SAINS TANAH – Journal of Soil Science and Agroclimatology

Journal homepage: http://jurnal.uns.ac.id/tanah

Assessing irrigation water demand and pumping operations for rice farming in the Bengawan Solo River, Indonesia

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ARTICLE INFO

Keywords:
Alluvial soil
Calcareous soil
Kinetic models
Phosphate desorption
Soil parameters

Article history
Submitted: 2023-05-17
Accepted: 2024-01-20
Available online: 2024-06-09
Published regularly: June 2024

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ABSTRACT

Owing to population growth, the rice demand in Indonesia has been increasing, which has led to an increase in rice consumption. One way to boost rice production is to enhance pump irrigation in rainfed fields. The aim of this study is to evaluate irrigation water usage and water pumping practices in the Bengawan Solo River, focusing on enhancing rice production. Data were sourced from governmental entities, which include the Indonesian Bureau of Meteorology, Climatology, and Geophysics and the Ministry of Public Works and Housing. Water requirement was calculated using the FAO Penman–Monteith equation. The study highlights that throughout the three distinct growing seasons (GS), the water requirements for irrigating rainfed rice fields vary, with the most substantial demand observed during the first growing season (GS I), followed by the third growing season (GS III), and the second growing season (GS II). In dry years, a consistent pattern of low water balances occurs, which persists below 500 mm across all months. Compared with the other two scenarios, the dry year shows higher variability in rainfall, as evidenced by its higher coefficient of variation of 0.620 compared with 0.347 and 0.416 for the wet and normal years, respectively. The electricity cost rate peaks in GS I, trailed by GS II and GS III, with rates of IDR 2,400, 1,180, and 1,028 per kilowatt-hour, respectively. The findings play a pivotal role in shaping regional planning decisions regarding the utilization and necessity of river water resources and the development of cropping calendars.

How to Cite: Trinugroho, M.W., Arif, S.S., Susanto, S., Nugroho, B.D.A.. (2024). Assessing Irrigation Water Demand and Pumping Operations for Rice Farming in the Bengawan Solo River, Indonesia. Sains Tanah Journal of Soil Science and Agroclimatology, 21(1): 42-54. https://doi.org/10.20961/stjssa.v21i1.79343

1. INTRODUCTION

Over the years, the rice demand in Indonesia has been steadily increasing due to population growth. The population and rice consumption are expected to experience significant growth, with projections indicating a 31% increase in population and a 45% increase in rice consumption (Gunning-Trant et al., 2015). This rapid increase poses the risk of potential food shortages and can have implications for food security (Ansari et al., 2021; Yuliawan & Handoko, 2016). Moreover, water scarcity due to changing rainfall patterns has been identified as a significant factor leading to a potential 40% reduction in annual agricultural production in the regions of South and Southeast Asia (Puphoung et al., 2016). Increasing temperatures have led to changes in rainfall patterns, negatively affecting future rice production (Al-Ansari et al., 2021; Sacolo & Mkhandi, 2021). Researchers have undertaken studies to understand the impact of rainfall variations on rice production in localized areas. The trend test carried out on rainfed rice yield in the Bengawan Solo Sub-Watershed reveals the influence of annual rainfall trends on the yield of rainfed rice per year (Trinugroho et al., 2022). An increase of 1°C in temperature and a 34% change in rainfall have been associated with a decrease of approximately 143.6 kg.ha^{-1} in rice production during the dry season in the Jakenan District (Estiningtyas & Syakir, 2018). Conversely, certain regions have experienced an increase in rice production due to increased local rainfall, with a 10% increment in rainfall that contributes to a 0.4% increase in rice production (Levine & Yang, 2014).

The rainfed field has the potential to increase rice production. Spatially, rainfed rice fields in Indonesia remain quite extensive, covering an area of 3.8 million hectares or 53.5% of the total rice field area (BPS, 2019). The faced threat in developing rainfed rice farming is the limited water availability during the dry season. Hence, land productivity must be enhanced by increasing water availability, extending the planting period, and reducing the risk of yield losses to promote sustainable agriculture (Expósito & Berbel, 2019).

River water plays an essential role in Bengawan Solo Watershed; this watershed is subject to typical monsoonal rainfall variability and increasing pressures on scarce water resources (Marhaento et al., 2021; Nugroho, 2020). Irrigation water interventions are assumed to enhance agricultural productivity significantly (Ayuningtyas & Waluyo, 2019; Bartolini et al., 2007; Saptomo et al., 2021). The utilization of river water through water pumping plays a crucial role in meeting the irrigation demands of the vast rice paddies in the Bengawan Solo Watershed. By implementing effective irrigation water management strategies, farmers can maximize crop yields and mitigate the challenges posed by monsoonal rainfall variability and the increasing pressures on water scarcity (Corcoles et al., 2016; Wu et al., 2018). Surface irrigation is a widely adopted and cost-effective method employed for irrigation by farmers in the Bengawan Solo Watershed. Farmers in this region rely on natural rainfall for water supply, and surface irrigation allows them to distribute the available water across their fields without the need for complex irrigation infrastructure (Auliyani & Wahyuningrum, 2020).

Surface irrigation is particularly beneficial in rainfed areas as it helps supplement rainwater during dry spells, reducing the risk of water stress and enhancing crop growth (Dwiratna et al., 2018; Singh, 2014; Yang, 2012). Furthermore, it is advantageous for smallholder farmers with limited resources. Nevertheless, this irrigation in the relatively flat area consumes water and energy to deliver water (Callahan & Astill, 1981; Jiménez-Bello et al., 2015). Only a limited number of research studies have explored the utilization of Bengawan Solo water resources for rainfed irrigation to improve rice production.

Several researchers study related to the general water balance, climate change impact on water resources, and land use change effect on streamflow at the Bengawan Solo Watershed (Anna et al., 2016; Marhaento et al., 2021; Sipayung et al., 2018). Although they provide vital system-level understanding, microlevel on-farm investigations that assess irrigation practices and their water–crop yield linkages in the region have been insufficient.

Our research intends to fill this niche gap by evaluating context-specific water pumping approaches for supplemental irrigation of rainfed rice in the Bengawan Solo River. Our study provides new evidence using audits of field-level irrigation volumes and durations and analysis of resultant rice yields over multiple cropping cycles spanning wet and dry spells. We aim to find the relationship between energy expended for pumping, irrigation water application on farms, and the final rice productivity outcomes across seasonal variability. Although there has been progress in Bengawan Solo hydrology, our differentiated analysis of field-level irrigation practices provides actionable insights into enhancing food production.

2. MATERIAL AND METHODS

The research was carried out in the rainfed rice field of Tambakromo Village, situated within the Cepu District of Blora Regency in Central Java close to Bengawan Solo River: 7°8′17″–7°12′5″S, 111°31′11″E–111°36′53″E (Figure 1). The study spanned from June to December 2022. Tambakromo was dominated by rainfed fields. Consequently, most of the rice fields were harvested once a year. The climate in the study area, in general, was classified as an area with low rainfall and often experienced drought during the dry season. The average recorded rainfall was 109 mm, with an average of six rainy days per month. December registered relatively high rainfall with 406 mm according to available data (Trinugroho et al., 2022).

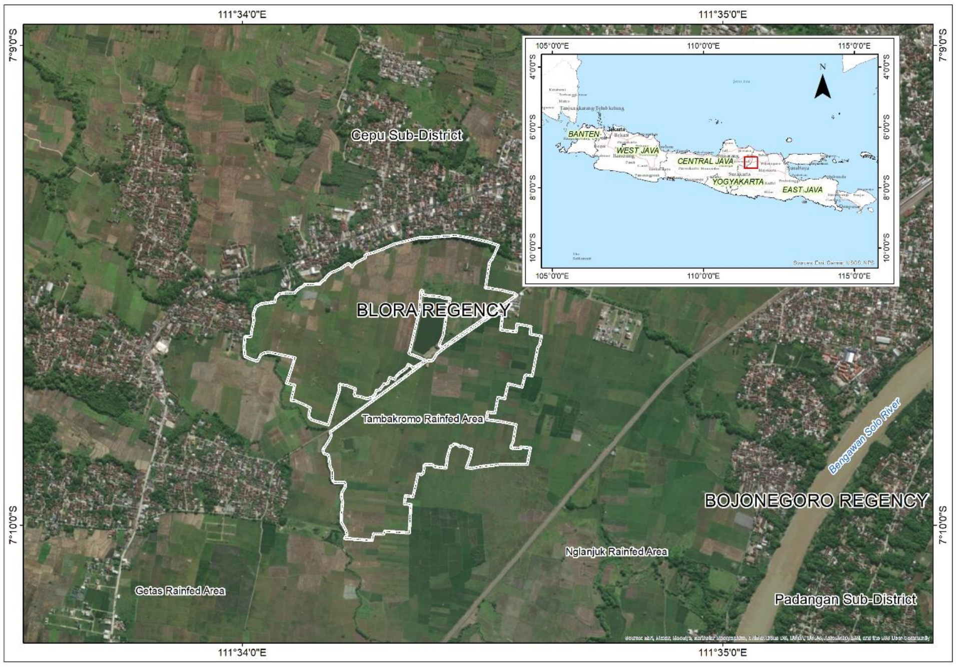

Figure 1. Research area at Tambakromo Rainfed, Cepu District, Blora Regency, Central Java

Notably, a pump irrigation initiative had been initiated in the preceding years of 2020–2021, specifically targeting rainfed rice fields in Tambakromo Village. This initiative was a collaborative endeavor that involved the local government of Blora Regency, the Ministry of Agriculture, and organized farmer groups with the specific aim of focusing on 100 ha of rainfed area. To determine the topographic elevation, delineate the irrigation target zone, and assess potential water sources, field measurement was carried out. To determine the pipe length, height level, and position for analyzing water pump requirements, topographic elevation measurements using Global Positioning System (GPS) technology were employed. Using a GPS RTK GNSS CHC i50 dual-frequency Real Time Kinematic (RTK) GPS with a base station set up on a precisely surveyed control point and rover unit for measurements, differential GPS measurement was conducted. The expected horizontal and vertical accuracy was ±10 mm. GPS coordinates of the water source and the discharge point were recorded with a GPS receiver. The elevation difference between the two points was calculated using the recorded coordinates, providing an accurate measurement of the static head. The RTK GPS-derived position and elevation of key points were input into the Hazen–William formula as described in the next section (Mohamed et al., 2019). The measurements start from the river embankment and extend for 1,600 m to cover 100 ha of the rainfed rice field.

Daily rainfall and discharge time series data were used from rain Cepu gauge stations. The Bengawan Solo Watershed Authority is responsible for managing and collecting this data, covering a span of 46 years from 1975 to 2020. Climate data were recorded at Tempuran Station, Blora Regency, Central Java Province. To analyze water pump requirements, conduct assessments of water needs and balances, and analyze pump operations, field measurement data and time series data were employed.

2.1. Water Requirement Analysis

The concept of irrigation requirement was calculated over specific time intervals. It represents the difference between crop evapotranspiration under standard conditions (ETc) and the actual effective rainfall received during the same timeframe. The calculation of ETc involves multiplying the reference evapotranspiration (ETo), determined using the FAO Penman–Monteith method, by the crop coefficient (Kc) (Allen et al., 1998). By considering ETo and Kc, a more comprehensive understanding of the crop's irrigation needs can be obtained. The Kc values for rice vary at different growth stages: (1) Initial stage (germination to seedling): 0.4; (2) Vegetative stage (Tillering to panicle initiation): 0.8; (3) Reproductive stage (Heading to maturity): 1.2.

Rainfall data were required to calculate effective rainfall; for this study, the USDA Soil Conservation Service method has been chosen for the calculating of effective rainfall (Eq. 1 and Eq. 2); the following criteria must be followed:

$$\mathrm{ER} = 0.6 \times \mathrm{P} - \frac{10}{3} \text{ For Pmonth } <= \frac{70}{3} \text{ mm} \quad [1]$$

$$\mathrm{ER} = 0.8 \times \mathrm{P} - \frac{24}{3} \text{ For Pmonth } > \frac{70}{3} \text{ mm} \quad [2]$$

Crop water requirement (CWR) and irrigation water requirement (IWR) are computed as follows (Eq. 3 and Eq. 4), based on the CROPWAT model:

$$\mathrm{CWR} = \mathrm{ETo} \times \mathrm{Kc} \quad [3]$$

$$\mathrm{IWR} = (\mathrm{ETo} \times \mathrm{Kc}) - \mathrm{ER} \quad [4]$$

where ETo is reference evapotranspiration, Kc is the crop coefficient, and ER is effective rainfall.

2.2. Water Balance and Pump Operation Analysis

The analysis of water availability from rainfall and river discharge was carried out for three scenarios: wet, normal, and dry. The wet scenario was established with a 25% reliability level of rainfall, a normal scenario at 50%, and a dry scenario at 80%. The reliability calculations utilize the Weibull formula (Eq. 5).

$$P = 100 \times \frac{r}{(n+1)} \quad [5]$$

The flow duration curve was derived by graphing the ranked streamflow against their corresponding rank, represented as the percentage of the total number of time intervals in the dataset. Here, P represents the proportion of time a specific flow was met or surpassed, n stands for the overall count of records, and r denotes the position of the flow magnitude in the ranking. Finally, the total water availability was compared to the total water demand. If the water supply is greater than or equal to the water demand, then there will be enough water to meet the crop requirements.

The irrigation system operates by harnessing surface water through a centrifugal pump, which subsequently disperses the water across rainfed rice fields. The water distribution was facilitated using a pipeline irrigation system. The process of determining a water pump in this study involves assessing various factors to choose the most suitable pump for efficiently delivering water to crops. This assessment typically considers aspects such as the required water flow rate, the distance the water must be pumped, the elevation difference between the water source and the fields, the pressure needed for proper distribution, and the specific irrigation method. The Hazen–Williams factor was used in fluid dynamics to calculate the friction loss in pipes. It is commonly utilized in the design and analysis of water distribution systems, including those used for irrigation (Lu et al., 2018). The factor considers pipe material, diameter, and flow rate to estimate the pressure drop or loss within the system (Eq. 6). In the context of water pump selection for irrigation, the Hazen–Williams factor is relevant when determining the pressure requirements and pipe sizes needed to transport water efficiently from the pump to the fields (Eq. 7).

$$hf = 10.67 . \frac{L}{D} \left(\frac{Q}{C^{1.85}}\right)^{1.85} \quad [6]$$

where *hf* is the head loss (in meters), *L* is the length of the pipe (in meters), *D* is the diameter of the pipe (in meters), *Q* is the flow rate (in cubic meters per second), and *C* is the Hazen–Williams roughness coefficient.

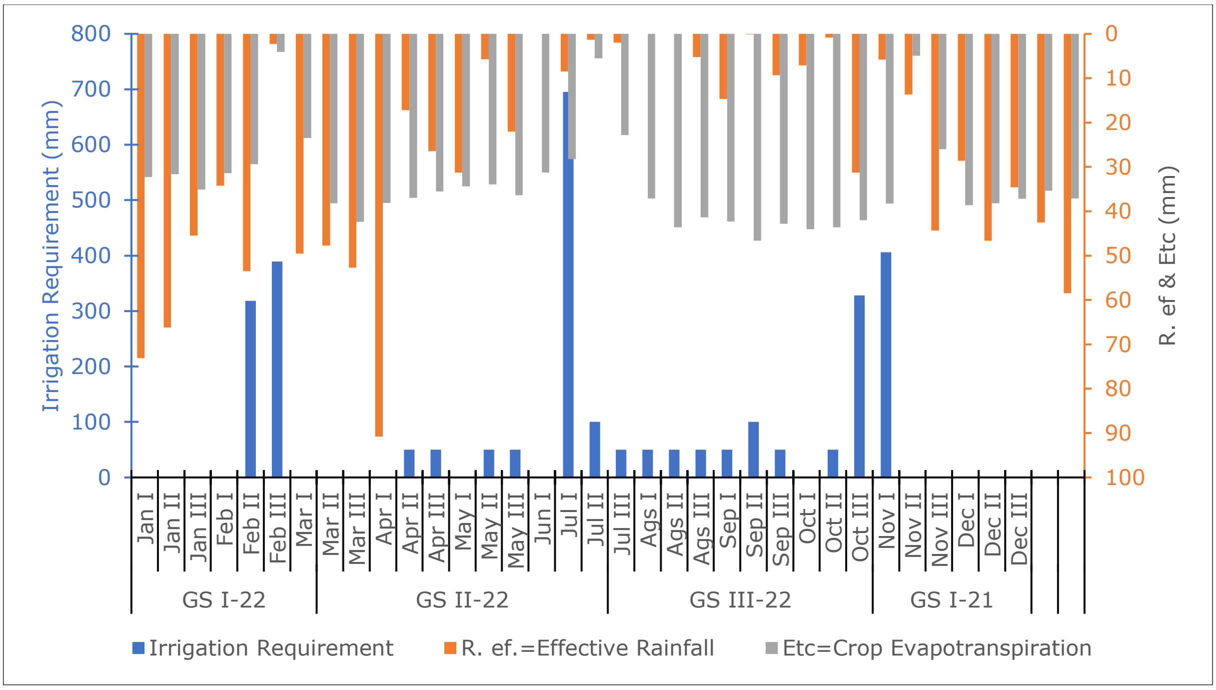

Figure 2. Irrigation requirement in three growing seasons (GS I, GS II, and GS III)

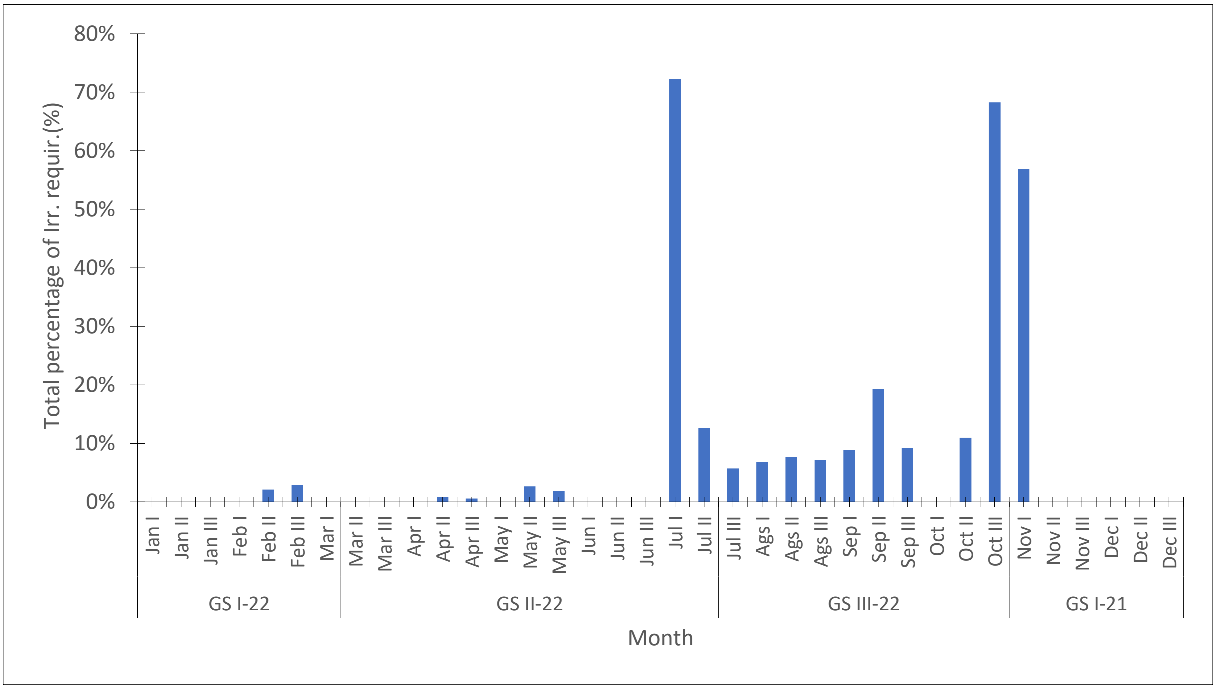

Figure 3. Irrigation requirement percentage of total water demand in the Bengawan Solo River

$$Q = \frac{C.D^{2.63}.H^{0.54}}{L^{0.63}} \quad [7]$$

where Q is the flow rate in cubic meters per second, C is the Hazen–Williams coefficient, representing the roughness of the pipe, D is the diameter of the pipe in meters, H is the head loss in meters, and L is the length of the pipe in meters

The electricity consumption and energy data used to operate the pumps was obtained from the State Electricity Company (PLN). Electricity consumption refers to the amount of electrical energy utilized by a device over a specific period. It was typically measured in units like kilowatt-hours (KWH) or megawatt-hours (MWh). The energy utilized to operate pumps specifically pertains to the electrical power required to run pumping systems. This includes the energy required to drive the motors that power the pumps, as well as any auxiliary systems or components associated with the pump operation.

3. RESULTS

3.1. Water Requirement

Irrigation becomes essential when the natural rainfall is insufficient to compensate for water lost through evapotranspiration. To determine the annual water requirements for three GSs of rice and irrigation in the study area, the CROPWAT model is employed. This involves considering a 60% irrigation efficiency and a time step of 10 days. Figure 2 illustrates the irrigation water needs in millimeters per 10-day period over three complete GSs, spanning from January to December. The depicted blue line charts the fluctuating irrigation demands throughout the seasons, initiating at a low level in January (0–100 mm per decade), gradually increasing to its peak between May and July (600–700 mm per decade), and subsequently decreasing by December. This pattern highlights that crops exhibit their highest water requirements during the dry season from late May to early July, necessitating over 60–70 cm of water per month while displaying the lowest irrigation demands from November to January, averaging less than 20 mm.10-day^{-1} period. Conversely, the orange line, representing factors like rainfall, evaporation, and other influences (labeled R.ef & Etc), maintains a relatively flat and low profile across the seasons, fluctuating between 0 and 100 mm per decade. This indicates that natural rainwater plays a modest role in fulfilling crop water requirements, with irrigation overwhelmingly dominating agricultural water needs. When considered collectively across the three consecutive GSs, the blue irrigation requirement line completes a full cycle, starting from a low point, reaching a peak, and returning to a low point again, aligning directly with crop development throughout the seasons. The prime of irrigation demands, peaking at approximately 600–700 mm in May through July, recurs during the same months in each subsequent annual season.

The Bengawan Solo River serves as the primary water source for irrigation while also being used for domestic water supply, industrial purposes, transportation, and environmental needs (BBWS Bengawan Solo, 2015). Nevertheless, the irrigation sector is the primary water user from the river, particularly during certain months. In July I, irrigation water demand accounts for 70% of the total requirement, followed by October III and November I with percentages of 68% and 57%, respectively, as shown in Figure 3. The irrigation requirement from the Bengawan Solo River source in the Tambakromo rainfed area dominates the total water demand only three times during a year, each spanning 36 10-day periods. Despite the high percentage of irrigation requirement, water supply satisfactorily fulfills the water demand across all sectors. The high irrigation demand correlates to the land preparation and expansion of irrigated areas, which require substantial water. Milano et al. (2013) urged that the study of the water resources in the Ebro watershed can completely meet domestic and agricultural water needs from October to June, even during the peak demand periods. The increase in irrigation demand is linked to a 30%–50% expansion of irrigated areas, leading to a 25% rise in irrigation requirements. Although irrigation dominates total water demand during those peak periods, the Bengawan Solo River is still able to adequately fulfill the requirements across all sectors. This indicates that there is sufficient water availability in the river to meet the various needs, including the high irrigation demand, at least during present conditions.

3.2. Water Availability

Figure 4 shows that the wet year has the highest total rainfall and average rainfall compared to the normal and dry years. Moreover, the dry year shows higher variability in rainfall compared to the other two scenarios, as evidenced by its higher coefficient of variation of 0.6207 compared to the wet and normal years, 0.347 and 0.416, respectively. These statistical characteristics provide insights into the variability and range of rainfall across the three scenarios, which are crucial for understanding water availability and planning irrigation strategies in each condition. Among the three scenarios, it is during the dry year that the availability of rainfall water becomes a significant issue. The figure representation indicates that in the first 10 days of November, the potential rainfall is less than 10 mm, which is inadequate for meeting the water demands of rice crops. The region experiences below-average rainfall, which results in water scarcity and reduced water availability for rice crops. The lack of rainfall has led to periods of water stress for the rice plants, especially during critical growth stages. Consequently, to address the shortfall in irrigation water requirements, supplemental irrigation from the Bengawan Solo River is vital.

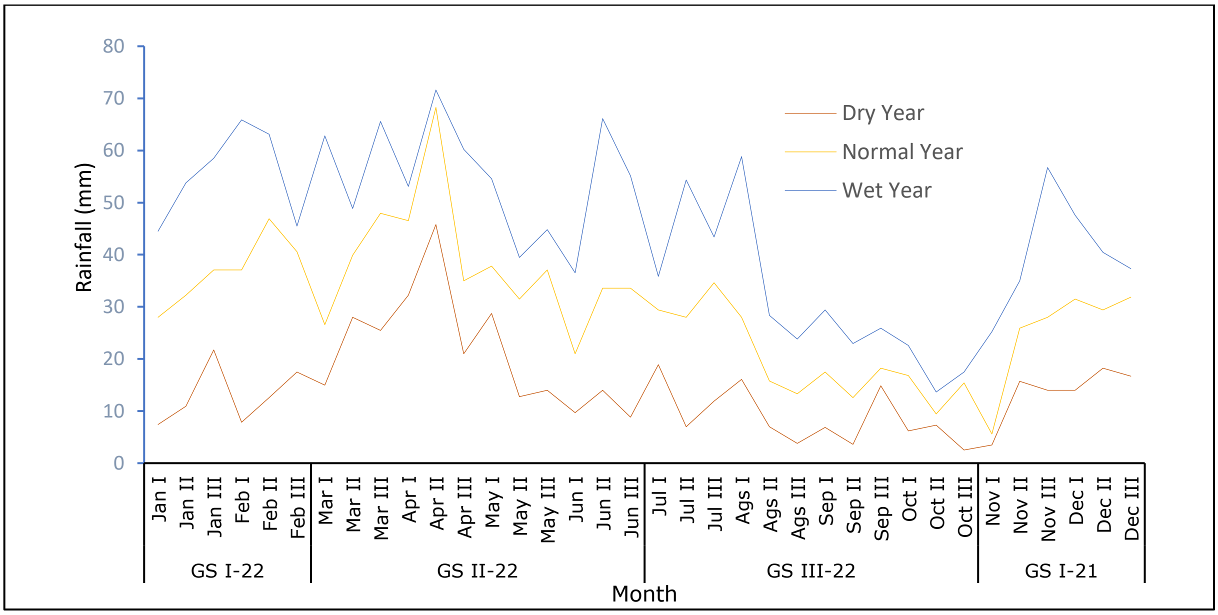

Figure 4. Rainfall potential in three scenarios

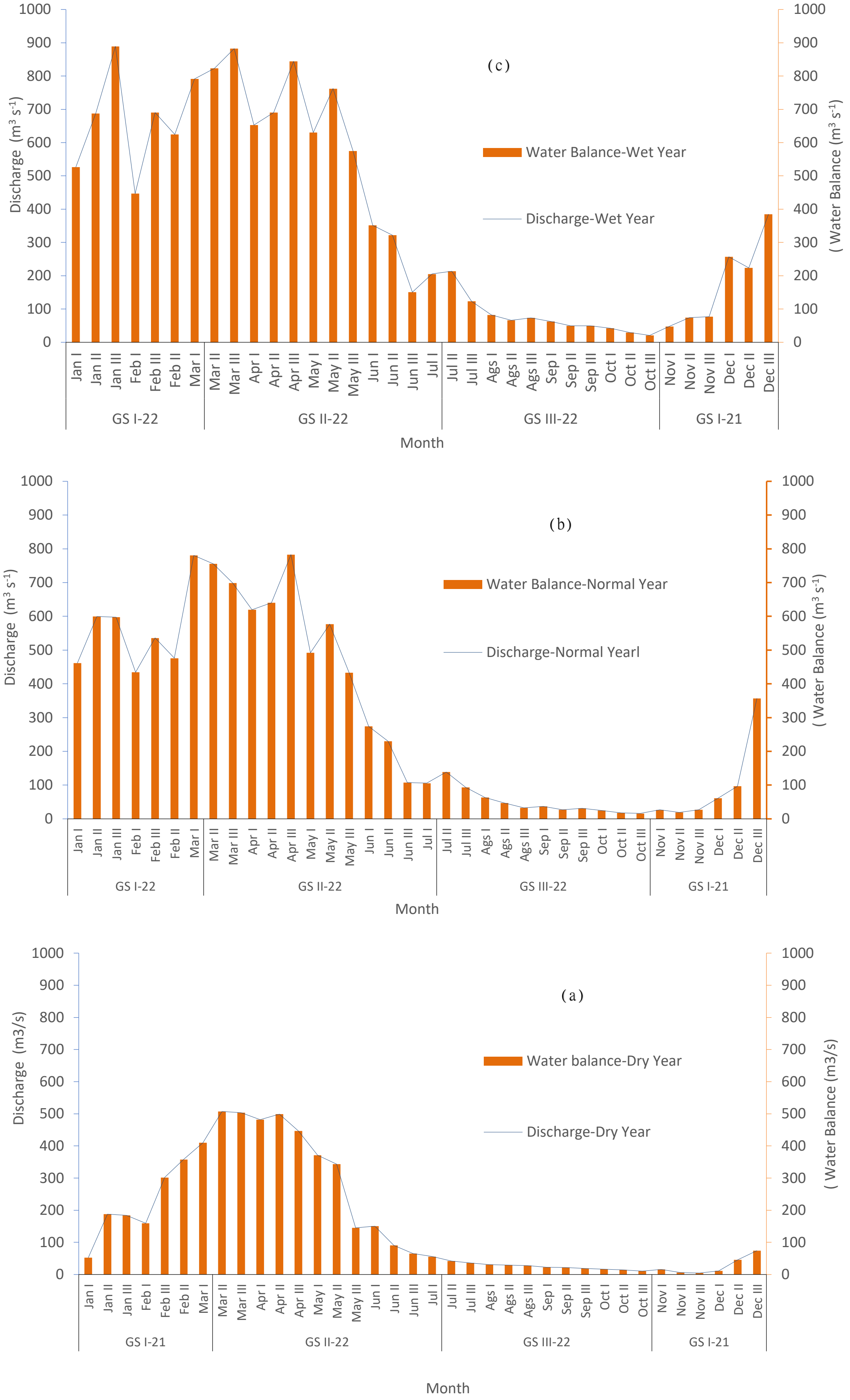

Figure 5. Water balance in three conditions: dry year (a), normal year (b), and wet year (c).

Table 1. Water pump variables for irrigation

Variables	Suction	Discharge
Dimension		
Diameter (m)	0.3048	0.3048
Length (m)	18	2,100.00
Fitting		
Elbow 45° (unit)	1.00	2.00
Elbow 22.5° (unit)	0	4.00
Head		
D head (m) (1)	16	
Pipe loses factor (2)	0.15	17.31
Fitting loses (3)	0.65	0.35
Total head ((1) + (2) + (3))	34.45	
Efficiency (%)	80	
Power		
Pump power (kilowatts)	45	
Power installation (kilowatts)	66	
Pump		
Torishima CEN 150x125-315		

In a wet year scenario, the region experiences relatively high rainfall, which exceeds the average rainfall. Accordingly, there is generally sufficient water available for rice crops. The irrigation demand during this scenario is low, as the rainwater adequately meets the water requirements of the rice crops. In a normal year scenario, the region experiences rainfall close to the long-term average. The amount of rainwater received is generally suitable for sustaining rice crops; however, there might be some periods with water stress depending on the distribution of rainfall throughout the GS. Trinugroho et al. (2022) reported that the water availability of Bengawan Solo Sub-Watershed remains relatively stable under normal conditions as well as during the occurrence of rainfall variability. Nevertheless, during the period of climate change, the rainfall water availability is lower than the normal conditions indicating a declining trend in precipitation.

Figure 5 illustrates the 10-day water balance, examining the interplay between river water availability and irrigation water demand under three scenarios: wet year, dry year, and normal year. The analysis focuses on the proportion of irrigation demand for the rainfed area concerning the total water demand. Overall, all three scenarios exhibit a surplus water balance, suggesting that the irrigation demand can be adequately fulfilled. The primary objective of these scenarios (wet, dry, and normal years) is to ascertain the appropriate discharge amount that can be allocated for irrigating the rainfed paddy fields in Tambakromo during each GS. The result shows that there are variations in the 10-day water balance under different scenarios: dry year, normal year, and wet year. In all scenarios, there is a positive water balance, which indicates that there is more water availability than irrigation requirements. This surplus of water ensures that the water allocation for irrigation can be fully met during dry, normal, and wet years. Conversely, a negative water balance would indicate water scarcity and unmet water demands. The scenario most likely to experience water scarcity is the dry year scenario. Despite having several periods with a high positive water balance (>100 $m^3\ s^{-1}$) from December II to July II, the water balance declines from July III to December I. Nevertheless, even during these drier periods, water availability remains sufficient to meet all existing water demands.

3.3. Water Pump Operation

Table 1 shows the result of water pump requirement. The centrifugal pump's capabilities encompass delivering water at a maximum head of 32 m and a flow rate of 300 $m^3\ h^{-1}$, equivalent to 100 L s^{-1}. Notably, the average efficiency of the power utilized by the water pump stands at 68%. This efficiency metric indicates the pump's capacity to convert electrical power into hydraulic power with minimal loss, contributing to reduced energy wastage and decreased electricity expenses. To ensure the safety of the centrifugal pump and associated electrical components during flood events in the rainy season, the pump is situated within the pump house. The base of the pump house is positioned at the same elevation as the average water surface level. This design choice guarantees that even if the water level of the nearby Bengawan Solo River recedes, it will not decrease more than 6 m, thereby enabling the centrifugal pump to consistently draw water from the river for irrigation purposes.

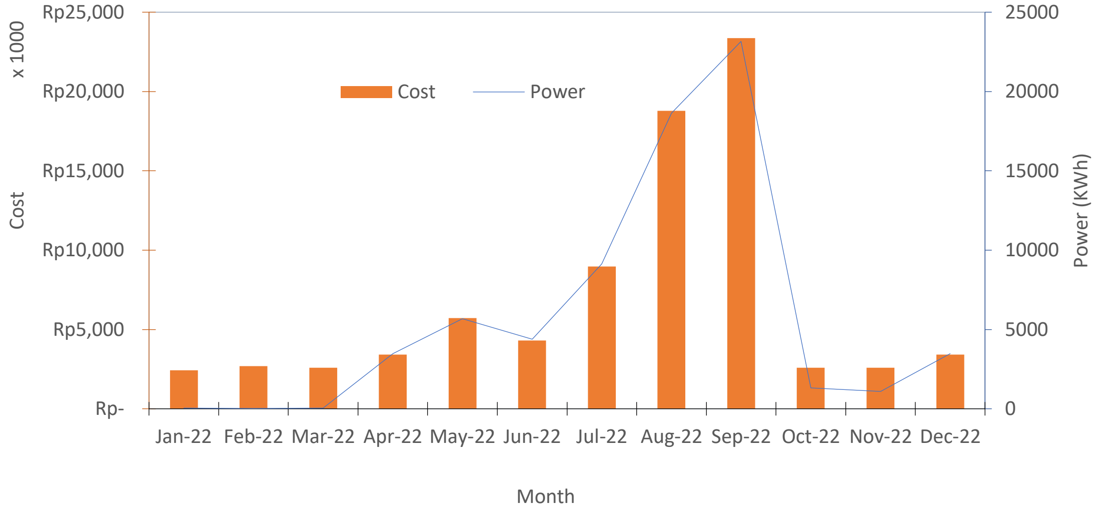

Figure 6. Power consumption of water pump irrigation

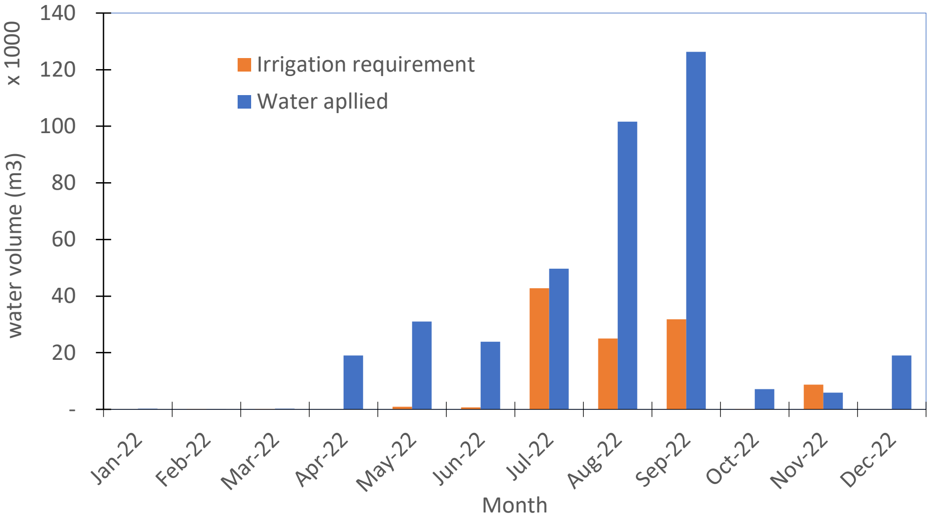

Figure 7. Water applied to the rainfed field at Tambakromo rainfed

During GS II spanning from April to July, as well as GS III from August to September in the year 2022, farmers in Tambakromo Village depend on the irrigation pump sourced from the Bengawan Solo River. This supplementary approach becomes necessary when natural rainfall falls short of meeting the water requirements of their crops. The irrigated area during GS II and GS III encompasses 90 ha, which allows farmer groups comprising 120 individuals to engage in a triple cropping system, which involves three cycles of rice planting within a single year. Moreover, in previous GSs, the farmers encountered difficulties due to water shortages. With the operation of the irrigation pump during GS II, they can overcome these water shortages and proceed with their planting activities. Oweis and Hachum (2009) argued that significant increases in crop yields occur when the farmers use relatively adequate irrigation water in the rainfed area, leading to improved harvest outcomes. This improvement was noticeable across regions with low and high yearly rainfall. The electricity expenses and power consumption linked to the operation of the electric pump for irrigating rice fields in Tambakromo are visualized in Figure 6 for the three growing seasons, with the highest costs occurring during GS III, closely followed by GS I. This variance is primarily attributed to the shifts in water demand. Specifically, the elevated electricity costs and pump usage observed in GS I and GS III can be attributed to the heightened requirements for irrigation during the dry season. This surge in demand necessitates more intensive pump operation, resulting in increased energy consumption and associated expenses. These costs primarily encompass electricity consumption expenses for powering the pump's dynamo. The application of water to the fields using the pump is consistently upheld to maintain an optimal water level above the ground. The utilization of the water pump experiences fluctuations between the rainy and dry seasons. Although the pump usage is infrequent during the rainy season (November to April), it predominantly operates during the dry season. Moreover, it can be engaged during the rainy season if insufficient rainfall occurs, particularly during land preparation stages (as shown in Figure 7). The graph illustrates the distinction between the irrigation requirement and the actual water application achieved using the pump. Remarkably, the rate of water application through the irrigation pump exceeds the actual water demand. Farmers follow a continuous pattern of irrigation water application, thereby sustaining a consistent water level that subsequently results in elevated water consumption. The considerations of farmers in choosing the flooding method are to suppress weed growth by limiting their access to sunlight and oxygen, reducing the need for additional weed management that is relatively easy to implement, and making it accessible to a wide range of farmers. Liu et al. (2016) revealed flooding method of 10 cm significantly reduced the survival rates and biomass accumulation of weed. Figure 8 shows case the working hours of the pump throughout the year 2022. Notably, the pump's operational hours are more extensive during GS III compared to GS II and GS I, reaching their peak in September. This pattern of increasing pump operational hours is accompanied by elevated power usage and associated electricity costs. The pinnacle of energy/power usage is recorded at 1,158 KW, correlating with a total pump operating time of 350.9 h. After September, pump usage diminishes alongside reductions in irrigation demand. From November onward, most of the water requirements for crops are fulfilled by natural rainfall.

A comprehensive overview of the performance of irrigation water pumps across three distinct periods/growing seasons (GS I, GS II, and GS III) is provided in Table 2. The variables analyzed include yield (tons.ha^{-1}), area (ha), water released (m^3), IWR (m^3), selling price of harvest (IDR.kg^{-1}), electrical power (KWH), and electricity cost (IDR). In GS I, the yield stands at 5.3 tons.ha^{-1} over an area of 30 ha, with 54,982 m^3 of water released and an IWR of 334,170 m^3. The selling price of the harvest is IDR 4,500.00 per kilogram, and the electrical power used is 4,634 KWH, incurring an electricity cost of IDR 11,122,320. Similar metrics are presented for GS II and GS III, with varying yield, area, water released, IWR, and associated costs. These facts provide quantified insights into the relationships between water demand, pump operation, electricity usage, and costs over multiple GSs. The efficiency of the water pump varies, with GS II showing more efficient water application compared to GS I.

Table 2. Performance of irrigation water pump

Variables	Growing Season I	Growing Season II	Growing Season III
Yield (tons.ha^{-1})	5.3	6.6	6
Area (ha)	30	65	100
Water released (m^3)	54,982	88,284	284,930.18
Irrigation water requirement (m^3)	334,170	60,000	1,022,905
Selling price of harvest (IDR.kg^{-1})	IDR 4,500.00	IDR 4,850.00	IDR 5,100.00
Electrical power (KWH)	4,634	13,585	52,237.20
Electricity cost (IDR)	IDR 11,122,320	IDR 16,036,646	IDR 53,707,691
Performance			
Water consumption (m^{3}.ton^{-1})	345.80	205.79	474.88
Power consumption (KWH.m$^{3\,-1}$)	0.084	0.154	0.183
Electricity cost rate (IDR.KWH^{-1})	2,400.2	1,180.4	1,028.2

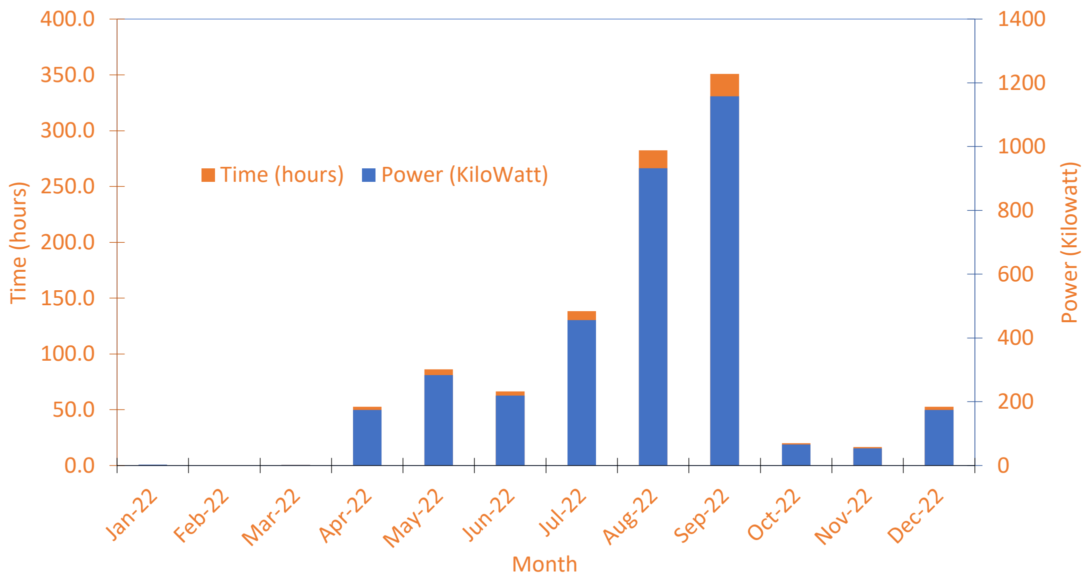

Figure 8. Time consumption of water pump.

4. DISCUSSION

The key findings of the study show that irrigation water demand for rainfed rice crops fluctuates across the three growing seasons, with the highest demand in GS III followed by GS I and lowest in GS II (Figure 2). The effective rainfall decreases from one 10-day period to another, whereas relative evaporation remains constant. Consequently, the rainfall during that period is insufficient to meet the irrigation requirement, leading to a rise in the irrigation demand. During periods of high evapotranspiration, such as dry seasons (Apr III to Nov I), the irrigation requirement tends to increase, even if there is some effective rainfall. This is because the higher rate of water loss from the soil and plants results in an increased water demand. Scharwies and Dinneny (2019) recorded increased water loss from the soil and plants occurring in conditions of rising temperature, low humidity, and strong winds. This water loss contributes to an increased water demand, potentially leading to drought stress in plants when the available water is less than 50%. Conversely, during GS I, the effective rainfall starts to increase, resulting in the irrigation requirement being adequately supplied by rainfall (Nov II to Feb I). This is evident from the irrigation requirement graph, showing a zero-water demand. The peak irrigation requirement in rice crops is during the land preparation phase, precisely on July 1, within GS II. The rice crops require a substantial amount of water to prepare the fields and establish optimal growing conditions, possibly due to the need for moist soil for seed germination and early plant development.

The analysis in Figures 4 and 5 delves into how these diverse rainfall volumes influence overall water balance and monthly river discharge rates. Dry years are characterized by consistently low water balances, remaining below 500 mm throughout all months. Discharge in dry years peaks early, reaching only 200–300 mm before sharply declining. By contrast, wet years maintain high water balances ranging from 800 to 1,000 mm, allowing for discharge peaks of 800–900 mm during rainy months. Normal year patterns fall intermediary to these extremes. The data underscores that seasons with increased precipitation exhibit enhanced capacity to replenish water reserves, facilitating greater volumes of water flow through river systems consistently. Conversely, reduced rainfall, as evident in dry years, significantly constrains available water supplies and flows, particularly beyond the initial wetter periods. These graphical representations underscore the susceptibility of river discharge to short-term weather fluctuations and long-term climate variations between drier and wetter regional seasons.

Electric water pumps have become widely favored and extensively utilized in regions dedicated to irrigation. At Tambakromo, farmers favor the adoption of electric water pumps due to the cost-effectiveness of electricity in comparison to diesel fuel, measured on a per-unit basis. This cost advantage can lead to reduced operational expenditures over an extended period, as electricity costs tend to exhibit greater stability and fewer fluctuations compared to diesel fuel prices (Martin et al., 2011). Three figures (Figures 6, 7, and 8) unveil a complex interplay between the demand for irrigation water, electricity usage, and associated costs. The challenges of relying on pumped irrigation are evident, particularly during the dry season, during which the agricultural system faces simultaneous peaks in electric costs, pump operation hours, and potential water shortages. The observed deficit in actual water application during certain months, notably dropping to 60,000–80,000 m^3, corresponds with the identified peak in power consumption and costs during the dry season. Moreover, Figure 8 reveals the monthly operating hours of the pumps and the resulting power consumption. The highest pump running times coincide with the dry period from May to August, further reinforcing the relationship between increased electricity usage, prolonged pump operation, and the demand for irrigation water during this critical period. The significant financial savings stem from the difference between the expenses associated with diesel and the costs linked to utilizing an electric system.

The performance of the water pump appears to be dynamic, with different strengths and areas for improvement in each period as shown in Table 2. The analysis indicates noticeable variability across critical metrics including yield per hectare, cultivated area, irrigation water utilization compared to crop requirements, electricity usage for pumping, and overall energy costs over the three growing periods. For instance, GS II demonstrates a higher level of efficiency in terms of water application versus the actual irrigation demand while also requiring less intensive pump operation leading to reduced electricity expenditure. By contrast, electricity consumption and expenses escalate in alignment with heightened pumping activity driven by elevated irrigation needs during GS I and GS III dry spells. These quantified relationships between factors such as crop water demands, pump system operation patterns, power usage levels, and cost implications provide a granular data-based understanding of the interdependencies underlying the irrigation infrastructure's performance. Evaluating the fluctuations in these metrics facilitates targeted identification of periods requiring efficiency improvements, cost re-evaluations, and behavioral shifts to achieve more optimal utilization of water, energy, and operational expenditure.

The cultivated area and IWR are influential variables that directly impact the performance values. Specifically, as the cultivated area and IWR increase, there is a corresponding change in power consumption and the rate of electricity cost. This means that a larger cultivated area and higher water demand lead to an increase in the amount of power consumed and a higher cost associated with electricity usage. These factors are interconnected and play a significant role in determining the overall efficiency and cost-effectiveness of the farming system.

Proper water management and irrigation practices become essential in dry and normal years to optimize water usage and meet the water requirements of rice crops throughout the GS (Benavides et al., 2021; Rao et al., 2014). To address months with a positive water balance, efforts are made to store the excess water for use during periods of declining water balance. This is achieved through water conservation activities in Tambakromo, utilizing two water reservoirs. Chen et al. (2005) reported the construction of reservoirs plays a significant role in water resource management. Reservoirs serve as storage facilities for water, capturing excess runoff during periods of high precipitation and subtracting it during times of scarcity. Moreover, the reservoirs serve not only for water conservation and additional irrigation purposes but also for agrotourism activities. The irrigation water pricing can assist in the management of irrigation water, ensuring that limited water resources are used efficiently. In the Tambakromo irrigation system, the payment for irrigation water is based on a percentage of the harvest. Farmers pay for irrigation water at a rate of 1/6 of the harvest. This percentage is established through consultations and agreements between the farmers and the irrigation management. Ashayeri et al. (2018) revealed that the concept of water savings can be realized through the implementation of irrigation water pricing mechanisms. In the agricultural lands of Guilan Province, Iran, a specific price has been determined for irrigation water, which is set at 0.5108 dollars per cubic meter ($ m^{-3}).

To overcome the risk of water scarcity, supplemental irrigation from external sources, such as rivers, becomes crucial to sustain the rice crops and prevent yield losses. Sustaining rice crops through supplemental irrigation from water rivers is vital for several reasons. First, inadequate water supply can lead to stress in plants, affecting their growth, development, and ultimately their yield. Second, water stress during critical growth stages can result in lower grain quality and quantity, which leads to economic losses for farmers (Bhatt et al., 2014). Hence, ensuring a reliable water source through pump irrigation of river water is instrumental in maintaining healthy and productive rice crops. Moreover, preventing yield losses is a key objective in agricultural practices. Yield losses can have significant economic consequences for farmers, impacting their livelihoods and the availability of food resources (Yohannes et al., 2017). By implementing supplemental irrigation from external sources such as rivers, farmers can mitigate the risk of yield losses associated with water scarcity.

The Bengawan Solo Watershed Authority plays a key role in terms of the management of annual water allocation for all water users. In terms of water pump utilization, optimization of water pump usage is required. Considering the higher pump usage during the dry season, farmers must effectively schedule and manage the pump operation. Implementing water-efficient irrigation techniques can enable further optimize water usage and reduce the need for constant pumping. Some strategies could enhance the performance of pumping irrigation leading to resource conservation, cost savings, and enhanced agricultural productivity. Regularly monitoring and maintaining the centrifugal pump is essential to ensure its optimal performance and efficiency. The pump's lifespan can be extended by conducting routine inspections, checking for wear and tear, and addressing any issues promptly. Proper maintenance practices not only prevent breakdowns but also contribute to energy savings by ensuring the pump operates at its peak efficiency (Glovatskiy et al., 2021; Martín Candilejo, 2020). Providing education and training to farmers regarding pump operation, maintenance, and irrigation techniques is a proactive approach to enhancing their understanding and skills. When farmers are knowledgeable, they can make informed decisions about when and how to operate the pump, how to troubleshoot minor issues, and when to seek professional assistance. Training can cover topics such as efficient scheduling of pump usage, adjusting flow rates, and recognizing signs of pump inefficiency. This knowledge empowers farmers to optimize their pump's performance and minimize unnecessary energy consumption (Kinanti & Amanah, 2017; Yonariza et al., 2019). To create a collective environment of learning and improvement, collaboration among farmers must be fostered. When farmers share their experiences, strategies, and lessons learned, it benefits the entire community. Collaborative platforms can facilitate discussions on effective pump usage, irrigation methods, and water management techniques. By sharing insights regarding successful practices and challenges faced, farmers can collectively devise innovative solutions. This not only leads to enhanced water resource management but also builds a sense of community and camaraderie among farmers, promoting sustainable and efficient agricultural practices (Brown et al., 2017; Handayani & Putra, 2022; Suciati et al., 2014).

5. CONCLUSION

The study clarifies the intricate relationship between energy consumption for pumping, irrigation water application, and rice productivity amidst seasonal variations. Notably, electricity usage for pumping irrigation water fluctuates across the three growing seasons, peaking during dry periods (GS II and GS III) when irrigation demand is highest. This heightened demand requires more intensive pump operation, which leads to increased electricity consumption and costs. The size of cultivated areas also directly influences electricity usage and costs. GS II had the highest yields (tons ha^{-1}) despite intensive water consumption (m^3 ton^{-1}) and electricity usage (KWH m^{-3}) between GS I and GS III. This indicates that the most performance pump during dry periods can pay off in terms of maintaining rice productivity. Supplemental irrigation from river water during dry periods is crucial for sustaining rice crops, preventing yield losses, and maintaining productivity. Strategies such as water-efficient techniques, pump maintenance, farmer training, and collaborative efforts can optimize resource usage, enhance agricultural productivity, and mitigate the impact of climate variability on crop yields. By adopting these measures, stakeholders can ensure the long-term sustainability of agricultural systems in the Tambakromo region.

Declaration of Competing Interest

The authors declare that no competing financial or personal interests that may appear and influence the work reported in this paper.

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