AGROMIX
pISSN (Print): 2085-241X; eISSN (Online): 2599-3003
Website: https://jurnal.yudharta.ac.id/v2/index.php/agromix

Optimizing irrigation efficiency and resilience: Advanced integration of SCH and SRI techniques for sustainable agricultural development and climate change mitigation

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Original article

Article history
Received : February 26, 2025
Accepted : September 29, 2025
Published: September 30, 2025

Keyword
Irrigation system optimization;
Water use efficiency;
Sustainable rice cultivation (SRI);
Sustainable crop husbandry (SCH);
Climate-resilient agriculture;

ABSTRACT

Introduction: Lempake Irrigation Area is one of the Irrigation Areas supporting rice barns in meeting food needs for the people in Samarinda City. The government continues to improve and maintain the Lempake irrigation area, but there is still a decrease in agricultural yields. This research aims to analyze the condition and performance of the irrigation system both physically and non-physically, then optimize the method of providing efficient and adaptive irrigation water to support sustainable agriculture. **Methods**: mode-median method to analyze irrigation water availability, then comparing SCH and SRI water application techniques to evaluate water use efficiency. Optimization of method selection was done using AHP and ANP with Super Decisions application. **Results**: Using the mode method, the maximum discharge occurred in period I in March, which was 519 l/second, and the minimum occurred in period II in October 29 l/second. The performance index value of the Lempake Irrigation Area irrigation network is 65.92% and is categorized as “less and needs attention”. With the existing water delivery method, the SCH K factor value of 1.58, the performance of the irrigation system is 65.92. Then if using the SRI water delivery method, the K factor value of 3.62 irrigation system performance increases to 80.14. Using the AHP method obtained ranking criteria that are prioritized in the proposed rehabilitation activities starting from physical conditions, human resource management, operating systems. Then with the ANP method obtained a ranking of channels in the Lempake Irrigation Network that gets priority in the proposed rehabilitation. **Conclusion**: in conclusion, the application of the SRI method of water application proved to be more efficient than the SCH method. Optimization of irrigation systems through more efficient methods can increase agricultural productivity in this region.

Cite this article:
Andawayanti, U., Hakim, L., & Lufira, R., D. (2025). Optimizing irrigation efficiency and resilience: Advanced integration of SCH and SRI techniques for sustainable agricultural development and climate change mitigation. *AGROMIX, 16*(2). 168–182. https://doi.org/10.35891/agx.v16i2.6086

INTRODUCTION

Indonesia's growing population continues to drive an increasing demand for food, posing a significant challenge to the agricultural sector. However, land scarcity and limited natural resources obstruct initiatives to increase food productivity (Muiz *et al.*, 2017). The Indonesian government recognizes us to action for the development of the agricultural sector with a rice self-sufficiency program to strengthen national food security (Nugroho *et al.*, 2018). Despite these initiatives, optimal agricultural output continues to be obstructed by the strong problem of irrigation water management. Current government efforts rely on the availability and effectiveness of preventive measures. Irrigation water distribution is still not at its most efficient level. Ananda et al (2019) stated that the gap between water supply and demand has a severe impact on agricultural productivity, especially in major rice-producing areas. This shows the need for a comprehensive analysis of water allocation for irrigation in various Irrigation Areas. It is important to understand these variations to optimize them. This is invaluable for sustainable water resource management and agricultural production. This study aims to address this issue by analyzing the efficiency and sufficiency of irrigation water distribution, providing insights that can inform more effective water management strategies to support food security in Indonesia.

The Lempake Irrigation Area; Lempake Irrigation Area is a highly important irrigation area for rice crop cultivation to fulfill the food needs of Samarinda City population. However, in recent years, frequent large floods have caused widespread crop failures, creating vulnerabilities in the irrigation system. While there are general assessments of irrigation systems (Hasily *et al.*, 2020), there is lack of research that focuses on the factors affecting the performance of irrigation systems, especially in flood-prone areas such as Lempake. Other studies have generally not examined how flooding conditions lead to increased system inefficiencies and begin to cause crop failure. This study is sought to overcome this gap by assessing the performance of the Lempake Irrigation Area and evaluating the impact of floods on system performance and crop yield. Therefore, by investigating these important areas, this study provides an understanding of what factors impact irrigation performance in flood-affected areas and helps achieve a more sustainable irrigation system. The evaluation of irrigation networks during operation is essential, as irrigation districts continue to develop and expand, often introducing new challenges or amplifying existing problems related to food security in Indonesia.

The current concrete step is the ongoing rehabilitation and rejuvenation project of the Lempake Dam so that it can irrigate the water needs of the Lempake Irrigation Area. However, there is often a decrease in the planting area every year of around 140 hectares (Badan Pusat Statistik Kota Samarinda, 2020). This decrease in area is thought to occur because the condition of some buildings in the irrigation network system is damaged and not functioning normally. This complicates the process of supplying water needs from the source to the most downstream areas. Based on the initial survey, it was found that several main buildings such as primary channels, secondary channels, buildings for tapping, tapping buildings experienced various levels of damage ranging from moderate to severe damage.

Based on Permen PUPR No.12/PRT/M/2015, the evaluation of irrigation system performance is intended to determine the performance condition of the irrigation system that is already in operation. This study will apply an evaluation of the performance of the irrigation system in the Lempake Irrigation Area using the AHP (analytical hierarchy process) method with a quantitative approach and using the Super Decision application program. Then the evaluation of water supply is also carried out with a comparison approach between the SCH (Stagnant Constant Head) method and the SRI (System of Rice Intensification) method. This research aims to analyze the condition and performance of the irrigation system both physically and non-physically, then optimize the method of providing efficient and adaptive irrigation water to support sustainable agriculture.

METHODS

The research employs a descriptive approach to provide an objective assessment of the Lempake irrigation area by integrating various analytical methods. The methods used are described based on their suitability in assessing water availability, irrigation effectiveness and optimal strategies. The specifics of each method and its application in this study are described in detail below:

Modus-median method

The availability of irrigation water is evaluated using the Modus-Median method with daily discharge data. This method is ideal for analyzing the dynamics in water availability as influenced by intake gate operations (Nagy *et al.*, 2023). This method overcomes the effect of extreme change, so that the determined representative discharge values can be better used as the basis of irrigation planning.

a. Median method

Median is the middle value of a distribution, or it can be said that the variate divides the frequency distribution into 2 (two) equal parts, therefore the probability of the median is always 50%.

1) Data that has not been grouped
   - Odd number of data
     For an odd number of data, the median is the data in order (k1) which can be calculated by the formula (Soewarno, 1995):
     $$k_1 = \frac{n+1}{2}$$
     To find the Median in a dataset, two key elements are used. k_1 represents the position of the median, and n is the total number of data points.
   - Even the number of data
     For an even number of data, the median is the data located at the midpoint of the data sequence to (k_1) and (k_2), calculated by the formula (Soewarno, 1995):
     $$k_1 = \frac{n}{2}$$
     $$k_2 = \frac{n+2}{2}$$
     In identifying the position of the median, especially when dealing with ungrouped or raw data, the values k_1 and k_2 represent the location(s) of the median within the dataset.

b. Grouped data

The median of the data that has been grouped into a frequency distribution can be calculated with the following formula (Soewarno, 1995):

$$M_d = b + i\left(\frac{\frac{n}{2}-F}{f}\right)$$

To determine the median (Md) in a grouped data set, several components are involved in the calculation. n is the total number of data points, while i represents the width of the class intervals. The median class frequency (f) refers to the number of observations within the class that contains the median. F is the cumulative frequency of all classes before the median class, and b is the lower boundary of the median class. Together, these elements are used in the median formula to estimate the central value of the data distribution more accurately.

c. Modus method

Modus is a variate that has maximum probability density. Existing data is arranged in a class interval frequency distribution and then the modus value is calculated using the following formula (Soewarno, 1995):

$$M_o = B + i\left(\frac{f-f1}{(f-f1)+(f-f2)}\right)$$

To calculate the mode (M_o) in a grouped data distribution, several key components are used. B represents the lower boundary of the modal class, the class interval with the highest frequency. I refer to the width of the class interval. The maximum frequency (f) is the number of data points in the modal class, while f_1 is the frequency of the class just before it, and f_2 is the frequency of the class just after. These values are used in the mode formula to provide a more accurate estimate of the most frequent value in a grouped dataset.

FPR (relative cropping factor) and LPR (relative cropping area) methods

These methods take into accounts the crop water requirements that depend on the local climatic conditions and cropping patterns. FPR measures the availability of irrigation water supply, and LPR measures the spatial pattern of irrigated land (Kelley & Johnson, 1991). Using these techniques, a study assesses whether crop needs match water distribution and ensures optimal allocation.

a. FPR (relative cropping factor) method

Relative Crop Factor is a method of calculating irrigation water requirements developed in East Java, with the following formula (Kunaifi, 2010):

$$FPR = \frac{Q}{LPR}$$

To estimate the irrigation demand more precisely, three key variables are considered. The relative crop factor (FPR) represents the amount of water needed per hectare, measured in liters per second per hectare. The river discharge (Q) indicates the volume of water flowing in the river, expressed in liters per second. Meanwhile, the related crop area (LPR) refers to the total area of crops that require irrigation, measured in hectares. These variables together help determine whether the available water flow is sufficient to meet the irrigation needs of the agricultural area.

If the soil type and water conditions in the field are known, the FPR value can be obtained using Table 1.

Table 1. FPR value based on soil specific gravity

Soil Type	FPR (liter/second/hectare)		
	Less water	Enough water	Sufficient water
Alluvial	0.18	0.18 – 0.36	0.36
Latosol	0.12	0.12 – 0.23	0.23
Grumosol	0.06	0.06 – 0.12	0.12
Turns	Need	Maybe	No

b. LPR (relative cropping area) method

The Land Productivity Ratio (LPR) represents a comparison of water requirements between one type of crop and another. The reference crop used in the comparison is a crop assigned a standard value of 1 (one). Thus, the water requirement of each crop can be expressed relative to that of the reference crop. Before calculating, all crop water needs are first converted into the equivalent water requirement of the secondary crop. This conversion process produces a single numerical value known as the conversion factor for each crop type, which serves as the basis for comparing water requirements among different crops. The values of these conversion factors refer to Table 2 as presented by Kunaifi (2010).

Table 2. LPR comparison coefficient

Plant Type	Comparison Coefficient
Crops	1
Rendeng Rice	
Nursery	20
Land cultivation	6
Growth/maintenance	4
Permitted Gadu rice	same as rending rice
Unlicensed Gadu rice	1
Sugarcane	
Seedling/young	1.5
Old	0
Tobacco/rosela	1
Pond filling (pond paddy)	3

Evaluation of irrigation network performance

The condition assessment of the irrigation system is based on Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat No. 12/PRT/M/2015, which mandates six evaluation parameters: physical infrastructure, planting productivity, supporting facilities, personnel organization, documentation, and the water-user association (P3A). For instance, Prasetyaningrum, Prayogo, & Sayekti (2022) obtained an irrigation performance index of 82.57% in the Kaligawe Irrigation Area using this regulation. Similarly, Yahdita et al. (2020) found a 65% performance index for the Seberang Gunung Irrigation Area, categorised as “needs attention”. These findings illustrate how the regulation provides a structured framework for evaluating irrigation system performance in Indonesia.

SCH (stagnant constant head) and SRI (system rice intensification) methods

The System of Rice Intensification (SRI) and the concept of Sustainable Crop Husbandry (SCH) are both aimed at improving water delivery in rice cultivation, but via different approaches. SRI emphasises alternating wetting and drying (AWD) and improved plant spacing to reduce water use while maintaining or improving crop yields. In contrast, SCH maintains an appropriate water level throughout the cultivation period to ensure optimal growing conditions. The usefulness of SRI for sustainable irrigation management is supported by numerous studies. For example, Dass & Dhar (2014) reported that SRI–AWD regimes saved up to 50% of irrigation water while improving water-use efficiency compared to conventional flooded systems. Additionally, in Tamil Nadu, India, Palanisamy et al. (2022) found that full SRI practices increased water productivity by about 100% (0.25 kg grain/m³ water) and achieved approximately 20% water savings relative to conventional cultivation. Thus, while SCH’s specific research base should be further elaborated, SRI clearly offers a viable strategy for achieving more sustainable irrigation management in rice systems.

a. *SCH (stagnant constant head) method*

SCH is the process of giving water to plants by flowing irrigation water into rice fields continuously throughout the irrigation area and left inundated starting a few days after planting until a few days before harvest. Schematically, this method of water application in the processing phase of the inundation height is 5-10 cm, while in the maintenance phase the inundation height is 2-3 cm. By knowing the area of processing and maintenance, the real water requirement using the FPR-LPR value can be calculated using the following equation (Musrady et al., 2019):

$$Q = LPR \times FPR \times A$$

In the analysis of water demand using the SCH method, the irrigation discharge (Q) is measured in liters per second. This calculation considers several key factors, including the relative crop area (LPR), the relative crop factor (FPR) expressed in hectares, and the total area used for activities such as nursery, processing, maintenance, and cropping (A), also measured in hectares. By incorporating these elements, the water demand estimation becomes more accurate and better reflects the actual agricultural conditions.

b. *SRI (system rice intensification) method*

The SRI method in rice cultivation is carried out by providing irrigation water intermittently based on alternation between wet (shallow inundation) and dry periods. By knowing the height of inundation in the field, it can be known how much discharge must be provided in the tertiary box. To convert the inundation height in the field into discharge is done by using the equation (Musrady et al., 2019):

$$Q_1 = \frac{H \; x \; A}{T} \; x \; 10{,}000$$
$$Q_2 = \frac{Q1}{86400} \; x \; \frac{1}{(1-L)}$$

In calculating water demand for rice fields, several important parameters are considered. The daily water demand in the field or plot is represented by Q1 (in cubic meters per day), while Q2 refers to the daily water demand at the intake gate, measured in cubic meters per second. Additional factors include the inundation height (H), which indicates how deep the water needs to cover the field; the total area of the rice field (A) in hectares; and the water application interval (T), which is the number of days between each irrigation. Water loss (L), which occurs both in the field and along the irrigation channels, is also factored in to ensure the calculation reflects actual field conditions as closely as possible.

AHP (analytical hierarchy process) and ANP (analytical networking process)

The AHP and ANP methods were used to prioritize the rehabilitation of irrigation networks by using Super Decision software. AHP is a very popular method for structured decision making, and ANP is a generalized form of the approach that examines factors interrelationships (Saaty, 2013). Farmer group questionnaires were analyzed to provide farmers perspectives in the decision-making process.

a. AHP (analytical hierarchy process)

The working principle of the AHP method is explained by the following basic idea:

1) Compilation of hierarchy

The problem to be solved is decomposed into its elements, namely criteria and alternatives, then arranged into a hierarchical structure. The simplest hierarchical model has a goal cluster containing goal elements, a criteria cluster containing criteria elements, and an alternatives cluster containing alternatives elements as shown in Figure 1.

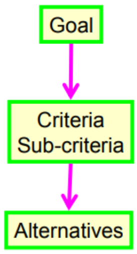

Figure 1. AHP hierarchy structure

2) Assessment of criteria and alternatives

Criteria and alternatives are assessed through pairwise comparisons. According to Saaty (2008), for various problems, a scale of 1 to 9 is the best scale in expressing opinions. The value and definition of qualitative opinions from Saaty's comparison scale can be seen in Table 3 (Marimin, 2010).

Table 3. Assessment of Criteria and Alternatives

Rate	Description
1	Criteria/Alternative A is as important as criteria/alternative B
3	A is slightly more important than B
5	A is clearly more important than B
7	A is very clearly more important than B
9	Absolutely more important than B
2,4,6,8	When in doubt between two near values

3) Prioritization

For each criterion and alternative, pairwise comparisons need to be done. The relative comparison values are then processed to determine the relative ranking of all alternatives. Both qualitative criteria, and quantitative criteria, can be compared according to predetermined judgments to produce weights and priorities. Weights or priorities are calculated by matrix manipulation or through mathematical solutions.

4) Logical consistency

All elements are grouped logically and ranked consistently according to a logical criterion.

The Super Decisions is a decision support software that implements AHP (Analytical Hierarchy Process). The software provides tools to create and manage AHP models, input your judgment, get results, and perform sensitivity analysis on results. Super Decisions models consist of groups of elements (or nodes) instead of elements (or nodes) organized in levels.

b. ANP (analytical networking process)

ANP is a development of the AHP method. The ANP method is able to improve the weaknesses of AHP in the form of the ability to accommodate the relationship between criteria or alternatives. The working principle of the ANP method is explained by the following basic idea:

1) Decomposition

decomposing or dividing an intact problem into its elements forms a hierarchy of decision-making processes, where each element or element is interconnected. The form of the decomposition structure is as shown in Figure 2 (Thakkar, 2021).

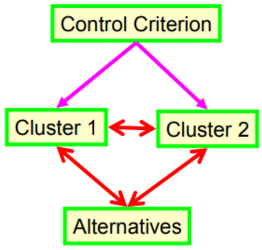

Figure 2. ANP hierarchy structure

2) Comparative Judgement

The preference scale used is scale 1 which shows the lowest level (equal importance) to scale 9 which shows the highest level (extreme importance) as in Table 3.

3) Synthesis of Priority

Synthesis of priority is done by using the eigen vector method to obtain relative weights for decision-making elements.

4) Logical Consistency

Logical consistency is an important characteristic of ANP. This is achieved by aggregating all eigen vectors obtained from various levels of the hierarchy and then obtaining a weighted composite vector that results in a decision-making sequence.

K Factor method

Measurement of irrigated area using the K Factor method. This approach measures the match between the water availability and crop water requirements and helps to detect potential surpluses or deficits (McCartney et al., 2022). If the water supply is sufficient, the K factor = 1, while if the water supply is insufficient, the K factor <1. Formula to calculate the K factor as follows:

$$K = \frac{\text{available discharge}}{\text{required discharge}}$$

With the K factor value that has been obtained, the watering criteria can be determined according to Table 4.

Table 4. Watering criteria with K factor

K Factor	Criteria
0.75 – 1.00	Continuous
0.50 – 0.75	Turns in tertiary channels
0.25 – 0.50	Turns in secondary channels
< 0.25	Turns in the primary channel

Data collection and sources

This research makes uses primary and secondary data. For this study, primary data was collected through farmer surveys and interviews on perceptions of irrigation and water management performance. Stratified random sampling was used to engage respondents, allowing for better representation of different types of farms. We designed a questionnaire that discussed important topics including water availability, cropping calendars, and irrigation issues. Secondary data included daily discharge data from the local water management authority (2015–2022), irrigation network maps from regional water agency, and cropping pattern records from the agriculture departments. These types of data provide a strong basis for conducting the analysis in this study.

Software and tools

To enable the AHP and ANP analysis, Super Decision software was used as it can resolve advanced multi-criteria decision-making situations. Specifically, the software helps provide pairwise comparison matrices and consistency checks that assist in ensuring reliable prioritization for the rehabilitation measures used (Ishizaka & Siraj, 2018).

Limitations

There are several limitations in this study that need to be recognized. Firstly, the Modus-Median approach assumes that changes in daily discharge reflect water availability over the long term, so it may not be sufficient to describe extreme events and climate extremes. Secondly, the FPR and LPR results are based on the data quality of specific cropping pattern, which may add uncertainty; Moreover, farmer survey responses may create subjective bias, but this can be minimized by using a structured questionnaire. Lastly, the criteria selected in the AHP/ANP methods may lead to biased prioritization, which should be verified by sensitivity analysis to improve the strength of the results. This study is very important as it will overcome the limitations of previous studies.

RESULTS AND DISCUSSION

Water availability discharge

The analysis of water availability was conducted using 15-day period discharge data from 2017 to 2021, specifically based on the discharge recorded through the intake door on the Belimau Primary Channel. An example of calculating the discharge using the Modus-Median method is as follows: the number of data points (n) is 5, the class interval (i) is 11.0, and the location of the median (k1) is 3. The lower edge (b) of the median class is 308.6, the frequency of the median class (f) is 1, and the cumulative frequency before the median class (F) is 2. This method is used to determine the discharge value by considering the data distribution and its central tendency, which helps in evaluating the water availability during the specified periods.

$$\text{QMd} = b + i\left(\frac{k1-F}{f}\right) = 308.6 + 11\left(\frac{3-2}{1}\right) = 319.57 \text{ l/second}$$

The calculation of discharge using the Mode method involves the following parameters: the class interval (i) is 11.0, and the lower limit of the class interval for the mode (B) is 297.6. The maximum frequency class for the mode (F) is 2, the frequency before the mode class (f1) is 0, and the frequency after the mode class (f2) is 1. These values are used in the formula to calculate the mode, which represents the most frequently occurring discharge value within the given class interval. This method helps in identifying the peak discharge within the data set for a more accurate representation of water availability.

$$\text{QMo} = B + i\left(\frac{f-f1}{(f-f1)+(f-f2)}\right) = 297.6 + 11\left(\frac{2-0}{(2-0)+(2-1)}\right) = 304.91 \text{ l/second}$$

The following is a graph of water availability based on the calculation of Q Minimum, Q Median, and Q Mode for all months.

Figure 3 describes the available discharge from the Lempake Dam, showing significant seasonal fluctuations with a peak of 519 l/second in March and a minimum of only 29 l/second in October. This pattern is consistent with Indonesia's monsoon climate, which has contrasting rainy and dry seasons, with annual rainfall variability tending to increase (Tirtalistyani et al., 2022). The low discharge in October specifically confirms the findings of Hidayat et al. (2016) who stated that the Mahakam watershed in East Kalimantan is highly susceptible to drought. Consequently, as seen in the graph, there is a surplus of water availability during the rainy season (November-June) to meet irrigation needs, but a critical water deficit occurs during the dry season (July-October). This surplus-deficit condition is a common challenge faced by many irrigation systems in Indonesia (Basri et al., 2023), underscoring the need for a water rotation system in the Lempake Irrigation Area during dry periods.

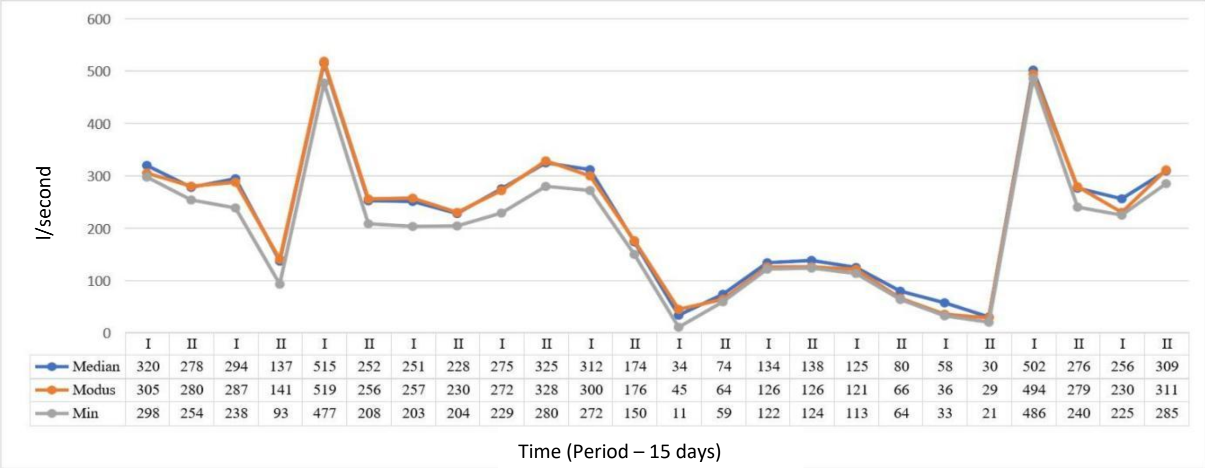

Figure 3. Water availability chart based on Q Minimum, Q Median, and Q Mode

Irrigation system performance index assessment

According to PUPR Regulation No. 12/PRT/M/2015 concerning the Exploitation and Maintenance of irrigation systems, the performance assessment of an irrigation system consists of six key indicators, each with a specific weight: physical infrastructure (45%), crop productivity (15%), supporting facilities (10%), personnel organization (15%), documentation (5%), and P3A/GP3A/IP3A (10%). The Lempake Irrigation Network inventory analysis includes data on the number, dimensions, type, condition, function, and value of all assets within the Lempake irrigation area. This inventory data will be used to determine the Lempake Irrigation Network Condition Index.

Based on PUPR Regulation No. 12/PRT/M/2015, the performance index of an irrigation system is assessed according to the following performance levels: excellent performance (80-100), good performance (70-79), underperformance requiring attention (55-69), and poor performance requiring immediate attention (<55). The maximum score is 100, the minimum is 55, and the optimum is 77.5. Based on the performance index assessment for the Lempake Irrigation Area, a value of 65.9% was obtained, indicating "underperformance and needs attention". This result highlights the need for improvements in the irrigation system to increase the performance index and enhance its overall effectiveness.

Stagnant constant head (SCH) method

Based on the type of crops and the area of crops planted, the method of water delivery at the study location, Lempake irrigation area, needs to be evaluated. If the evaluation results obtained a lack of water availability, it is necessary to modify the water supply method such as water supply in rotation in each block of rice fields, or a combination of continuous and rotating according to water needs, or water supplying the SRI (System Rice Intensification) method. The calculation stages of the evaluation analysis of the water supply method of the Lempake irrigation area study location based on the SCH (Stagnant Constant Head) method of plant water supply as follows:

a. *Adjustment of the number of paddy field blocks*

In this study location, there are 3 blocks of rice fields separated by village roads, rivers, and the administrative areas of each farmer group.

Table 5. Block division in Lempake irrigation area

No.	Block I		Block II		Block III	
	Plots	Area (Ha)	Plots	Area (Ha)	Plots	Area (Ha)
1	BELIMAU KA I	13.47	BELIMAU KA 2	75.02	MUANG KA 1	6.05
2			BELIMAU KI 2	67.22	MUANG KI 2	22.84
3					MUANG KI 3	23.10
	Total	13.46	Total	142.24	Total	51.99

Table 5 shows the division of the Lempake Irrigation Area into three blocks. Block I contains two plots, BELIMAU KA I (13.47 Ha) and BELIMAU KI 2 (67.22 Ha), with a total area of 13.46 Ha. Block II includes BELIMAU KA 2 (75.02 Ha) and MUANG KI 2 (22.84 Ha), totaling 142.24 Ha. Block III consists of MUANG KA 1 (6.05 Ha) and MUANG KI 3 (23.10 Ha), totaling 51.99 Ha. The data is based on primary data analysis conducted in 2022.

1. Determination of percentage of land area

The determination of the percentage of land area is based on the predetermined cropping pattern plan and is conducted for each of the first, second, and third cropping seasons. This approach aims to accurately represent seasonal variations in crop distribution and to optimize irrigation water allocation throughout the year.

Table 6. Percentage of land area to total irrigated area

No.	Plant Type	Planting Season I		Planting Season II		Planting Season III		Total	
Irrigation Area = 207.01 hectares									
1	Rice	90%	186.94	80%	166.17	75%	155.78	245%	508.89
2	Secondary Crop	5%	10.39	15%	31.16	20%	41.54	40%	83.08
3	Miscellaneous	5%	10.39	5%	10.39	5%	10.39	15%	31.16
Total Intensity		100%	207.71	100%	207.71	100%	207.71	300%	623.13
Rice and Cropping Intensity		95%	197.33	95%	197.33	95%	197.33	285%	591.98

Table 6 presents the percentage of land area allocated to rice and secondary crops across three planting seasons in an irrigation area of 207.01 hectares. In Planting Season I, 90% of the area is dedicated to rice, with 5% allocated to secondary crops. In Planting Season II, the area for rice decreases to 80%, while the percentage for secondary crops increases to 15%. For Planting Season III, the area for rice is reduced to 75%, and 20% of the area is dedicated to secondary crops. The total area planted with rice over the three seasons amounts to 508.89 hectares, while the area for secondary crops totals 83.08 hectares. The table also includes the total intensity of land use, which is 623.13 hectares across all seasons, and the rice and cropping intensity, which accounts for 591.98 hectares. This distribution highlights the primary focus on rice cultivation, with a gradual reduction in rice cultivation area and an increasing focus on secondary crops over time. The table reflects how land allocation adjusts across the planting seasons to accommodate both rice and other crops, indicating efforts to optimize land use and adapt to seasonal variations.

b. Determination of percentage comparison of rice crop land

Determining the percentage ratio of land for each planting phase to the total area for rice plants is done on the basis that the rice planting process consists of three phases, namely the tillage phase, the rice plant nursery phase, and the rice plant maintenance phase until harvest.

c. Study site LPR value

The LPR value used in the calculation is the LPR value that corresponds to the type of crop planted at the Lempake Irrigation Field study site.

d. Study site FPR value

FPR values are used based on the study location in Lempake according to the type of crop planted, the area of each phase and the type of crop in each growing season.

e. Plant water requirement SCH method (stagnant constant head)

The calculation of water requirements is adjusted to the irrigation watering that has been determined based on the habits of local farmers, namely by maintaining the height of inundation in a certain period according to the development of plant growth rates. The following is an example of the calculation of water requirements for plant watering using the SCH method.

$$Q = LPR \times FPR \times A = 20.00 \times 0.16 \times 5\% \times 13.46 \times 90\% = 1.95 \text{ l/second}$$

The parameters used for the calculation are as follows: The LPR (Land Preparation Requirement) value for the nursery phase of rice plants is 20.00, while the existing FPR (Field Preparation Requirement) value, based on the evaluation for the first cropping season, is 0.16. Additionally, 5% of the land is allocated for the nursery planting phase of the rice crop. The rice field area in Block I is 13.46 hectares, and 90% of the rice paddy area is dedicated to the planned rice crop. These values are essential for determining the water and land requirements during the nursery phase of rice cultivation in Block I of the irrigation system.

Table 7 provides the calculation of water supply requirements using the Stagnant Constant Head (SCH) method for three planting seasons across the Lempake Irrigation Area. The total water requirement for the entire area is 207.71 l/second. In Planting Season I (90% rice), the water requirements for Block I, Block II, and Block III are 1.95 l/second, 20.64 l/second, and 7.55 l/second, respectively, with additional needs for nursery, land processing, and maintenance. Planting Season II (80% rice) shows reduced water demand across all blocks, with Block II requiring the highest supply. Planting Season III (75% rice) has a further reduction in total water requirements, particularly for rice, with Block II still showing the highest demand. The table also includes water needs for Secondary Crop and other crops in each season, which are relatively small compared to rice cultivation. The data is based on primary analysis from 2022.

Table 7. Calculation of SCH (*Stagnant Constant Head*) method water supply

No.	Planting Season		Irrigation Water Requirement (l/Second)		
Irrigation Area	=	207.71	Block I	Block II	Block III
1.	Planting Season I				
	a. Rice	90%			
	- Nursery		1.95	20.64	7.55
	- Land processing		11.14	117.67	43.02
	- Maintenance		7.82	82.58	30.19
	b. Secondary Crop	5%	0.11	1.15	0.42
	c. other crops	5%	0.11	1.15	0.42
2.	Planting Season II				
	a. Rice	80%			
	- Nursery		1.68	17.77	6.50
	- Land processing		9.59	101.27	37.02
	- Maintenance		6.73	71.07	25.98
	b. Secondary Crop	15%	0.32	3.33	3.33
	c. other crops	5%	0.11	1.11	1.11
3.	Planting Season III				
	a. Rice	75%			
	- Nursery		1.51	15.92	5.82
	- Land processing		8.59	90.75	33.18
	- Maintenance		6.03	63.69	23.28
	b. Secondary Crop	20%	0.40	4.25	1.55
	c. other crops	5%	0.10	1.06	0.39

The effectiveness of the System of Rice Intensification (SRI) method in significantly reducing water use compared to conventional flooding methods has been well documented in the scientific literature. Various studies consistently report substantial water savings; for example, studies in South India have shown irrigation water savings of 40% (Narayanamoorthy, 2018), while studies in Korea have reported reductions in irrigation requirements of up to 50% (Choi et al., 2014; Park et al., 2016). In fact, a study in Iraq recorded a reduction in water consumption of up to 57.6% simply by implementing intermittent irrigation intervals (Al-Hasanie & Al-Maadhedi, 2017). In addition to direct water volume savings, SRI has also been shown to drastically improve water use efficiency, with Zhao et al. (2010) finding efficiency improvements of up to 91.3% compared to traditional methods. Therefore, the results of the Lempake study showing a sharp decrease in water demand after implementing SRI are not an anomaly, but are strongly supported by a broad consensus in international research.

2. SCH method (stagnant constant head) water balance

The calculation of the water balance is carried out with the aim of knowing the value of the K factor at the study location, namely Lempake irrigation area. Based on the results of the calculation of the water balance of the SCH method and the evaluation of water supply with factor assessment criteria, the average value of the K factor for the water supply method at the Lempake irrigation area study site is still in "good" condition, namely 1.58 (exceeding the standard value of the K factor of 1.00). It is also known that the plant water requirement of the total blocks is a maximum of 204.2 Liter/sec and a minimum of 100.7 l/second. This figure will be compared with the alternative watering method, namely the SRI method.

System rice intensification (SRI) method

To increase the value of the irrigation system performance index, the authors suggest and experiment efforts to improve the performance of the irrigation system from criterion number 2, namely about "Plant Productivity", by changing the method of giving water to plants and changing the cropping pattern plan. The recommended watering method is the System Rice Intensification (SRI) method. The following are the stages of calculating the watering method of the Lempake irrigation area based on the SRI method of plant watering.

a. Determination of waterlogging plant height

The planned inundation height is determined for each growing season and each growing phase, which varies according to the water requirements for the crop and the age phase of the crop growth.

Table 8. Inundation height plan of SRI method water application

Phase	Planting Season I	Planting Season II	Planting Season III
Vegetative Phase	2 cm (8 Days)	2 cm (5 Days)	2 cm (5 Days)
Generative Phase	2 cm (10 Days)	2 cm (7 Days)	2 cm (7 Days)
Nursery Phase	7.5 cm (5 Days)	7.5 cm (5 Days)	7.5 cm (5 Days)
Processing Phase	2.3 cm (5 Days)	2.3 cm (5 Days)	2.3 cm (5 Days)

Table 8 presents the inundation height plan for water application using the SRI (System of Rice Intensification) method across three planting seasons. During the Vegetative Phase, the water level is maintained at 2 cm for 8 days in Planting Season I, 5 days in Planting Season II, and 5 days in Planting Season III. In the Generative Phase, the water height remains at 2 cm for 10 days in Planting Season I, 7 days in Planting Season II, and 7 days in Planting Season III. For the Nursery Phase, the water level is set at 7.5 cm for 5 days in all three planting seasons. In the Processing Phase, the water height is kept at 2.3 cm for 5 days in each planting season. This plan follows the SRI method to optimize rice growth while conserving water during various stages of rice cultivation. The data was obtained from primary data analysis in 2022.

b. Calculation of Plant Water Requirement of SRI Method

The FPR-LPR value used in this calculation is based on current conditions according to the type of plants in the Lempake irrigation area. The following is an example of the calculation of water requirements for plant watering using the SRI method.

$$Q = \frac{H\ x\ A}{T}\ x\ 10{,}000 = \frac{0.075 \text{ x } 13.47 \text{ x } 5\% \text{ x } 90\%}{5} \text{ x } 10{,}000 = 90.91 \text{ m}^3/\text{day}$$

In this calculation, the waterlogging height for the nursery phase of rice plants is 0.075 mm. The rice field area in Block I is 13.47 hectares, and 5% of this area is allocated for the nursery planting phase of the rice crop. Additionally, 90% of the rice paddy area is designated for the planned rice crop. The water application interval for the nursery transplanting phase is set at 5 days. These parameters are used to determine the water requirements and management strategies for the nursery phase of rice cultivation in Block I of the irrigation system.

Table 9. Calculation of water application of SRI method

No.	Planting Season		Irrigation Water Requirement (m^3/day)			Irrigation Water Requirement (l/second)		
Irrigation Area	=	209	Block I	Block II	Block III	Block I	Block II	Block III
1	Planting Season I							
	a. Rice	90%						
	- Nursery		90.91	960.15	350.99	1.05	11.11	4.06
	- Land processing		529.73	5594.45	2045.10	6.13	64.75	23.67
	- Maintenance (Vegetative)		303.05	3200.49	1169.97	3.51	37.04	13.54
	- Maintenance (Generative)		242.44	2560.39	935.97	2.81	29.63	10.83
	b. Secondary Crop	5%	0.12	1.23	0.45	0.12	1.23	0.45
	c. Other Plants	5%	0.12	1.23	0.45	0.12	1.23	0.45
2	Planting Season II							
	a. Rice	50%						
	- Nursery		37.50	461.25	165.00	0.43	5.34	1.91
	- Land processing		218.50	2687.55	961.40	2.53	31.11	11.13
	- Maintenance (Vegetative)		200.00	2460.00	880.00	2.31	28.47	10.19
	- Maintenance (Generative)		142.86	1757.14	628.57	1.65	20.34	7.28
	b. Secondary Crop	45%	0.78	9.61	3.44	0.78	9.61	3.44
	c. Other Plants	5%	0.09	1.07	0.38	0.09	1.07	0.38
3	Planting Season III							
	a. Rice	0%						
	- Nursery		0.00	0.00	0.00	0.00	0.00	0.00
	- Land processing		0.00	0.00	0.00	0.00	0.00	0.00
	- Maintenance (Vegetative)		0.00	0.00	0.00	0.00	0.00	0.00
	- Maintenance (Generative)		0.00	0.00	0.00	0.00	0.00	0.00
	b. Secondary Crop	75%	1.75	18.52	6.77	1.75	18.52	6.77
	c. Other Plants	5%	0.12	1.23	0.45	0.12	1.23	0.45

Table 9 presents the water application requirements for the SRI (System of Rice Intensification) method across three planting seasons, detailing both the water requirements in cubic meters per day and in liters per second for each block. For Planting Season I, where 90% of the area is planted with rice, the water required for the nursery phase is 90.91 m³/day (1.05 l/second) in Block I, 960.15 m³/day (11.11 l/second) in Block II, and 350.99 m³/day (4.06 l/seconds) in Block III. The total water required for land processing and maintenance varies significantly across the blocks. In Planting Season II, where 50% of the area is planted with rice, the water requirements decrease to 37.50 m³/day (0.43 l/second) in Block I, 461.25 m³/day (5.34 l/second) in Block II, and 165.00 m³/day (1.91 l/second) in Block III. The water requirement for Secondary Crop crops is also accounted for, though significantly less than rice. Planting Season III has 0% rice, and the water requirement focuses more on other plants, with 75% of the area planted with Secondary Crop. The irrigation needs for each phase are calculated for all blocks, showing the application of water in a highly specific, phase-based approach. The data was derived from primary data analysis in 2022.

Based on research by Mahender Kumar et al. (2019), the implementation of the SRI method in India reduced water requirements by approximately 29%. Furthermore, research by Abdullahi et al. (2023) in Nigeria showed that the water requirement for rice with SRI was between 1696–2635 mm per season, compared to 3733.4 mm in conventional systems, resulting in savings of approximately 30–60%. Furthermore, research Too et al. (2020) reported that irrigation requirements in the SRI scheme were 2316.7 m³/ha compared to 2966.7 m³/ha in conventional practices (a saving of ≈21.9%). Therefore, the results in Table 9, which show variations in water requirements between blocks and between growing seasons, are consistent with the finding that SRI allows for reductions in irrigation water volume and increased water use efficiency.

c. Calculation of water balance based on SRI method water application

Based on the calculation of the water balance of the SRI method and the calculation of the K factor value above, the average value of the K factor for alternative water application methods at the Lempake irrigation area study site is still in "very good" condition as well as during the growing season. This means that there is no need for rotation in the water application method.

Comparison of K factor values of SCH method and SRI method

Table 10 is a recapitulation table of the comparison of K factor values between the SCH (Stagnant Constant Head) method and the SRI (System Rice Intensification) method.

Table 10. Recapitulation of K factor value comparison between SCH and SRI methodsS

Month	Period	Q Mode (l/second)	SCH Method			SRI Method		
			Water Demand (l/second)	K Factor	Water Sharing Criteria (l/second)	Water Demand (l/second)	K Factor	Water Sharing Criteria (l/second)
Nov	I	493.7	135.05	3.66	Continuously	56.7	8.7	Continuously
	II	279.2	169.35	1.65	Continuously	84.6	3.3	Continuously
Dec	I	230.1	204.21	1.13	Continuously	113.2	2.0	Continuously
	II	311.1	177.64	1.75	Continuously	109.3	2.8	Continuously
Jan	I	304.9	151.07	2.02	Continuously	105.4	2.9	Continuously
	II	280.0	123.93	2.26	Continuously	101.0	2.8	Continuously
Feb	I	287.5	123.93	2.32	Continuously	101.0	2.8	Continuously
	II	140.8	123.93	1.14	Continuously	101.0	1.4	Continuously
Mar	I	518.5	141.34	3.67	Continuously	85.3	6.1	Continuously
	II	255.8	158.75	1.61	Continuously	69.6	3.7	Continuously
Apr	I	257.2	178.48	1.44	Continuously	58.6	4.4	Continuously
	II	230.1	157.46	1.46	Continuously	69.1	3.3	Continuously
May	I	271.6	136.43	1.99	Continuously	79.7	3.4	Continuously
	II	328.4	113.08	2.90	Continuously	85.6	3.8	Continuously
Jun	I	299.7	113.08	2.65	Continuously	85.6	3.5	Continuously
	II	176.1	113.08	1.56	Continuously	85.6	2.1	Continuously
Jul	I	45.2	127.83	0.35	Rotate in block II	57.7	0.78	Continuously
	II	64.3	142.58	0.45	Rotate in block III	29.7	2.2	Continuously
Aug	I	125.9	159.39	0.79	Continuously	10.8	2.2	Continuously
	II	126.3	140.53	0.90	Continuously	19.8	11.6	Continuously
Sep	I	121.1	121.67	1.00	Continuously	28.8	6.4	Continuously
	II	66.4	100.75	0.66	Rotate in block III	28.8	4.2	Continuously
Oct	I	35.9	100.75	0.36	Rotate in block II	28.8	2.3	Continuously
	II	28.8	100.75	0.29	Rotate in block II	28.8	1.2	Continuously
Year-round K Factor Value				1.58			3.62	

Based on the summary of K factor values in Table 10, the Stagnant Constant Head (SCH) method produced an average K value of 1.58, while the System of Rice Intensification (SRI) method produced an average K value of 3.62. Thus, the application of the SRI method showed a 228% increase in K value compared to the SCH method. This increase in K value indicates increased water use efficiency, meaning the SRI method is able to optimize water availability in rice fields. This condition also indicates a water surplus at the Lempake Dam intake that can be diverted to irrigate additional rice fields in potential areas. With more efficient water use, it is hoped that rice productivity can increase through expanded planting areas and improved water management.

This finding aligns with previous research. Dass and Dhar (2014) reported that the application of the SRI method can increase water use efficiency (WUE) by 68–94% compared to conventional cropping systems, because intermittent water management and better soil aeration enhance plant nutrient absorption. Another study by Arianta, Nurrochmad, and Sujono (2016) also showed that applying the SRI method to organic rice paddies in Indonesia can increase water productivity by up to 235% compared to conventional methods. These results reinforce the point that the SRI method is not only more efficient in water use but also has the potential to increase rice productivity and allow for more equitable water distribution to additional land around dams.

Then the comparison table of the K factor value of the SCH (Stagnant Constant Head) method and the SRI (System Rice Intensification) method against the total percentage of the Lempake irrigation system performance assessment is shown.

Table 11. Recapitulation of comparison of K factor values against irrigation system performance assessment

Methods	Sub Criteria	Final Weight %	Part Value %	Condition Index		Performance Assessment %
				Existing %	Maximum %	
SCH	K factor	14.22	60	158	15	65.92
SRI	K factor	28.44	60	316	15	80.14

Based on the recapitulation in Table 11, the adoption of the SRI method had a significant impact on the overall performance assessment of the irrigation system. The total performance index score increased from 65.92%, which falls into the category of "poor performance and needs attention," to 80.14% or "Very Good Performance." This increase was primarily driven by an increase in the weight of the sub-criteria value of Factor K by 100%, from 14.22% to 28.44%. This finding underscores that technical interventions at the farm level (*on-farm*), such as changes in water delivery methods, can be a major lever for improving irrigation system performance at the macro level. This conclusion is in line with various other studies that also demonstrate a direct relationship between farmer-level interventions and overall system performance. For example, research in Bangladesh has shown that farm-level water management approaches have successfully increased irrigation coverage and overall land productivity (Mondal et al., 1993), while another study in India found that on-farm water storage has significantly increased crop yields and the overall economic value of canal irrigation projects (Amarasinghe et al., 2012). These results thus confirm that the implementation of water efficiency practices such as SRI in the Lempake Irrigation Basin is an effective and proven strategy to significantly improve its performance status.

Carrier channel prioritization efforts

In the Lempake irrigation area, there are four types of carrier channels, divided into two village areas: the Belimau Primary Channel and Belimau Secondary Channel in the Belimau Village area, and the Muang Datu Primary Channel and Muang Datu Secondary Channel in the Muang Datu Village area. These channels are assessed directly by local farmer groups through questionnaires. The results of these questionnaires are then analyzed using the AHP (Analytical Hierarchy Process) method to determine which carrier channel buildings should be prioritized for rehabilitation. Based on this analysis, the ranking of the carrier channels for rehabilitation priority is as follows: the Belimau Primary Channel ranks first with a score of 0.377, followed by the Belimau Secondary Channel with 0.260, the Muang Datu Primary Channel with 0.198, and the Muang Datu Secondary Channel with 0.165. Additionally, when combining the respondents' opinions, the ranking of the criteria for the rehabilitation activities is as follows: the physical infrastructure condition is the most prioritized with a score of 0.497, followed by human resources at 0.260, and the operating system at 0.243. Furthermore, when using the ANP (Analytical Networking Process) method with the Super Decisions application, the prioritization of the alternatives is similar, with the Belimau Primary Channel (SPB) ranking first with a score of 0.376, followed by the Belimau Secondary Channel (SSB) with 0.260, the Muang Datu Primary Channel (SPMD) with 0.199, and the Muang Datu Secondary Channel (SSMD) with 0.166.

CONCLUSION

The weighted value of the irrigation network performance index at Lempake irrigation area is 65.92% which is included in the category of irrigation system performance assessment “less and need attention”. Therefore, efforts were made to increase the value of the irrigation system performance index at Lempake irrigation area related to crop productivity, namely by changing the method of giving water to plants and changing the cropping pattern plan. The results obtained by improving the method of giving water from the SCH method to SRI, namely the assessment of the K factor sub criteria has increased by 100 percent and increased the total irrigation system performance assessment from 65.92% to 80.14%. So that the assessment of the performance of the Lempake irrigation area irrigation system is in the "Very Good Performance" category, this explains that there is no need for rotation or rotation in the water delivery method. By using the AHP method, the ranking of criteria that are prioritized in the proposed rehabilitation activities starting from physical conditions, human resource management, operating systems. Then with the ANP method obtained the ranking of channels in the Lempake Irrigation Network that are prioritized in the proposed rehabilitation are Belimau Primary Channel, Belimau Secondary Channel, Muang Datu Primary Channel, Muang Datu Secondary Channel.

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