited to installing electrical equipment; it also included stakeholder coordination, site surveys, hydrometric measurements, topographic mapping, civil design, construction, commissioning, and community training [12]. This approach is consistent with the principle that rural renewable energy projects should not only provide electricity, but also strengthen productive activities, local management capacity, and community ownership [13].

Accurate spatial and hydraulic data are important for selecting an appropriate micro-hydro location and preparing a reliable engineering design. Drone-based mapping, digital terrain modeling, and GIS-based analysis can support site suitability assessment by providing spatial information on topography, access, channel alignment, land use, and infrastructure layout [14]. UAV photogrammetry has been increasingly used in engineering and rural infrastructure planning because it can generate orthomosaics and digital surface models efficiently with relatively low fieldwork requirements [15]. In addition, GIS-based multicriteria decision analysis can assist in identifying suitable sites by combining technical, spatial, environmental, and accessibility criteria [16].

Figure 2: Nagari Rice Milling Business

Community participation is another key factor for the sustainability of rural renewable energy systems. A technically functional system may fail to provide long-term benefits if local users are not involved in planning, operation, maintenance, and decision-making [17]. For micro-hydro projects, local operators must understand routine maintenance tasks such as cleaning trash racks, controlling sediment, checking mechanical rotation, inspecting electrical panels, and monitoring water flow conditions [18]. Therefore, technical training and community-based operation and maintenance arrangements are essential to ensure that the system remains functional after the construction phase [19].

Figure 3: Irrigation System for Paddy Fields

Based on these considerations, this article reports on the community-based implementation of a waterwheel-based micro-hydro power system through the construction of a civil water intake in Nagari Kamang Hilia, Agam Regency. The article specifically emphasizes the civil engineering aspect of the program, particularly the planning and construction of the water intake and supporting structures, which serve as the enabling infrastructure for reliable micro-hydro operation. The expected contributions of this program include providing renewable electricity for rice milling and street lighting, reducing dependence on costly diesel fuel, and strengthening local capacity for sustainable operation and maintenance. This model is expected to support sustainable rural development and may be replicated in other agricultural villages with similar hydrological and socioeconomic

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characteristics [20].

METHOD

This community service program was designed as a participatory and technology-based intervention in Nagari Kamang Hilia, Agam Regency, West Sumatra. The program integrated social engagement, field survey, engineering design, civil construction, electrical integration, and community capacity building. The main objective was to ensure that the waterwheel-based micro-hydro power system was technically feasible, socially acceptable, and manageable by the local community after construction and handover.

The implementation method consisted of six main stages: stakeholder coordination, beneficiary identification, hydrometric and topographic surveys, drone-based spatial mapping, civil water intake design and construction, and operational training and commissioning. This staged approach was selected to ensure that each technical decision was based on field conditions, community needs, and long-term operation and maintenance considerations.

The initial stage involved structured coordination with the Nagari government, farmer groups, rice mill owners, local technicians, and community representatives. This activity was conducted to identify the community's main problems, determine the priority needs of the rice milling facility, select a potential location for the intake structure, and establish the division of roles during construction, operation, and maintenance. Community participation was emphasized to strengthen local ownership and ensure that the system could be operated independently after the program ended.

The target beneficiaries consisted of three main groups. The first group was the rice mill owners and operators, as the direct users of productive energy. The second group was the farmer group located around the irrigation channel and intake area. The third group was local youth and technicians selected by the Nagari government to be trained as future operators and maintenance personnel. Participants were purposively selected for their proximity to the construction site, direct involvement in farming and rice milling activities, and willingness to participate in technical training and routine maintenance.

Field data collection was carried out through hydrometric measurements, topographic survey, and spatial documentation. Water discharge was measured using the velocity-area method at representative channel sections. Flow velocity, channel width, flow depth, water level, and elevation difference were recorded to estimate the available hydraulic potential. Topographic data were collected using field-measuring instruments to support the layout design of the intake, guide channel, waterwheel chamber, outlet, and distribution route.

To support site geometry planning, drone-based mapping was conducted using a multirotor UAV equipped with an RGB camera. The aerial images were processed to generate orthomosaic images and a digital surface model. These spatial data were used to identify relationships among the irrigation channel, rice milling facility, access route, surrounding paddy fields, and planned micro-hydro infrastructure. The mapping results were then processed using Geographic Information System (GIS) and Computer-Aided Design (CAD) software to support site suitability analysis and the preparation of the Detailed Engineering Design.

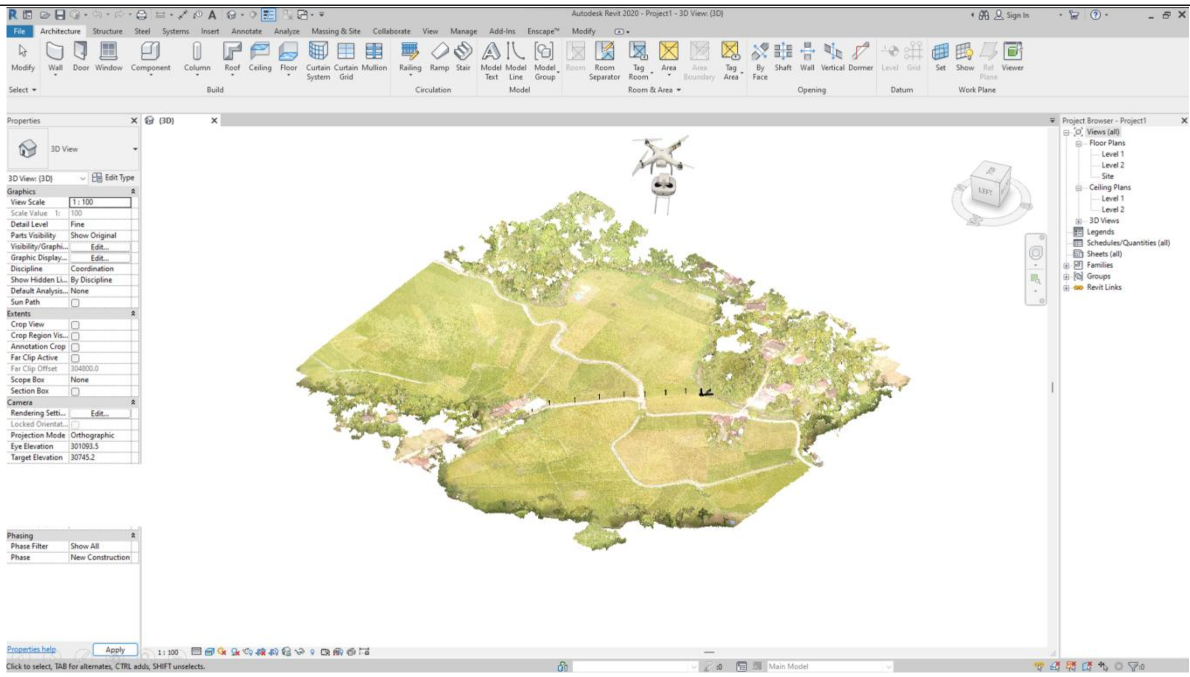

Figure 4: Drone-based mapping of the community service location in Nagari Kamang Hilia

The drone-based mapping results were combined with field survey data and processed using Geographic Information System (GIS) and Computer-Aided Design (CAD) software. The site suitability analysis considered several criteria, including elevation difference, slope gradient, distance to the irrigation channel and rice milling facility, construction accessibility, and environmental constraints. A weighted overlay approach was used to support a more objective and transparent selection of the intake and powerhouse locations [16].

The civil engineering design focused on the construction of a water intake structure and its supporting components. The main components included the intake opening, guide channel, forebay, sluice gate, trash rack, inlet and outlet channels, and waterwheel chamber. These components were designed to regulate inflow, maintain a stable water supply, reduce sediment and debris entering the system, and direct the flow efficiently toward the waterwheel. The power potential was estimated using the basic hydropower equation:

$$P=\rho gQH\eta \quad \text{...} \quad (1)$$

where P is the estimated power output (W), ρ is the density of water (kg/m³), g is the gravitational acceleration (m/s²), Q is the flow discharge (m³/s), H is the effective hydraulic head (m), and η is the overall system efficiency. The calculation was used to determine an initial system capacity of approximately 5 kW, with potential expansion depending on future improvements in hydraulic conveyance and electromechanical components.

After the civil structure and waterwheel layout were prepared, the electrical system was integrated to convert mechanical rotation into usable electrical energy. The main electrical components included the generator, control panel, battery backup, inverter, protection devices, monitoring instruments, and distribution connection to the rice milling facility and street lighting points. This electrical integration was included as a supporting stage because the main focus of this article remains the civil water intake construction, which serves as the enabling infrastructure for the micro-hydro system.

The final stage consisted of technical training, initial commissioning, and preparation of a

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preventive maintenance plan. Training was delivered to selected operators and farmer group representatives to introduce basic micro-hydro operation, intake cleaning, sediment control, waterwheel inspection, and electrical safety. Initial commissioning included no-load and loaded system inspections, mechanical and electrical checks, and observation of water flow stability through the intake and guide channel.

RESULTS AND DISCUSSION

The implementation of the community service program in Nagari Kamang Hilia produced several technical and social outcomes. These outcomes include identifying local energy needs, selecting a feasible water source, preparing spatial and engineering design data, constructing civil intake components, integrating the waterwheel-based micro-hydro system, and strengthening local capacity for operation and maintenance.

Community Needs and Partner Agreement

The coordination stage led to a shared understanding among the implementation team, the Nagari government, farmer groups, and rice mill owners of the community's main problems. The most urgent issue was the need for reliable, affordable electricity to support rice milling and street lighting. Field discussions also showed that some rice harvests were still marketed outside Kamang Hilia through intermediary traders, including to Payakumbuh and Tanah Datar. This condition indicated that post-harvest processing at the village level needed strengthening to enable farmers to obtain greater added value from their agricultural products.

Based on this discussion, the stakeholders agreed that the program should focus on providing renewable electricity to the local rice milling facility by utilizing the existing irrigation water flow. This agreement became the basis for selecting the waterwheel-based micro-hydro system as the community intervention. The involvement of the rice mill owner, farmer groups, and local technicians also helped establish early responsibility-sharing for future operations and maintenance.

Hydrometric and Spatial Survey Results

The field survey confirmed that the selected irrigation channel had the potential to support a small-scale micro-hydro system. The hydrometric measurement showed an average flow velocity of approximately 2 m/s. This result indicated that the water flow was sufficient to rotate the waterwheel and support the initial development of a community-scale power system. The elevation survey also provided the required information for determining the intake position, the guide channel alignment, the waterwheel chamber, and the outlet direction.

Drone-based mapping produced a spatial overview of the program location, including the irrigation channel, paddy fields, rice milling facility, access route, and surrounding land condition. The generated orthomosaic and surface model helped the team prepare a more accurate site layout and construction plan. The mapping result was particularly useful because the micro-hydro system had to be located near both the water source and the rice milling facility. This reduced the need for long water conveyance structures and simplified the electricity distribution route.

Detailed Engineering Design and Civil Intake Construction

The survey and mapping results were translated into a Detailed Engineering Design for the civil water intake and supporting structures. The design included the intake opening, guide channel, sluice gate, trash rack, waterwheel chamber, inlet and outlet channels, and supporting protection elements. The design was prepared to ensure stable inflow, reduce disturbance from sediment and debris, and direct water efficiently toward the waterwheel.

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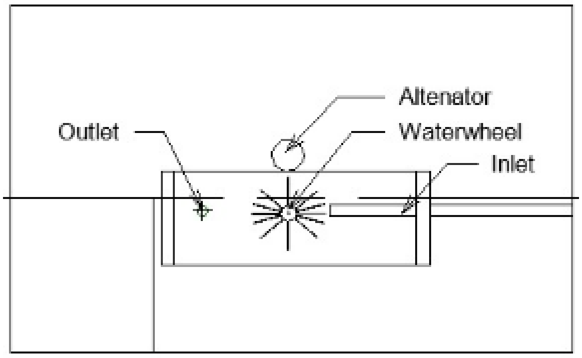

Figure 5: Waterwheel profile

The construction stage produced the main civil components required for the waterwheel-based micro-hydro system. The intake structure functioned as the first control point for the system. The trash rack was installed to filter debris carried by the water flow, while the sluice gate allowed the operator to regulate the amount of water entering the system during operation and maintenance. The guide channel directed the flow toward the waterwheel chamber, enabling the waterwheel to rotate more stably under low-head conditions.

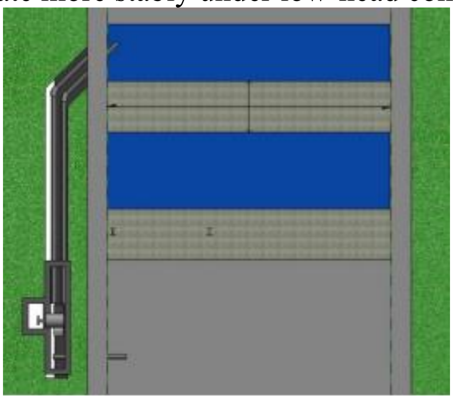

Figure 6. Waterwheel installation

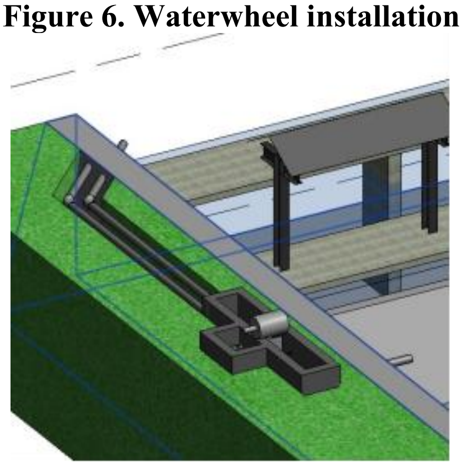

Figure 7: Three-dimensional design of the waterwheel-based micro-hydro system

The constructed civil intake structure became the key outcome of this program because it provided the hydraulic control required for micro-hydro operation. Without stable flow regulation from the intake, the waterwheel and generator would not operate consistently. Therefore, the civil works served as enabling infrastructure, connecting the available water resource to the community's productive energy needs.

System Integration and Initial Operation

After the civil works were completed, the waterwheel and electrical components were installed and connected to the control panel. The waterwheel converted hydraulic energy into mechanical rotation, which was then transmitted to the generator via a pulley-and-belt system. The generated electricity was regulated through the electrical panel before being distributed to the rice milling facility and street lighting points.

The initial operation demonstrated that the integrated system could meet the planned community's electricity needs. The system was designed with an initial capacity of approximately 5 kW, considered sufficient to support rice milling activities and basic street lighting. The use of a battery backup and inverter also provided additional flexibility in managing electricity distribution, particularly for lighting. Although the electrical system is not the main focus of this article, its successful integration confirms that the civil intake construction effectively supported the micro-hydro system's operation.

Community Training and Sustainability

The program also increased local capacity through technical training and the direct involvement of community members. Selected operators and farmer group representatives were trained to understand the basic principles of system operation and maintenance. The training covered intake cleaning, trash rack inspection, sediment control, waterwheel observation, simple electrical monitoring, and safety procedures.

The training stage was important because the system's sustainability depends on regular maintenance by local users. The community was introduced to a simple preventive maintenance checklist that included periodic trash rack cleaning, inspection of water flow conditions, observation of waterwheel rotation, inspection of the control panel, and reporting of operational problems. This activity strengthened local stakeholders' sense of ownership and reduced dependence on external technicians for routine maintenance.

Figure 8: Electrical panel installation

Overall, the program demonstrated that civil water intake construction, integrated with a waterwheel-based micro-hydro system, can provide a practical solution to support productive rural activities. The system contributes to the availability of renewable energy, supports rice milling operations, improves public lighting, and reduces dependence on costly diesel fuel. From the social perspective, the program strengthened collaboration between the university, local government, farmer groups, and rice milling partners. This implementation model can be replicated in other agricultural villages with similar hydrological conditions and community needs.

CONCLUSION

This community service program demonstrated that constructing a civil water intake structure can effectively support the implementation of a waterwheel-based micro-hydro power system in Nagari Kamang Hilia, Agam Regency. The program integrated participatory planning, field surveys, drone-based mapping, preparation of Detailed Engineering Design, civil construction, electrical integration, commissioning, and community training. The constructed intake, guide channel, sluice gate, trash rack, and waterwheel chamber were able to regulate water flow and support the operation of a small-scale micro-hydro system with an initial capacity of approximately 5 kW.

The system provides renewable electricity for rice milling activities and community street lighting, helping reduce dependence on diesel fuel and supporting local post-harvest processing. In addition to the technical outcome, the program strengthened community capacity through training in operations, inspections, intake cleaning, sediment control, and basic electrical safety. This capacity-building component is essential to ensure that the system can be maintained independently by the local community.

The program still requires continuous monitoring, particularly regarding seasonal water discharge, debris accumulation, sediment control, and electrical output stability. Future improvement may focus on optimizing hydraulic conveyance, improving waterwheel efficiency, and expanding the productive use of electricity. Overall, the program demonstrates that integrating civil engineering infrastructure, renewable energy technologies, and community participation can serve as a practical, replicable model for sustainable rural development.

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