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THE RESILIENCE ANALYSIS OF PROVINCIAL IRRIGATION INFRASTRUCTURE IN REALIZING FOOD SECURITY IN WEST SUMATRA, INDONESIA

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ABSTRACT: At the end of 2022, Indonesia authorized the import of up to 500,000 tons of rice, a decision that was extended to 2023, with an additional 1.5 million tons. West Sumatra Province, with a vast irrigation area of 421,718 hectares, directly manages 15.41 percent of this area (65,000 hectares) under the provincial authority. While 60 percent of the irrigation infrastructure is in good condition, the remaining 40 percent is in moderate to severe despair. This paper presents the results of research evaluating the performance of irrigation systems in West Sumatra. The study identified key factors influencing the performance of the system quantitatively using e-PAKSI software and further conducted qualitative assessments through field observations and in-depth interviews with relevant stakeholders. These findings revealed a decline in the management of the irrigation network, indicating the need for improvement. The performance of West Sumatra's irrigation system was evaluated, with an average performance index of 66.48 percent, which was classified as poor and in need of attention. Key issues include low infrastructure performance, weak farmer association engagement, inadequate supporting facilities, low crop productivity, and suboptimal coordination among agencies and stakeholders. To address these challenges, the provincial government must take several actions: rehabilitate damaged irrigation structures, provide more facilities, enhance water control systems, optimize inter-agency coordination, and empower farmers through education and involvement. These interventions should be implemented holistically and in phases, starting with a pilot project to ensure sustainable irrigation management and to strengthen food security in West Sumatra.

Keywords: Food security, Improvement solution, Irrigation network, Performance assessment, Rehabilitation

1. INTRODUCTION

According to the Secretary of the Cabinet of the Republic of Indonesia [1], the Indonesian government received an award from the International Rice Research Institute (IRRI) for establishing a robust food security system and achieving rice self-sufficiency from 2019 to 2021. The Resilient Food and Rice Self-Sufficiency System Award was granted due to the successful use of innovative rice technology. However, toward the end of 2022, the government unexpectedly permitted the import of 500,000 tons of rice through the Public Logistics Agency. By the end of 2023, the option to import an additional 1.5 million tons of rice had also been introduced. On January 16, 2024, the head of the National Food Agency stated that this decision stemmed from a rice production shortfall at the end of 2023. Furthermore, in 2024, the government also planned to import another 3 million tons of rice [2].

Rice production is strongly influenced by the performance of irrigation infrastructure, which ensures that farmers receive irrigation promptly, at the right volume and precisely where it is needed for their crops [3].

West Sumatra is a province with an irrigation area covering 421,718 hectares and a total of 3,888 irrigation infrastructure units. This irrigation area includes 15.41 percent of the irrigation areas under the provincial authority, 61.68 percent under the district/city authority, and 22.91 percent under the central government authority [4]. The condition of the irrigation infrastructure under the provincial authority shows that only 5 percent of the irrigation structures are in good condition, with the remainder having light, moderate, or severe damage. For primary irrigation networks, only 8 percent are in good condition, with the remainder experiencing light, moderate, or severe damage. Among secondary irrigation networks, only 30 percent are in good condition, with the remaining structures in varying states of despair [5]. The conditions of tertiary irrigation networks and farm-level irrigation channels are even more concerning.

The Plantation, Food Crops, and Horticulture Offices of West Sumatra Province reported a decrease in rice production, attributed to some farmers switching crops, pest infestations, and irrigation issues [6]. The connection between food security and irrigation infrastructure is evident, as the deterioration of irrigation infrastructures resulting in the supply of

water failing to meet the precise amount and timing needs of crops has led to a decline in rice production, prompting the government to increase rice imports in recent years (see Table 1).

Table 1. Harvested area and rice production in West Sumatra

Year	Rice production (Tons)	Rice crop harvest area (Ha)	Productivity (Tons/Ha)
2022	1,373,532.19	271,883.11	5.05
2021	1,317,209.38	272,391.95	4.84
2020	1,387,269.29	295,665.47	4.69
2019	1,482,996.01	311,671.23	4.76
2018	1,483,076.76	313,050.82	4.74

Sources: BPS West Sumatera Province (2023)

Managing an irrigation system involves overseeing irrigation networks, which includes activities such as the operation, maintenance, and rehabilitation of these networks [7]. An integrated irrigation system consists of primary, secondary, and tertiary irrigation systems, which rely on a consistent supply of irrigation water, infrastructure quality, management practices, irrigation management institutions, and human resources. Effective management of this system directly impacts the harvested area [8]. If management is effective, ensuring that the required amount of water can be provided when farmers need it, then the harvested area will remain stable or even increase [9,10]. Conversely, if the water supply is insufficient, the harvested area will shrink, leading to a decline in rice production.

Irrigation system management is crucial in supporting agricultural productivity and national food security [11]. Field observations indicate that the irrigation infrastructure under provincial and district/city authorities can suffer from functional decline due to several factors: insufficient allocation of operation and maintenance funds; improper operation of the irrigation system; and inadequate water availability in the channels. As a result, the irrigation management program designed to support agricultural production and national food security following the implementation of the Minister of Public Works and Housing regulation number 12/PRT/M/2015 on Guidelines for the Exploitation and Maintenance of Irrigation Networks requires enhancement in its execution.

Irrigation management in West Sumatra is generally characterized by a poorly maintained system, especially within irrigation networks managed by provincial and district/city authorities. The contributing factors include a weak institutional framework for water-user farmer associations, inadequate agricultural extension services, a technology gap in farming practices, limited farmers' financing access, and various other issues [12,13]. This suboptimal irrigation system management has led to a decline in rice production, prompting the government to rely on rice imports to meet demand.

Based on data regarding the condition of the irrigation network system and the fluctuations in the harvested rice area in West Sumatra, it is essential to assess the readiness of all irrigation networks under provincial and district/city authorities. This assessment aims to prevent a continued decline in functionality and ensure that efforts to improve infrastructure and institutional aspects are not delayed. These measures are crucial for supporting food security, particularly in rice production. The performance of the irrigation system demonstrates that poor operation and maintenance shorten the service life of irrigation networks, leading to an annual deterioration [14-16]. Conversely, consistent and effective management ensures that the irrigation system meets its intended lifespan. Repairs or upgrades are required to restore the irrigation network's functionality when operation and maintenance are inadequate.

Considering the explanation above, the problems addressed in this article are as follows. a. Some irrigation infrastructures under provincial and district/city authorities are damaged and have exceeded their planned lifespan. This deterioration has led to insufficient irrigation water availability for rice crops, resulting in a yearly decline in production. b. The lack of water in irrigation networks has caused rice paddies to be switched to other crops, and in some cases, the land has been repurposed for other uses. c. The management of irrigation among stakeholders has not been optimal.

Katic et al. [17] emphasized the importance of sustainable irrigation practices in enhancing crop yields and food security, particularly in developing countries. They reported that adopting a water-efficient irrigation system significantly increases crop productivity, reducing the risk of food insecurity. Tirtalistyani et al. [18] highlighted the relationship between irrigation management and global food security, noting that inefficient irrigation systems contribute to lower agricultural outputs, directly affecting food availability. Sutcliffe [19] examined how farmer participation in irrigation management affects overall system performance and crop productivity.

The research gap addressed by this study is the limited understanding of how integrated, data-driven approaches can be used to assess and improve irrigation system performance. While previous studies have often focused on specific elements such as infrastructure, farmer involvement, or water distribution efficiency, this research offers a more holistic perspective. This study aims to provide a comprehensive understanding of the current performance of irrigation systems, identify the

dominant factors affecting that performance, and provide solutions and recommendations for improving system efficiency and the sustainability of irrigation areas. The primer data for this research were sourced from e-PAKSI software, which measures the performance indices of irrigation systems.

Following the introduction, the second section discusses the significance of this research in improving the management of irrigation areas to support food security. The third section, which focuses on the research methodology, outlines the research location, data collection, and analytic techniques. The fourth section presents the results and discussion, covering the performance index of irrigation systems, identifying existing problems, proposing solutions, and detailing necessary interventions. The final section provides a conclusion by summarizing the findings and addressing the research objectives.

2. RESEARCH SIGNIFICANCE

Previous research has focused primarily on the technical aspects of infrastructure without delving into the institutions that affect the implementation and management of irrigation. This article examines the relationships among the decline in irrigation infrastructure management, the involvement of managers, and the role of farmer water users as beneficiaries. This report compares irrigation system performance index results with insights gained from field interviews conducted with irrigation managers, agricultural extension workers, local officials, and farmers who use irrigation water to propose solutions for improving irrigation management and increasing production.

3. METHODS

3.1 Study Area

The irrigation area under the authority of West Sumatra Province consists of 65 irrigation units, covering a total area of 65,474 hectares, with a covering area per unit ranging from 1,000 to 3,000 hectares. The quantitative research was conducted across all 65 provincial irrigation areas, while qualitative research was conducted on 15 of those areas via purposive sampling. This sampling method represented various irrigation conditions, ranging from well-performing to poorly performing. It included various types of irrigation, ranging from technical to simple systems located across 11 districts/cities in West Sumatra's mountainous and coastal regions.

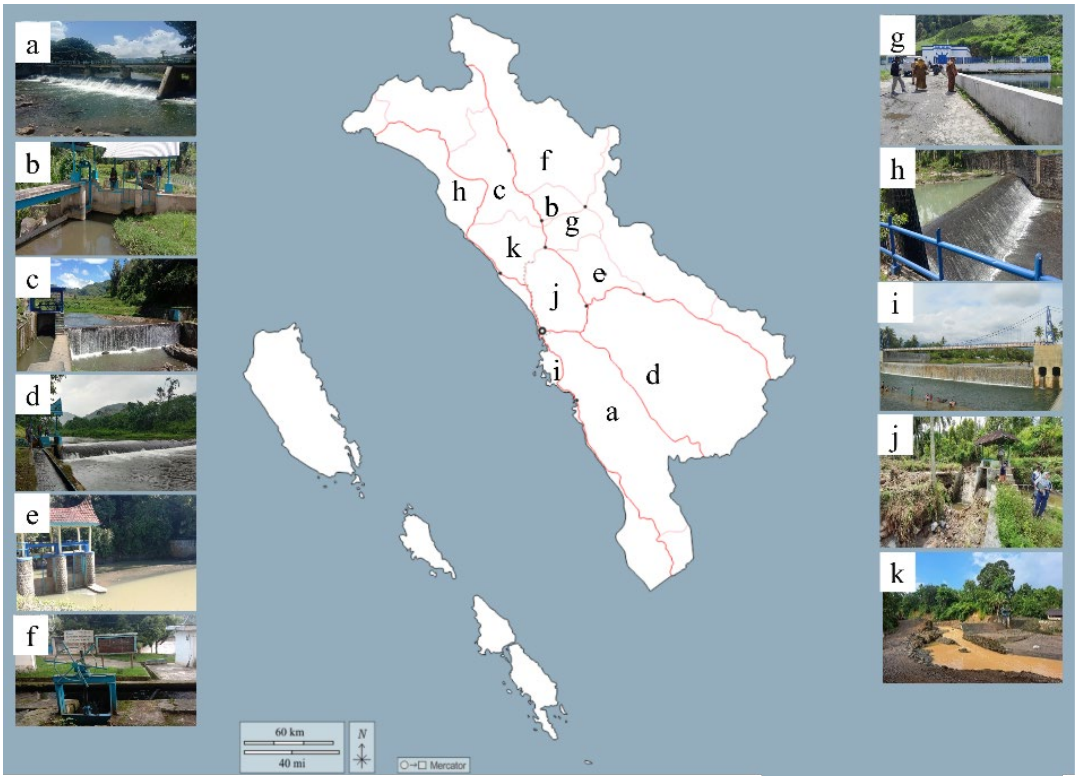

Fig. 1. Study area irrigation in West Sumatera Province, Indonesia: (a) Pesisir Selatan, (b) Bukit Tinggi, (c) Agam, (d) Solok Selatan, (e) Tanah Datar, (f) Lima Puluh Kota, (g) Padang Panjang, (h) Pasaman Barat, (i) Padang, (j) Solok, and (k) Padang Pariaman

3.2 Data Collection and Analysis

This research employed a mixed method approach, specifically an explanatory sequential design. According to Creswell (2018), this design further explains a set of quantitative data by incorporating additional qualitative information. It helps determine which quantitative results require further explanation and contextualization [20]. This approach was initiated with quantitative data processing utilizing data based on the Minister of Public Works and Housing regulation number 12/PRT/M/2015 and the e-PAKSI application.

The quantitative research primarily utilized indicators such as physical infrastructure performance, crop productivity, support facilities, personnel organization, documentation, and farmer institutions. Therefore, there is a possibility that some indicators not initially captured could be obtained through the qualitative approach, such as institutional performance indicators, stakeholder involvement, and the roles of relevant government or agencies.

The obtained findings were subsequently deepened and expanded through interviews and field observations to confirm the results of the previous quantitative analysis and potentially lead to the discovery of novel findings. The assessment of irrigation system performance was regulated under the Ministry of Public Works and Housing Regulation and utilizes the e-PAKSI application, which included the following components and their maximum values:

a. Physical infrastructure, with a maximum value of 45 percent.
b. Crop productivity, with a maximum value of 15 percent.
c. Supporting facilities, with a maximum value of 10 percent.
d. Personnel organization, with a maximum value of 15 percent.
e. Documentation, with a maximum value of 5 percent.
f. Institutional conditions of Farmer Water User Associations (P3A), with a maximum value of 10 percent.

The assessment of the irrigation system performance index was calculated as the sum of the values of each component mentioned above, categorized as follows:

a. 80 percent – 100 percent: Very good performance
b. 70 percent – 79 percent: Good performance
c. 55 percent - 69 percent: Poor performance and requires attention
d. <55 percent: Very poor performance and requires immediate attention

To prioritize steps for addressing issues in this research, the Hanlon method (qualitative) was used. The criteria used in the Hanlon method are urgency (U), seriousness (S), and growth (G), with the following steps:

a. Creation of a problem-handling matrix.
b. Listing of all problem treatments along the vertical and horizontal axes.
c. Comparison and matching of the existing problem handling, and scoring them accordingly as follows: (1) if the problem in the left column is more important than the one at the top, then a (+) sign is placed in the corresponding box, and if it is less important, then a (-) sign is placed; (2) work only to the right of the diagonal line; (3) sum the (+) marks horizontally and record them in the Total (+) horizontal box; (4) sum the (-) marks vertically and record them in the vertical Total (-) box; (5) sum the vertical and horizontal results and record them in the Total box; (6) the sum in the total column with the highest value indicates the priority order of the problems.

Table 2. Problem handling matrix of the Hanlon qualitative method

Problem	a	b	c	d	Horizontal
a					
b					
c					
d					
Total Vertical					
Total Horizontal					

Table 3. Scoring matrix of the qualitative Hanlon method

Problem	U	S	G	Total	Priority
a					
b					
c					
d					

4. RESULTS AND DISCUSSION

Quantitative data processing of the 65 irrigation areas using the e-PAKSI software yielded the following average performance results: physical infrastructure performance of 27.57 percent, planting productivity performance of 11.30 percent, supporting facilities performance of 6.59 percent, personnel organization performance of 11.34 percent, documentation performance of 4.04 percent, and water user farmers association's performance of 5.64 percent. When summed, these figures yielded a total

average performance index of 66.48 percent for the irrigation system, thus categorizing it as poor performance that requires attention. The assessment results for each irrigation areas' performance conditions are illustrated in Figure 2.

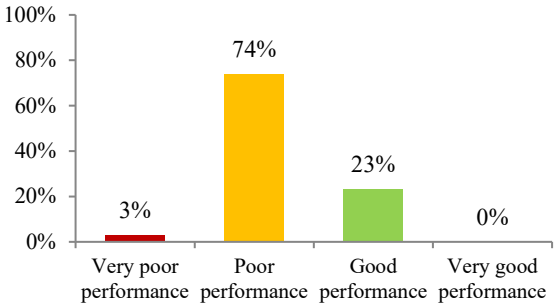

Fig. 2. Assessment of the performance condition of the irrigation system under the provincial authority

As shown in Figure 2, the assessment of those 65 irrigation areas revealed that 15 irrigation areas exhibited good performance, indicating that the management and maintenance of irrigation infrastructure in these districts is quite effective. In contrast, 48 areas demonstrated poor performance requiring attention, and two irrigation areas showed very poor performance necessitating immediate intervention. An assessment of the performance of irrigation districts shows that most districts experience significant problems that require further attention.

The dominant factors contributing to the low performance of the irrigation system were identified and were influenced by the performance of the various components, as illustrated in Figure 3, and the performance recapitulation of the irrigation system components, as illustrated in Figure 4.

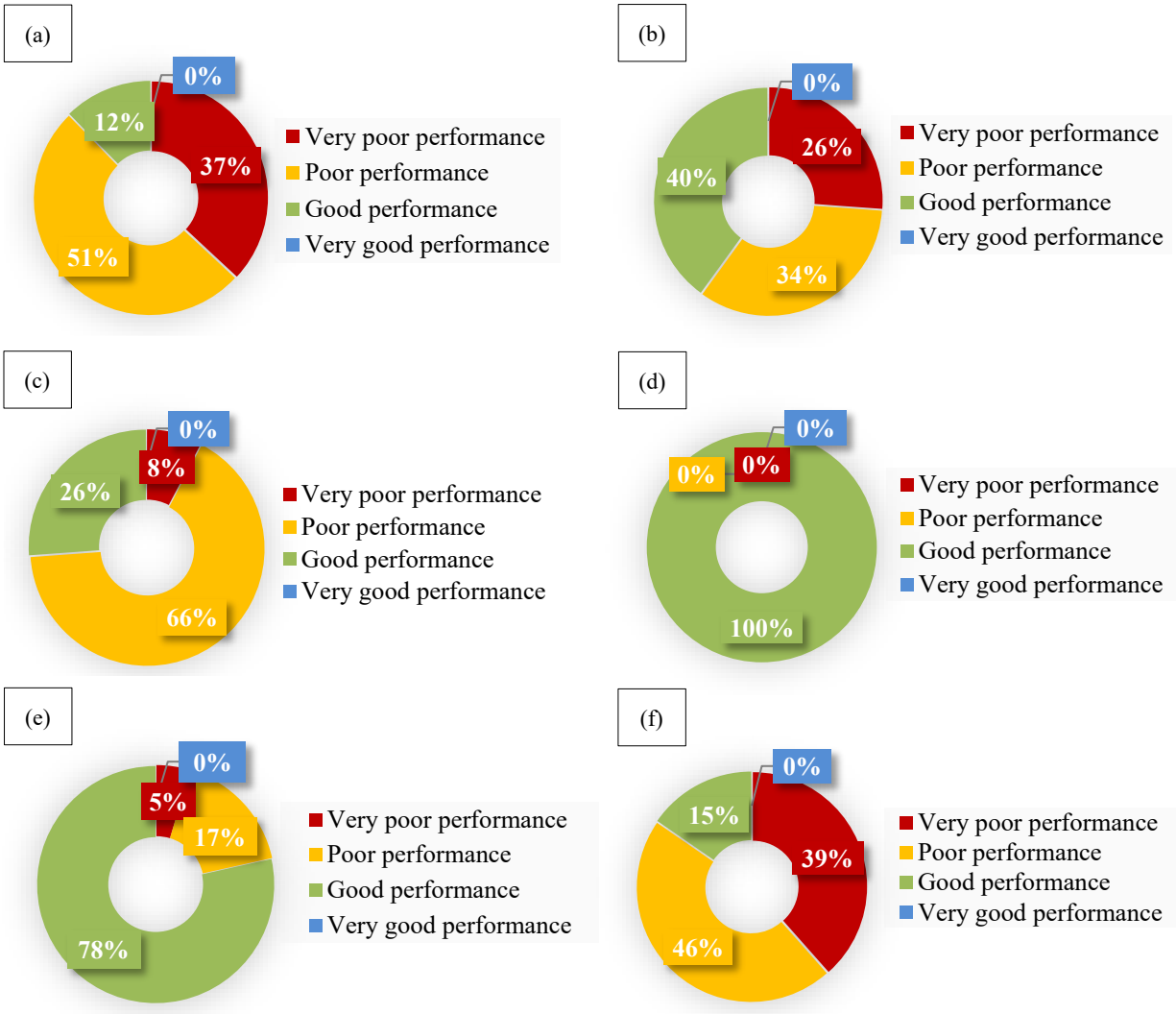

Fig. 3. The performance conditions of provincial irrigation system components: (a) physical infrastructure, (b) cropping productivity, (c) supporting facilities, (d) personnel, (e) documentation and, (f) water user farmers association

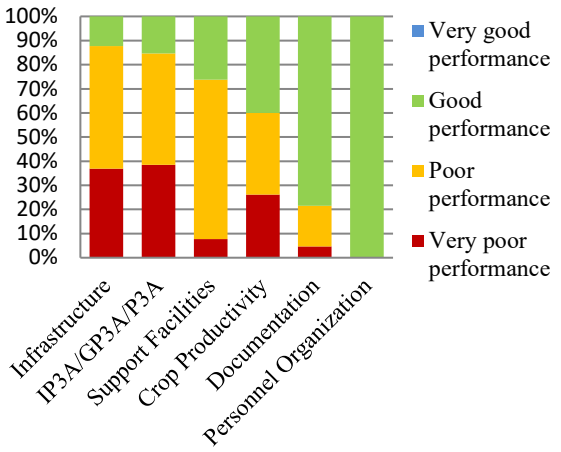

Fig. 4. Performance recapitulation of the irrigation system components

The findings from the performance analysis of the irrigation system were subsequently classified on the basis of their performance levels. Components exhibiting suboptimal performance, specifically those exceeding 60 percent, were identified as a group of performance components exerting a significant influence on the overall performance of provincial irrigation systems.

On the basis of the findings from the quantitative data analysis using the guidelines from the Minister of Public Works and Housing Regulation, further qualitative checks and triangulations were conducted. This process involved deeper exploration and identification of underlying causes through field observations and interviews in sample irrigation areas categorized as good, poor, and very poor performance. The study focused on 15 irrigation areas, each covering 1,000 to 3,000 hectares, and included cross district/city irrigation areas under the provincial authority.

The qualitative research conducted through interviews and field observations revealed that in these provincial irrigation areas, personnel and documentation performance were not significant issues, which was consistent with the findings of the quantitative analysis and thus should be given lower priority. However, the qualitative research also revealed new findings, particularly regarding a lack of coordination and integration among stakeholders in managing these irrigation areas. In-depth interviews further highlighted that these coordination problems were compounded, ultimately contributing to the low performance of the crop productivity component.

Based on the quantitative analysis results and the qualitative data from key informants, several issues and corresponding solutions were identified to improve the performance of the provincial irrigation system:

a. Repair of irrigation canals and irrigation structures;
b. Installation of measurements and water control structures;
c. Procurement and enhancement of supporting facilities;
d. Increased empowerment and counseling for farmers;
e. Optimization of programs and activity integration among agencies and stakeholders.

The solutions proposed in this study address various aspects contributing to the performance challenges of the provincial irrigation system. Given the limited resources available, to effectively phase and implement improvements, these solutions need to be prioritized. The Hanlon method was applied to rank the solutions in order of importance (as shown in Tables 4, 5, 6, and 7).

The ranking process was conducted by a team of experts on the basis of observations and in-depth interviews with key informants. Solutions with higher scores were those most frequently mentioned by most informants, whereas lower scores were given to solutions selected by fewer informants.

Table 4. Urgency Category

Problem Solution	a	b	c	d	e	Horizontal
a		-	+	+	+	3
b			+	+	+	3
c				+	-	1
d					-	0
e						0
Vertical Total	0	1	0	0	2	
Horizontal Total	3	3	1	0	0	
Total	3	4	1	0	2	

Table 5. Seriousness Category

Problem Solution	a	b	c	d	e	Horizontal
a		+	+	+	+	4
b			-	+	+	2
c				+	+	2
d					-	0
e						0
Vertical Total	0	0	1	0	1	
Horizontal Total	4	2	2	0	0	
Total	4	2	3	0	1	

Table 6. Growth Category

Problem Solution	a	b	c	d	e	Horizontal
a		+	+	+	+	4
b			-	-	-	0
c				+	+	2
d					-	0
e						0
Vertical Total	0	0	1	1	2	
Horizontal Total	4	0	2	0	0	
Total	4	0	3	1	2	

The results of the assessments were then summed to determine the priority ranking, as shown in Table 7.

Table 7. Matrix of the Scoring Results of the Hanlon Method

Number	Solution	Urgency	Seriousness	Growth	Scoring	Ranking
a	Repair of irrigation canals and irrigation structures	3	4	4	11	I
b	Installation of measurements and water control structures	4	2	0	6	III
c	Procurement and enhancement of supporting facilities	1	3	3	7	II
d	Increased empowerment and counseling for farmers	0	0	1	1	V
e	Optimization of programs and activity integration among agencies and stakeholders	2	1	2	5	IV

Based on the calculation results shown in Table 7, the priority actions that need to be taken by the West Sumatra Provincial Government to improve the performance of the provincial irrigation system are as follows. The first priority is to repair damaged irrigation canals and structures across primary, secondary, and tertiary irrigation networks. The second priority is to provide and increase equipment and supplies for irrigation operations and maintenance, such as lawnmowers, handyman tools, and pick-up vehicles, to optimize irrigation asset management. The third priority is to construct and install flow meters and water regulators to measure and regulate the water distribution more effectively, efficiently, and equitably.

The next priority is to improve the synergy and integration of programs and activities among stakeholders to ensure that limited budgets and resources yield optimal results. The last priority is to increase farmer empowerment and provide more counseling to increase farmer competence and active participation in irrigation management. This initiative is also expected to encourage the growth and involvement of younger farmers. Efforts to improve irrigation system performance must be executed holistically, thematically, integratively, and spatially by all stakeholders, ensuring comprehensive handling and maximizing the benefits. Studies by Gohar et al. [21] and Balana et al. [22] highlight that the modernization of irrigation canals and the use of smart irrigation techniques lead to both increased crop productivity and water use efficiency. Similarly, findings by Adji et al. [23] and Ma'Mun et al. [24] indicate that coordinated efforts between government agencies and private entities result in more effective irrigation systems and improved food security, especially in water-scarce regions.

After implementation of the abovementioned prioritized steps, it is expected that the sustainability of irrigation areas and the fulfillment of irrigation water needs will improve, contributing to an expansion of planting areas, an increase in planting seasons, and enhanced agricultural production. This improvement will help bolster food security in West Sumatra. In the long term, the provincial government must initiate the modernization of the irrigation systems in the region. To support the priority steps mentioned above, it is essential to allocate a sufficient budget for the operation, maintenance, and rehabilitation of existing irrigation networks, as well as for the improvement and construction of infrastructure and new irrigation networks. The budgetary allocations from the previous government should be increased to ensure the continued performance and enhancement of the current irrigation system. The government's commitment to maintaining and improving the irrigation system and empowering the Water Users Farmers Association should be clearly outlined in the regional medium-term development plan and the strategic plan of the regional apparatus organization and integrated into the annual budget preparation process for all stakeholders. Based on the above discussion, an intervention plan has been developed, as shown in Table 8, along with an action plan for improving the performance of irrigation systems in West Sumatra Province, as shown in Figure 5.

Table 8. Interventions to improve the performance of irrigation systems under provincial authority

Component	Intervention	Program and Activity	Institution
Infrastructure	Repair of primary and secondary irrigation canals and structures.	Operation, Maintenance and Rehabilitation of Irrigation Networks	Department of Water Resources and Construction Development
	Manufacture of discharge meter and water control structures.	Irrigation Network Improvement	Department of Water Resources and Construction Development
	Improvement of tertiary irrigation canals and buildings.	Rehabilitation of Tertiary Irrigation Networks Mutual cooperation	Department of Plantations, Food Crops and Horticulture Water User Farmers Association
Supporting Facilities	Procurement of lawnmowers, handyman tools, and pick-up cars.	Procurement of lawnmowers, handyman tools, pedicabs/motorized pick-up cars	Department of Water Resources and Construction Development
	Procurement of agricultural tools and machinery.	Procurement of pre and postharvest agricultural tools and machinery	Department of Plantations, Food Crops and Horticulture
Institutions	Integration of programs and activities between agencies and *stakeholders.*	Coordination and synchronization of institutional capacity building for irrigation management under provincial authority (Irrigation Commission)	Regional Development Planning Agency, Department of Water Resources and Construction Development, and Department of Plantations, Food Crops and Horticulture
P3A/GP3A/IP3A/Water Users Farmers Association	Empowerment and counseling for farmers.	Development and empowerment of the Water User Farmers Association (P3A/GP3A)	Department of Plantations, Food Crops and Horticulture
		Institutional Development and Empowerment of Provincial Authority Irrigation Management.	Department of Water Resources and Construction Development

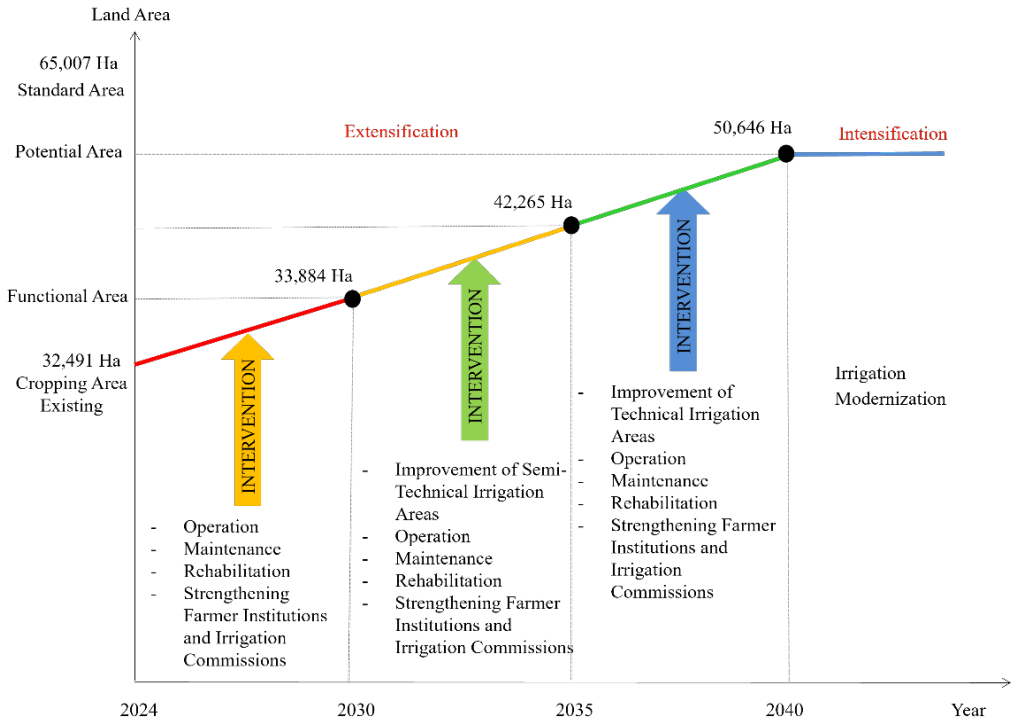

Fig. 5. Provincial Irrigation Area Management Intervention Action Plan

5. CONCLUSIONS

Based on the research results, it was concluded that the performance of the irrigation system in West Sumatra Province had an average performance index of 66.48 percent, placing it in the poor category and requiring attention. Various problems were identified, and the analysis of system performance revealed the dominant factors behind suboptimal management in more than 60 percent of the irrigation areas. These factors include low infrastructure performance, poor performance of water-user farmer associations, inadequate supporting facilities, low crop productivity, and insufficient coordination between agencies and stakeholders involved in irrigation management.

To improve the performance of irrigation systems to a satisfactory level, the provincial government requires several interventions, including the rehabilitation of irrigation channels and structures, provision of necessary facilities such as flow measurement and water control structures, optimization of program coordination among agencies and stakeholders, and increases in farmer engagement through more intensive empowerment and extension programs. This intervention must be implemented holistically and in phases, starting with a pilot project to ensure optimal results. This approach will help maximize the benefits of irrigation management, ultimately supporting the sustainability of irrigation areas and strengthening the food security in West Sumatra.

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