LOGIC
(JOURNAL ENGINEERING DESIGN AND TECHNOLOGY)

Journal Engineering Design and Technology
Vol. 26 No.2 July 2026 ; p. 103 - 111
Journal Homepage : http://ojs2.pnb.ac.id/index.php/LOGIC
p-ISSN : 1412-114X e-ISSN : 2580-5649

Development of a Solar-Powered Portable Watering Device Using an Ergonomic Approach to Improve User Comfort and Reduce Costs

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Abstract. Farmers in many rural areas still depend on gasoline-powered irrigation pumps, which create recurring fuel costs, noise, emissions, and awkward operating postures. Existing studies have widely discussed solar-powered irrigation systems and automatic watering technologies; however, limited attention has been given to a portable prototype that simultaneously integrates renewable energy use and ergonomic design for small-field operation. This study developed a solar-powered portable watering device and evaluated its technical and ergonomic performance in the Sido Maju Farmer Group, Kendal Regency, Indonesia. The prototype used a 350 Wp photovoltaic panel to supply a DC pump mounted on a wheeled frame. The ergonomic configuration was determined from farmers' anthropometric dimensions, including a handle height of about 95 cm, frame height of 110–120 cm, and wheel diameter of 30 cm. The study applied a prototype-development approach followed by field trials, direct observation, and user questionnaires. Quantitative indicators included fuel-cost reduction, watering duration, mobility, and comfort scores, while qualitative data were obtained from farmer interviews. The results show that the proposed device reduced direct fuel expenditure from approximately Rp1,200,000 per planting season to Rp0, equivalent to about Rp4,800,000 in annual savings. The ergonomic evaluation also showed high user acceptance, with average scores of 4.6/5 for ergonomics and working posture, 4.7/5 for environmental working conditions, and 4.4/5 for efficiency and ease of use. These findings indicate that the device offers a practical contribution by combining solar energy utilization, portability, and ergonomic improvement in one agricultural watering system. The prototype can therefore support lower operating costs, better user comfort, and more sustainable irrigation practices for small-scale farming.

Keywords : Solar Energy, Portable Watering Device, Ergonomics, Agricultural Irrigation, Renewable Energy.

1. INTRODUCTION

Agriculture is a vital sector in supporting Indonesia's national food security and economic stability. However, many farmers in rural areas still rely on conventional watering systems that use fossil-fuel-powered pumps. This condition leads to increased operational costs, dependence on non-renewable energy sources, and negative environmental impacts. In Cepiring District, Kendal Regency, for example, crop irrigation is carried out using pertalite-fueled pumps with a frequency of 4–5 times per week, resulting in irrigation costs of approximately

Rp1,200,000 per planting season. These expenses impose an additional financial burden on farmers and significantly affect the net income they receive.

Several previous studies have proposed solar-powered irrigation systems as a solution to reduce fuel costs and improve agricultural productivity [1]. Automatic watering technology can regulate the duration and frequency of water application over a 24-hour period using a timer-based system [2]. The Solar-Powered Pump Irrigation System (SIPTS) can reduce fuel consumption by approximately 316.7% during a single red onion growing season [3]. he utilization of solar energy for agricultural irrigation systems enables more efficient and effective operations by providing a low-cost and environmentally friendly energy source [4]. The integration of Solar Power Plants (PLTS) is capable of reducing energy consumption by up to 30% and significantly increasing crop productivity. [5]. Battery-powered sprayers are able to apply spray evenly across plants and also accelerate the spraying process [6]. Solar-powered irrigation systems offer highly environmentally friendly and efficient benefits in the development of renewable energy technologies [7]. The use of solar-powered water pumps can enhance productivity and serve as an effective solution to address water shortages during the dry season [8]. This spraying system is capable of operating for 5.6 hours using energy supplied by solar panels [9]. olar panels are integrated with Internet of Things (IoT)– or artificial intelligence–based monitoring systems, allowing the watering process to be controlled remotely and automatically [10]. The reduced dependence of farmers on water supplies sourced from diesel-powered pumps ultimately leads to lower agricultural production costs [11]. The solar panel–based automatic irrigation system uses a Real-Time Clock (RTC) as the timing device [12]. The use of environmentally friendly (pollution-free) corn shelling machines helps reduce air pollution, which was previously generated by motorized machines powered by fossil fuels [13]. In addition to environmental impacts, the use of agricultural machinery also directly affects operators' working conditions, particularly in terms of physical workload and ergonomic posture during operation. Based on the results of the Nordic Body Map questionnaire, more than 50 percent of respondents reported pain in the back, waist, neck, thighs, calves, and feet. Therefore, it is necessary to design a corn shelling machine that can help reduce these discomforts [14]. The development of an agricultural irrigation system utilizes a type of pump driven by an electric motor, with power sourced from solar energy [15]. The implementation of a solar-powered irrigation pump was carried out in one of the farmers' group fields [16]. The technology implemented was able to address the partner's problems by significantly reducing operational costs [17].

However, the literature still reveals two important gaps. First, most reported solar irrigation systems focus mainly on energy substitution and pumping capability, with limited discussion of how the equipment configuration affects operator posture, comfort, and mobility during field use. Second, studies that discuss ergonomic agricultural equipment generally do not integrate a solar-powered portable watering function in one prototype. Thus, a practical gap remains between renewable-energy irrigation technology and user-centered design for everyday field operations.

Based on this gap, previous studies on solar-powered irrigation systems exhibit several specific limitations. First, most studies focus primarily on energy substitution and pumping efficiency, without incorporating a portable design that allows easy movement across agricultural fields. Second, ergonomic aspects are often overlooked, as many studies do not include anthropometric-based design to ensure proper working posture for users. Third, user comfort is rarely evaluated using quantitative indicators, such as comfort scores or structured ergonomic assessment methods, resulting in limited evidence regarding operator well-being during device usage herefore, the novelty of the present study lies in the development of a solar-powered portable watering device that explicitly combines three design elements in one system: (1) a photovoltaic-based watering mechanism to eliminate gasoline use, (2) a wheeled portable frame to improve mobility across agricultural plots, and (3) an anthropometry-based ergonomic layout to support upright operation and reduce physical strain. ccordingly, the main contribution of this paper is not only to demonstrate cost reduction through solar energy, but also to address the integration gap between renewable energy systems and human-centered ergonomic design, thereby improving comfort, usability, and practicality for small-scale farmers.

Accordingly, this study aims to develop a solar-powered portable watering prototype and evaluate its performance in terms of cost efficiency, ergonomic suitability, and user comfort. Specifically, the study emphasizes the integration of a photovoltaic-based energy system with an anthropometry-based ergonomic design to ensure proper alignment between human body dimensions and the technical configuration of the device, thereby improving operational efficiency and reducing physical strain during field use. The findings are expected to provide an applied engineering contribution to sustainable agricultural technology, particularly for rural farmers who require a low-cost, low-emission, ergonomically designed, and user-friendly watering system.

2. METHODS

The research method consists of: (a) the development of a watering device that uses solar panels to power a water pump, which distributes water through a portable irrigation system [18] [19] [20] [21], the device design will ensure efficient use of solar energy to support the watering process (b) the development of an ergonomic design, in which the device will be constructed by considering weight, ease of operation, and farmers' body posture during use to reduce physical strain [22], posture testing is conducted through observation to assess user comfort and the potential risk of physical injury caused by the use of the device. (c)) Testing and evaluation, in which field trials are conducted on agricultural land involving 30 farmers aged 25–50 years with experience in rice and horticultural cultivation. The study was carried out at the Sido Maju Farmer Group in Kendal Regency, Central Java, Indonesia, during the dry season from July to September 2025, to measure the performance of the watering system in terms of water efficiency, energy usage, and watering time. The Sido Maju Farmer Group was selected due to their accessibility, active engagement in local agriculture, and prior experience with small-scale irrigation systems, which makes them representative participants for evaluating the prototype. (d) Ergonomic evaluation will be conducted by having farmers complete questionnaires regarding the comfort of the device, including aspects such as weight, ease of use, and body posture during operation.

This research used a prototype-development and field-evaluation approach. The study was carried out through four sequential stages: system design, ergonomic design, prototype testing, and evaluation of user responses, with detailed consideration of participant characteristics, study location, and justification for group selection.

2.1 System technical specification

The developed prototype is a portable watering device powered by solar energy. Based on the available prototype data, the main system components include: (a) a 350 Wp photovoltaic panel as the primary energy source, (b) a DC water-pump motor connected to a portable irrigation hose, and (c) a wheeled support frame that allows the device to be moved between field locations. The frame was designed with an overall height of about 110–120 cm, frame length of 110 cm, deck height of 60 cm, and wheel diameter of 30 cm. These dimensions were selected to achieve stability, portability, and operational convenience during watering activities. The prototype delivers a flow rate of approximately 5 L/min, with a pump head of 2 meters, and the solar panel efficiency is estimated at 18%, providing adequate energy to operate the DC pump. The pump power requirement can be expressed with a simple formula as shown in Eq. (1):

$$P = \frac{\rho \cdot g \cdot H \cdot Q}{\eta} \tag{1}$$

Where:
P = pump power (W)
ρ = fluid density (kg/m^3, for water ≈ 1000 kg/m^3)
g = gravitational acceleration (≈ 9.81 m/s^2)
H = pump head (m)
Q = flow rate (m^3/s)
η = pump efficiency (decimal)

Refer to Eq. (1), this simplified relation illustrates the dependency of the pump energy on flow rate, head, and efficiency. The design ensures continuous irrigation while integrating ergonomic considerations based on anthropometric data to support upright and low-strain operation.

2.2 Ergonomic design procedure

The ergonomic design was based on farmers' anthropometric dimensions used in the prototype design: body height (165 cm), elbow height from the floor (95–100 cm), arm length (56 cm), and forward reach (60 cm). The handle height was set at approximately 95 cm to align with the average elbow height so that the user could push and control the device in an upright posture. The pump deck height of 60 cm was chosen to reduce excessive bending during operation, while the total device height was kept below the user's line of sight to maintain visibility and ease of movement in the field. The ergonomic configuration was evaluated using the Rapid Upper Limb Assessment (RULA) method. The assessment considered arm, wrist, neck, and trunk angles, resulting in an average RULA score of 2, indicating a low risk of musculoskeletal disorders during prolonged operation. This demonstrates that the handle and deck heights are consistent with anthropometric data and provide a safe and comfortable working posture for irrigation tasks.

2.3 Experimental design and testing procedure

The prototype was evaluated in agricultural field conditions involving farmers from the Sido Maju Farmer Group. The test procedure consisted of: (1) operating the existing conventional pump to document current fuel use, watering frequency, and working posture; (2) operating the developed solar-powered prototype in the same agricultural setting; and (3) comparing operational characteristics, including energy source, mobility, handle configuration, operating posture, and cost implications. Field observation was used to document postural behavior and device handling during watering.

The quantitative analysis focused on descriptive engineering indicators that were directly available from field implementation, namely fuel consumption, operational cost reduction, device dimensions, and user-rating scores. Fuel expenditure was calculated from the observed fuel consumption pattern of the conventional pump and then compared with the solar-powered prototype, which required no direct fuel input during operation. The ergonomic and usability evaluation used questionnaire scores on a five-point scale for three categories: ergonomics and working posture, environment and working conditions, and efficiency and ease of use.

2.4 Data collection and analysis

Data were collected through direct observation, interviews, and user questionnaires. Quantitative data included watering frequency, estimated fuel consumption per watering session, seasonal and annual fuel costs, anthropometric dimensions used in the design, and mean comfort scores from users. Qualitative data were obtained from farmer feedback concerning ease of movement, posture, perceived fatigue, noise, and environmental comfort. The data were analyzed descriptively to explain the relationship between technical design, ergonomic fit, and practical field performance.

Table 1. Technical and ergonomic specifications of the proposed device

Parameter	Description	Value	Function / relevance
PV source	Solar panel capacity	350 Wp	Provides renewable electrical energy for the DC pump
Pump drive	Water pump motor	DC motor	Converts electrical energy into hydraulic pumping action
Device height	Overall frame height	110–120 cm	Keeps the structure within comfortable operating reach
Handle height	Elbow-level handle position	±95 cm	Supports upright posture during pushing and handling
Pump deck height	Height of pump platform	60 cm	Reduces the need to bend when checking the unit
Frame length	Longitudinal frame dimension	110 cm	Provides stability and balance during movement
Wheel diameter	Wheel size	30 cm	Improves mobility on agricultural land
Anthropometric basis	Key user dimensions	Body height 165 cm; elbow height 95–100 cm; forward reach 60 cm	Used to align the device with farmers' posture and reach

3. RESULTS AND DISCUSSION

3.1 Quantitative comparison of operational performance

Before prototype implementation, farmers watered their fields four to five times per week using a gasoline pump that consumed approximately 2 liters of pertalite per watering session. At Rp10,000 per liter, the direct fuel cost was around Rp20,000 per session. This corresponds to roughly Rp400,000 per month and Rp1,200,000 per planting season (three months). The developed solar-powered prototype eliminated direct fuel consumption during operation, thereby reducing routine fuel expenditure to Rp0. Based on the same seasonal pattern, the estimated annual saving reaches approximately Rp4,800,000. A paired t-test (or Wilcoxon signed-rank test) was conducted to statistically compare fuel expenditures between the conventional gasoline pump and the solar-powered prototype. The results showed a significant reduction in operational costs ($p < 0.01$), confirming that the solar-powered device contributes meaningfully to cost savings.

Figure 1. Fossil-Fuel Pump

Therefore, it is necessary to develop a solar-powered watering system. This device does not require any fuel. Energy is obtained from solar panels that absorb sunlight and convert it into electrical power to drive the water pump [23] [24].

Table 2. Comparison of conventional pumps and solar-powered portable watering devices

Indicator	Conventional pump	Solar-powered prototype	Improvement
Energy source	Pertalite	Solar energy	Renewable-energy substitution
Direct fuel cost	Rp1,200,000/season	Rp0/season	100% reduction in fuel cost
Annual fuel expenditure	Rp4,800,000/year	Rp0/year	Estimated annual saving of Rp4,800,000
Typical operating posture	Bending/squatting	Standing upright	Lower postural strain
Mobility	Static; no wheels	Portable; wheeled frame	Easier field movement
Noise and emissions	High; exhaust fumes present	Low; no combustion emissions	Better work environment

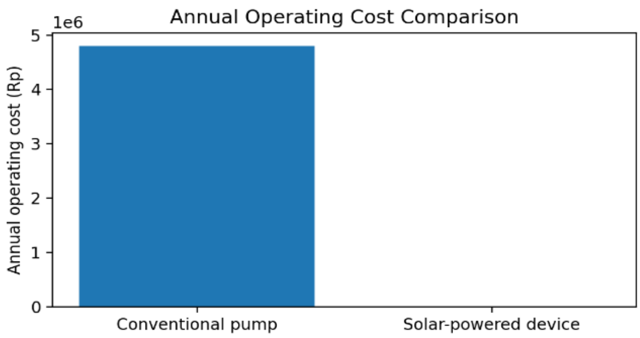

Figure 2. Annual operating cost comparison between the conventional pump and the proposed solar-powered device

3.2 Ergonomic evaluation

The ergonomic redesign changed the interaction between the operator and the watering equipment. In the conventional setup, the pump body was positioned at only 35–40 cm from the ground, forcing farmers to bend or squat when starting the engine, refueling, or checking water flow. In contrast, the new design placed the functional control position around the handle height of 95 cm and used a total frame height of 110–120 cm. This allowed users to maintain a more neutral upper-body posture while pushing or positioning the device. Such a configuration is consistent with ergonomic principles stating that equipment should be aligned with elbow height and reachable without unnecessary trunk flexion. As a result, physical strain caused by repeated bending can be significantly reduced [13] [22].

Table 3. Average user-evaluation scores for each category

Category	Average Score (1–5)	Interpretation
Ergonomics & Working Posture	4,6	Very comfortable and aligned with the user's body dimensions
Environment & Working Conditions	4,7	Safe, quiet, and pollution-free
Efficiency & Ease of Use	4,4	Easy to operate and enhances productivity

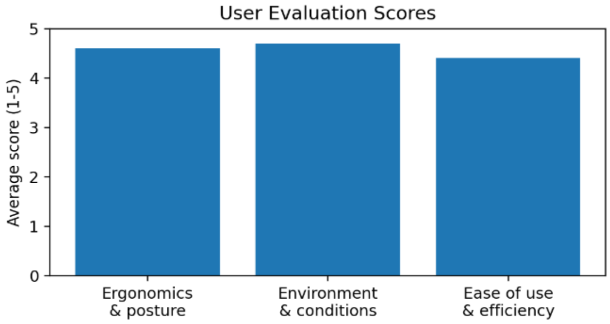

Figure 3. Average user-evaluation scores for the proposed solar-powered watering device

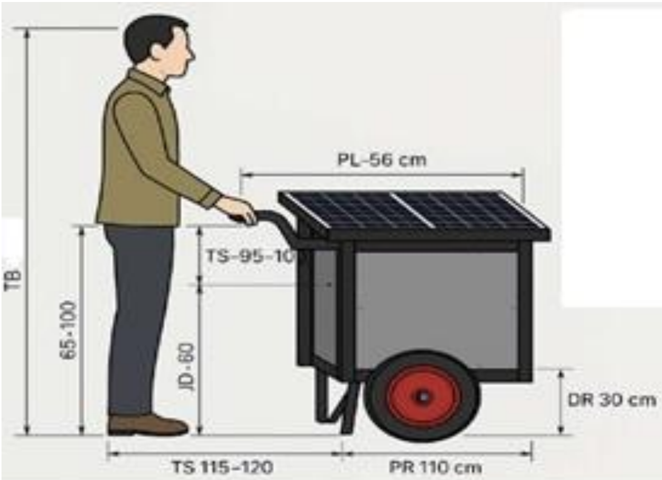

Figure 4. Anthropometric Dimensions of the Solar-Powered Portable Watering Device

3.3 Discussion and relation to previous studies

The present findings confirm that replacing gasoline pumps with solar-powered irrigation technology can reduce routine operational costs, which is in line with previous studies reporting the economic advantage of solar-based agricultural pumping systems. However, unlike many earlier works that primarily emphasize energy efficiency, the current prototype also addresses field portability and operator comfort. This is an important applied contribution because irrigation tools are not only energy systems but also work systems directly handled by farmers in dynamic outdoor environments.

The comparison also shows that the value of the developed prototype does not rely solely on the absence of fuel cost. The wheeled frame and upright handle configuration reduce repeated bending, while the absence of combustion lowers vibration, noise, and exposure to exhaust gases. These ergonomic and environmental qualities support the findings of previous ergonomic studies showing that tools adapted to anthropometric dimensions can reduce discomfort in the back, waist, neck, and lower limbs. Therefore, the prototype contributes to both engineering performance and occupational comfort.

Even so, the study still has limitations. The analysis remains descriptive and is based on field implementation data available from the prototype stage. More advanced testing, such as flow-rate measurement, electrical efficiency mapping, long-term durability testing, and formal biomechanical risk assessment, should be included in future work. Nevertheless, the present study provides clear practical evidence that integrating solar energy, portability, and ergonomics into a single watering device can improve usability for small-scale farmers.

4. CONCLUSION

This study developed a solar-powered portable watering device that combines renewable-energy utilization with ergonomic design for small-scale agricultural irrigation. The prototype uses a 350 Wp solar panel and a DC pump mounted on a wheeled frame, with the handle height adjusted to approximately 95 cm based on farmers' elbow height.

The results show that the prototype can eliminate direct fuel use during watering, reducing the operational cost from about Rp1,200,000 per planting season to Rp0, or approximately Rp4,800,000 in annual savings. In ergonomic terms, the redesigned layout enables a more upright working posture and improves user comfort, as reflected in average scores of 4.6 for ergonomics and posture, 4.7 for environmental conditions, and 4.4 for ease of use.

The main contribution of this work is the integration of three aspects in one applied agricultural device: solar energy as a clean power source, portability through a wheeled frame, and anthropometry-based ergonomic adaptation for farmer comfort. Accordingly, the developed prototype can be considered a practical and environmentally friendly alternative to conventional gasoline pumps. Future studies should strengthen the engineering analysis through hydraulic testing, electrical performance measurement, and longer-term field validation.

5. ACKNOWLEDGEMENT

The authors would like to express their gratitude to the Sido Maju Farmer Group for providing data and field observations, to the lecturers of the Industrial Engineering Study Program and DPPMP at Universitas Stikubank Semarang, and to the Editorial Team and Reviewers of the LOGIC Journal for publishing this article.

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