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Analysis of Irrigation Modernization Readiness Using FAHP Method

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ABSTRACT

Irrigation modernization is a solution proposed to achieve an effective, efficient, and sustainable participatory irrigation management system. The purpose of this study was to measure the value of irrigation modernization readiness (IKMI) and determine the priority order of the Batang Anai Irrigation Area (IA). The IKMI method used 5 criteria for irrigation modernization (reliability of water supply, water and irrigation resource facilities and infrastructure, management of water and irrigation resources systems, water and irrigation resource management institutions, and human resources) and determines the priority order for modernization preparation using the Fuzzy Analytical Hierarchy Process method. Direct observation activities were carried out for the pillars of irrigation infrastructure and water availability, while interviews and questionnaires were used to assess management systems, management institutions, and human resources. The IKMI value 67.50 for the Batang Anai IA implies modernization is postponed, and irrigation system improvements can be carried out for 1-2 years. The priority order for irrigation modernization is water availability, management institutions, irrigation management, irrigation infrastructure, and human resources. Recommended actions for modernization readiness include checking the water supply system, normalizing irrigation channels, repairing damaged irrigation infrastructure, increasing farmer participation through socialization and training activities, and building synergy between irrigation managers.

1. INTRODUCTION

Irrigation performance is one of the criteria that describes the management of irrigation systems. Irrigation plays an important role in supporting agricultural production and national food security. Irrigation services in Indonesia still have many shortcomings, some of which are irrigation management that has been carried out so far is considered ineffective, inefficient, and unsustainable (Saadah *et al*., 2012).

Irrigation infrastructure in Indonesia faces serious challenges, with a service life reaching 49%, while the irrigation area as a whole is 50 years old (Putri *et al*., 2022). Meanwhile, irrigation conditions with increasingly limited water resources have the potential to cause conflict among water users (Saadah *et al*., 2012). Amid increasing population growth, increasing water needs, and limited water resources due to sedimentation and critical watersheds, there is competition between sectors, including the irrigation sector. This competition has reduced the water supply for the irrigation sector, which is very important to meet increasing food needs along with population growth. Therefore, concrete actions are needed to overcome these obstacles, through operation, maintenance, rehabilitation, and most importantly, comprehensive renewal, including managerial, institutional, technical, and human resource aspects (PUPR, 2015).

In the last few decades before entering the 21st century, many countries in the world have faced critical problems such as lack of food production, lack of energy availability, and weak management of water resources (Arif et al., 2019). Irrigation modernization is the solution proposed to achieve an effective, efficient, and sustainable participatory irrigation management system. The concept of modernization does not only focus on the physical aspects of infrastructure, but also emphasizes improvements in the institutional aspects of management and development of human resources (Nugroho & Arif, 2019). In this context, irrigation modernization is interpreted as a continued projection of irrigation water resource management with the aim of increasing resource utilization and providing better services to farmers.

Modernization of irrigation areas is a dynamic concept. The Ministry of Water Resources clearly emphasizes the characteristics of modern irrigation areas in terms of water saving and efficiency, perfect facilities, management, and good ecology (Zhang *et al*., 2022). The implementation of irrigation modernization requires comprehensive renewal that includes managerial, institutional, technical, and human resource aspects of irrigation management. The main focus is to meet water needs, ensure more optimal, efficient, effective, and sustainable irrigation system management.

The method used to assess the readiness of irrigation modernization is to calculate the IKMI value based on the five pillars of irrigation modernization (Direktorat Irigasi dan Rawa, 2011). Meanwhile, to determine the priority order of the modernization pillars using the FAHP method. Various methods are widely used to evaluate the current situation of irrigation areas, such as analytical hierarchy process, entropy method, fuzzy comprehensive evaluation method, and gray correlation method, these methods are easily affected by subjective judgment (Prasad et al., 2021). Research by Zhang *et al*. (2022) combines the analytical hierarchy process with the fuzzy comprehensive evaluation method to reduce the interference of subjective factors and increase the scientific and accuracy of research results in assessing the readiness of the modernization of the Lailong irrigation area. In their research, Sari *et al*. (2019) also used FAHP to obtain the priority scale order for the implementation of the pillars of irrigation modernization in East Java Province.

One of the irrigations in Padang Pariaman Regency, namely the Batang Anai Irrigation Area (IA), needs comprehensive irrigation management. In order to support food security by improving irrigation services effectively, efficiently and sustainably, it is necessary to increase the reliability of water availability, improve irrigation infrastructure, irrigation and human resources. Batang Anai IA in Padang Pariaman Regency has significant potential to support agriculture. The command area of rice fields in the Batang Anai IS covers 13,604 ha, with details of Batang Anai I of 6,764 ha and Batang Anai II of 6,840 ha. Modernization of irrigation areas is an important guarantee of national food security, so an assessment of the readiness of modernization of Batang Anai IA needs to be carried out. The purpose of this study was to measure the level of readiness of Batang Anai IA for irrigation modernization and to determine the modernization priority scale of the pillars of the Batang Anai IA.

2. MATERIALS AND METHODS

2.1. Development of Hierarchical Structure

The developed hierarchical structure includes criteria and sub-criteria to assess the readiness of irrigation modernization. The criteria consist of 5 pillars, namely water availability, irrigation infrastructure, irrigation management, irrigation institutions, and human resources. The hierarchical structure as in Figure 1 is a guide in the assessment and data collection.

2.2. Data Collection

Primary data collection was carried out through field observations and questionnaires. Determination of IKMI values using 5 criteria, with assessment references in accordance with research (Sari, 2019) Determination of the priority order of criteria in modernization preparation using a paired comparison matrix questionnaire. The questionnaire was given to a group of respondents called experts, namely officials from related agencies (the PU Water Resources Service of West Sumatra Province), water-using farmers, and officers of the Batang Anai IA. Secondary data was obtained from relevant sources such as irrigation-related documentation, related rules, regulations, and previous studies.

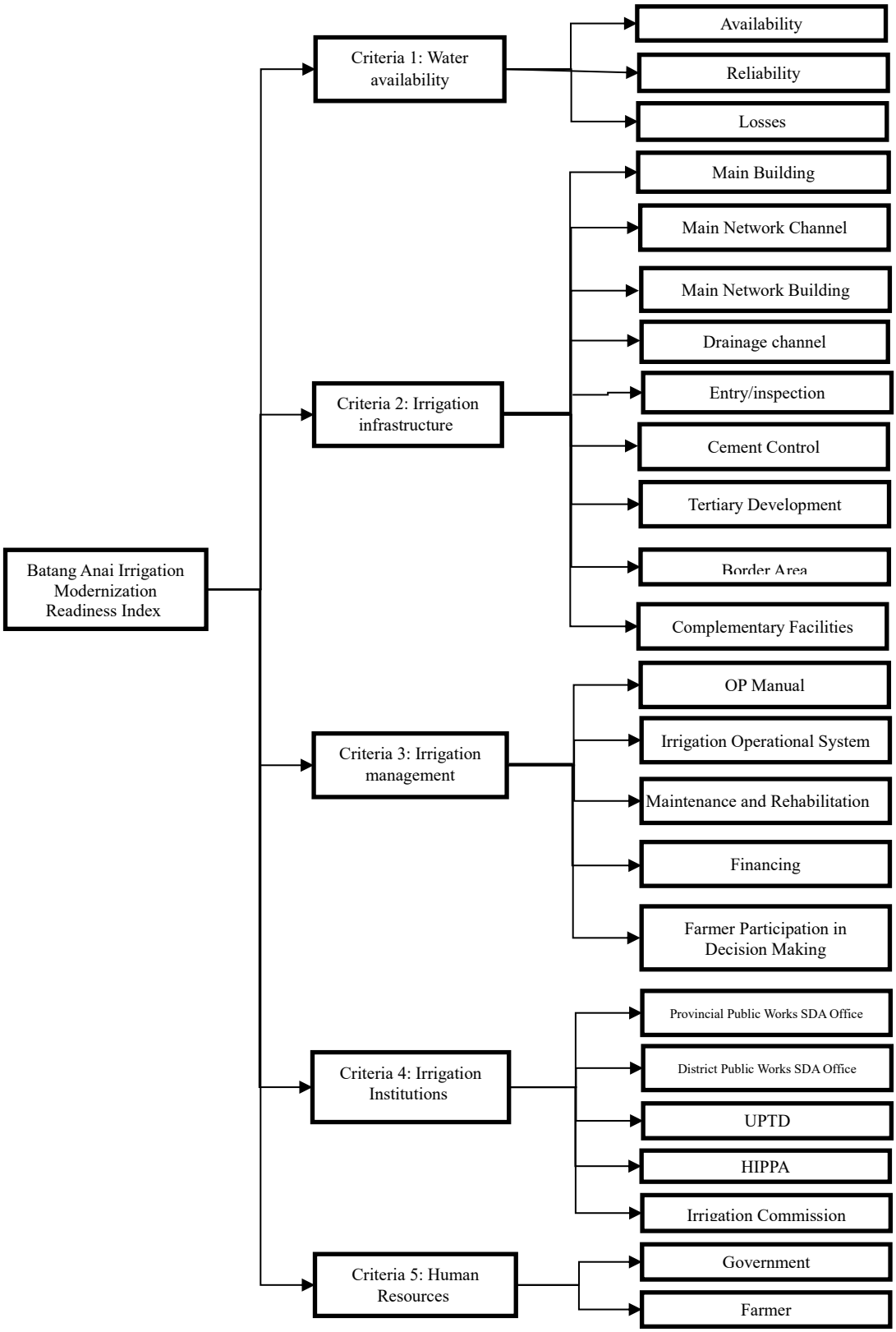

Figure 1. Hierarchical model for determining IKMI in the Batang Anai IA

2.3. Assessment of Readiness of Irrigation Modernization

Determination of the category of readiness of irrigation areas in the implementation of modernization is seen from the IKMI (Irrigation Modernization Readiness Index) value, with the following equation:

$$IKMI\ value = \sum(\text{criteria weight} \times \text{criteria value}) \quad (1)$$

Each criterion (modernization pillar) has a different proportion. The proportions for the pillars of water availability, irrigation infrastructure, irrigation management, irrigation institutions, and human resources are 20%, 25%, 15%, 20%, and 20% (Direktorat Irigasi dan Rawa, 2011). The weight for each sub-criterion also has a different proportion. The results of the IKMI value in an Irrigation Area can be categorized into 4 parts:

1. Value > 80 adequate predicate: modernization can be applied immediately
2. Value 50-80 sufficient predicate: modernization is postponed, irrigation system improvements are made for 1-2 years
3. Value < 50 less predicate: modernization is postponed, irrigation system improvements are made for 2-4 years
4. Value < 30 very less predicate: modernization cannot be carried out in the area, or improvements are made as a whole.

2.4. Fuzzy Analytic Hierarchy Process (FAHP) Analysis

FAHP will be used to calculate the weight of the level of importance of the criteria. With the following stages: compiling a fuzzy scale matrix), data consistency testing, and calculating the weight of the level of importance of the criteria. Implementation of pairwise comparison weighting in a comparison matrix represented by three variables called Triangular Fuzzy Number (TFN). The TFN is symbolized by (l, m, u) where $l \leq m \leq u$ and l is the lower or lowest value, m is the medium or middle value, and u is the upper or highest value.

2.5. Formulation of Recommendations

Based on the results of the analysis, recommendations for action are formulated based on the IKMI value and the priority order of the criteria that need to be prepared based on the weight value of the level of importance.

3. RESULTS AND DISCUSSION

The Batang Anai irrigation area is one of the mainstay irrigation areas in West Sumatra Province and is one of the technical irrigation areas under the authority of the central government with a service area of 13,604 hectares divided into two observation areas, namely Anai I (6764 ha) and Anai II (6840 ha). The assessment of the modernization readiness of the Batang Anai IA was carried out on the BLBA1-BLLBA5 and B1-BM5 irrigation channels with a service area of 1183.8 ha. The irrigation network scheme of the study location is presented in Figure 2.

3.1. Modernization Readiness of the Batang Anai IA

3.1.1. Water Availability Pillar

One of the pillars in assessing the readiness of irrigation modernization is water availability with assessment indicators including water availability, reliability, and loss. The availability of irrigation water describes the potential of surface water that can be used as a source of irrigation. The availability of irrigation water represents the irrigation discharge available per unit area of agricultural land (expressed in unit of $L.s^{-1}.ha^{-1}$) (Heryani *et al*., 2020). Meanwhile, the reliability of irrigation water is the condition/state of irrigation water that can be available in quantity, time, place, and quality according to plant needs to support maximum business productivity. Irrigation water loss is the amount of water lost in the irrigation process.

The efficiency of the BLBA1-BLLBA5, and B1-BM5 irrigation channels is 60.82% or water loss in the channels is 39.18%. The efficiency of irrigation channels under normal conditions must meet the minimum standards for primary channels of 90%, secondary channels of 90%, and tertiary channels of 80% (Wirosoedarmo *et al*., 2016; Direktorat

Jenderal Pengairan, 1986). The efficiency of the secondary irrigation channels of the Batang Anai IA, sections BLBA1-

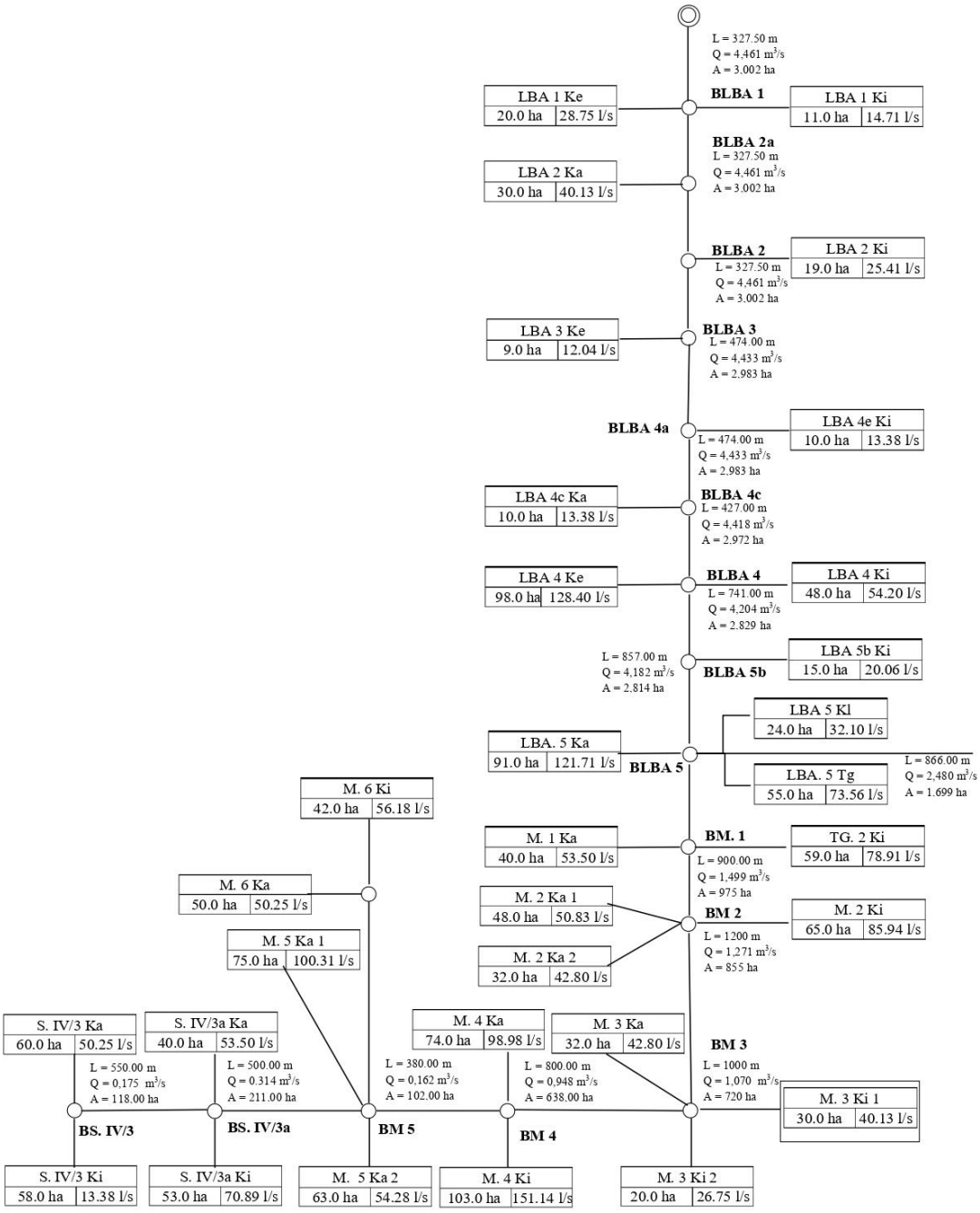

Figure 2. Batang Anai Irrigation Network Scheme (Secondary Channels BLBA1-BLLBA5 and B1-BM6)

BLLBA5, and B1-BM5 are below standard. This lack of efficiency is due to the large amount of sedimentation in the channels and many irrigation channels pass through residential areas. Although the efficiency of the channels is below standard, the discharge is available to meet the needs of the planting season 2 (two) times a year. In Table 1, it can be

seen that the value for the water availability pillar of the Batang Anai IA is 60, which is classified as the sufficient category.

Table 1. Water Availability Assessment in Batang Anai Irrigation Area (D.I. Batang Anai)

Indicator	Sub-Criteria Weight	Assessment	Score
Water Availability	50%	60.00	30.00
Reliability	30%	60.00	18.00
Losses	20%	60.00	12.00
Total			**60.00**

The reliability of irrigation water supply can be improved by optimizing water allocation, as in the research conducted in the Belitang IS (Imron *et al*., 2022). Optimization of irrigation water allocation begins with an analysis of the factors that influence the provision of irrigation water including water availability, water needs, water balance and planning of planting patterns for both types of plants and planting schedules (Sayekti, 2010).

3.1.2. Irrigation Infrastructure Pillar

Infrastructure is one of the pillars of irrigation that has the highest proportion compared to other pillars in terms of assessing the irrigation modernization readiness index. Irrigation infrastructure is an important factor that can affect water availability if the institutions and human resources of O&P do not show good performance. Technically, the irrigation structures of the BLBA1-BLLBA5 and B1-BM6 sections are still functioning well with irrigation channel damage <10%. The score for irrigation infrastructure pillar of the Batang Anai IA is 68 (Table 2).

Table 2. Irrigation infrastructure assessment in Batang Anai Irrigation Area (D.I. Batang Anai)

Indicator	Sub-Criteria Weight	Assessment	Score
Main Network Structures	10%	80.00	8.00
Main Network Channels	10%	80.00	8.00
Main Network Buildings	20%	60.00	12.00
Drainage Channels	10%	60.00	6.00
Access/Inspection Roads	10%	80.00	8.00
Sediment Control	10%	60.00	6.00
Tertiary Development	10%	60.00	6.00
Border Area	10%	80.00	8.00
Supporting Facilities	10%	60.00	6.00
Total			**68.00**

Based on PUPR (2015), the condition of the channels and buildings is good if the level of damage is <10% of the initial condition of the building and channel, then routine maintenance is required. In the irrigation maintenance and operation module, routine maintenance can be maintenance and minor repairs. This minor damage affects irrigation efficiency. Several maintenance actions that need to be carried out on the BLBA1-BLLBA5 and B1-BM6 irrigation channels are cleaning the channels and buildings from wild plants and bushes, cleaning the channels and buildings from garbage and dirt, and removing mud deposits in the measuring structure.

3.1.3. Irrigation Management Pillar

Irrigation management is an activity that includes the operation, maintenance, and rehabilitation of irrigation networks in irrigation areas. Irrigation management also includes the disposal of irrigation water and efforts to maintain and secure the irrigation network so that it can always function properly. The results of the irrigation management system assessment at the Batang Anai IA (Table 4) are 72. Farmer participation in decision-making in the Batang Anai IA has the lowest value compared to other indicators. This is because farmers often feel unclear about their involvement in making decisions. Farmers feel more involved in the operation and maintenance of irrigation networks.

The results of the study (Ristiyana et al., 2020), the Batang Anai IA management system is in quadrant III (Opportunities - Weaknesses), where the Batang Anai Irrigation Area management system has been able to take advantage of existing opportunities, but internal weaknesses have led to the introduction of potential internal strengths that are actually good, but have not been activated in all management elements related to irrigation.

Table 4. Irrigation Management System Assessment in Batang Anai Irrigation Area (D.I. Batang Anai)

Indicator	Sub-Criteria Weight	Assessment	Score
Operational & Maintenance Manual	20%	80	16.00
Irrigation Operational System	30%	60	18.00
Maintenance and Rehabilitation	30%	80	24.00
Financing	10%	80	8.00
Farmers' Participation in Decision-Making	10%	60	6.00
Total			**72.00**

3.1.4. Irrigation Institution Pillar

Irrigation institutions are important because they play a role in the management and development of irrigation networks in a sustainable manner. Good irrigation institutions can help increase agricultural productivity, community welfare, and national food security. The score of the assessment of the irrigation management system in the Batang Anai IA (Table 5) is 68. Institutional performance is influenced by the condition of personnel organization, maintenance procedures and operation of irrigation networks, management success and farmer satisfaction. In the Batang Anai IA, the Provincial PU SDA Service, the Regency PU SDA Service, and UPTD have played a role in managing landfill, but need to synergize to be able to implement modernization. HIPPA has been formed, but not all personnel are active, socialization and training need to be carried out to improve farmers' abilities in irrigation management.

Table 5. Irrigation institutional system assessment in the Batang Anai IA

Indicator	Sub-Criteria Weight	Assessment	Score
Provincial Public Works SDA Office	40%	80.00	32.00
District Public Works SDA Office	25%	60.00	15.00
UPTD	15%	60.00	9.00
HIPPA	10%	60.00	6.00
Irrigation Commission	10%	60.00	6.00
Total			**68.00**

3.1.5. Human Resource Pillars

The most important factor in driving and realizing irrigation modernization is human resources, because the availability of irrigation facilities and infrastructure without being supported by human resources will greatly affect the success of this irrigation modernization. It is undeniable that the role of humans is the most important factor because humans will always be the main role. All pillars of irrigation modernization are directly related to the role of humans (Ernawati *et al*., 2023). The score for the human resource indicators of the Batang Anai IA is 70 (Table 6). The assessment of the government as a human resource in the Batang Anai IA includes the number and quality of OM (operating and maintenance) officers. The number of officers is sufficient and understands the OM. Meanwhile, for farmer resources, there is still a low sense of responsibility, appreciation of irrigation, and real response in

Table 6. Human resource assessment in the Batang Anai IA

Indicator	Sub-Criteria Weight	Assessment	Score
Government	50%	80.00	40.00
Farmers	50%	60.00	30.00
Total			**70.00**

participation. Farmer contributions can be increased through socialization activities and involving farmers in irrigation management activities.

The assessment of irrigation modernization readiness in the Batang Anai Irrigation Area is based on direct field observations of the pillars of water availability and irrigation infrastructure. Meanwhile, the assessment of the pillars of management systems, management institutions, and human resources is based on the results of interviews and questionnaires. Based on the five pillars of irrigation modernization, the Irrigation Modernization Readiness Index (IKMI) value is 69.90. The IKMI scores for the Batang Anai Irrigation Area are presented in Table 7.

Based on the Modernization Guidelines (Direktorat Irigasi dan Rawa, 2011), the value is classified as sufficient with the condition that modernization is postponed, then the irrigation system must be improved within 1-2 years. Overall, the results of the identification of the existing conditions of the Batang Anai Irrigation Area against the 5 pillars of irrigation modernization can be seen in Figure 3. The existing conditions of Batang Anai do not yet meet the ideal irrigation conditions for irrigation modernization. The water availability pillar is the lowest condition compared to the other pillars. The availability of irrigation water describes the potential of surface water that can be used as a source of irrigation. The availability of irrigation water represents the irrigation discharge available per unit area of agricultural land (expressed in unit of $L.s^{-1}.ha^{-1}$). Recommendations for actions that need to be taken for each pillar of the modernization of the Batang Anai Irrigation Area are presented in Table 8.

Based on the research results (Sulistiawan *et al*., 2020), DI with central authority is more ready to undergo irrigation modernization than district authority. The difference in the level of readiness is possible due to aspects of human resources, area size and institutional strength. The challenge of irrigation modernization in different management systems is flexibility and adaptation to the diversity of a DI such as the level of management authority

Table 7. Irrigation modernization readiness index in the Batang Anai IA

No.	Indicator	Criteria Weight	Criteria Score	Score
1	Water Availability	20%	60.00	12.00
2	Irrigation Infrastructure	25%	68.00	17.00
3	Management System	20%	72.00	14.40
4	Management Institution	20%	68.00	13.60
5	Human Resources	15%	70.00	10.50
Total				**67.50**

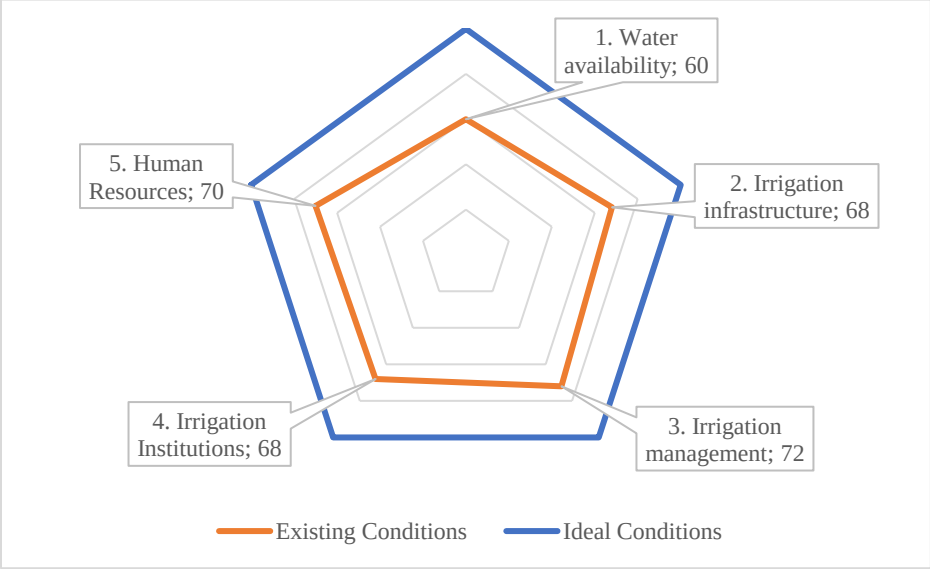

Figure 3. Existing conditions of the Batang Anai Irrigation Area against the 5 pillars of irrigation modernization

Table 8. Modernization Action Recommendations for Batang Anai Irrigation Area (D.I. Batang Anai)

No	Criteria	Action Recommendations
1	Water Availability	- Inspection of the water supply system. - Raising human awareness of the environment. - Enhancing active participation in preserving watershed (DAS) functions through physical (civil works or vegetation) and non-physical means. - Increasing active participation from the community and all DAS stakeholders (e.g., TKP SDA and SDA Council) to maintain upstream-downstream harmony.
2	Irrigation Infrastructure	- Normalization of irrigation channels. - Repair of damaged irrigation infrastructure.
3	Irrigation Management	- Increasing farmer participation through socialization and training activities.
4	Management Institution	- Building synergy among irrigation managers.
5	Human Resources (SDM)	- Socialization and training from the Central level to Provincial and District/City levels. - Training and empowerment of HIPPA.

between the center and regions. The Batang Anai IA is an area of central authority, so by implementing several recommended actions according to the needs of existing conditions (Table 8), the Batang Anai IA will be more ready for irrigation modernization. According to Alarcon *et al*., (2018), modernization in some cases, can be justified. First, if more productive planting patterns are implemented. Second, saving water is a cheaper option than using alternative resources only under certain conditions.

3.2. Priority Scale in Preparation of Irrigation Modernization

Before determining the priority scale of criteria in irrigation modernization readiness, it is necessary to conduct a data consistency test on the results of the comparison matrix questionnaire. The results of the data consistency test are presented in Table 9. Data can be said to be consistent if the CR value is <0.1 (Armin *et al*., 2022). Table 9 shows that the CR value of each criterion is <0.1, meaning that the results of the data comparison matrix questionnaire are consistent. After conducting the data consistency test, the next step is to calculate the fuzzy synthesis value, then defuzyfication to obtain the centroid of area value, then normalize. The priority scale of the criteria in the readiness of Batang Anai irrigation modernization is presented in Table 10.

Table 9. Data Consistency Test

No	Criteria	CR Value
1	Water Availability	0.043
2	Irrigation Infrastructure	0.023
3	Irrigation Management	0.067
4	Management Institution	0.004
5	Human Resources (SDM)	0.000

Based on the results of the FAHP analysis, it can be seen that the criteria and sub-criteria are the priority scales that need to be improved in assessing the readiness of irrigation modernization. The priority order for improving the pillars of irrigation modernization in D.I Batang Anai IA water availability, management institutions, irrigation management, irrigation infrastructure, and human resources. Recommended actions for modernization readiness include checking the water supply system, normalizing irrigation channels, repairing damaged irrigation infrastructure, increasing farmer participation through socialization and training activities, and building synergy between irrigation managers.

4. CONCLUSION

Based on the five pillars of irrigation modernization, the IKMI value of Batang Anai IA 67.50 with a sufficient predicate, namely modernization is postponed, irrigation system improvements are carried out for 1-2 years. The priority order for improving the pillars of irrigation modernization in the Batang Anai IA is water availability, management institutions, irrigation management, irrigation infrastructure, and human resources. The recommended

Table 10. Priority scale of criteria for irrigation modernization readiness

No	Criteria	Sub-Criteria	Weight	Priority
1	Water Availability	Availability	0.321	
		Reliability	0.454	
		Losses	0.225	
		Average	0.333	**1**
2	Irrigation Infrastructure	Main Building	0.281	
		Main Network Channels	0.226	
		Main Network Buildings	0.112	
		Drainage Channels	0.086	
		Access/Inspection Roads	0.056	
		Sediment Control	0.117	
		Tertiary Development	0.059	
		Border Area	0.028	
		Supporting Facilities	0.028	
		Average	0.142	**4**
3	Irrigation Management	Operational & Maintenance Manual	0.195	
		Irrigation Operational System	0.195	
		Maintenance & Rehabilitation	0.192	
		Financing	0.192	
		Farmer Participation	0.346	
		Average	0.199	**3**
4	Management Institution	Provincial PU SDA Office	0.677	
		District PU Office	0.092	
		UPTD	0.092	
		HIPPA	0.076	
		Irrigation Commission	0.063	
		Average	0.241	**2**
5	Human Resources (SDM)	Government	0.500	
		Farmers	0.500	
		Average	0.050	**5**

actions for modernization readiness include checking the water supply system, normalizing irrigation channels, repairing damaged irrigation infrastructure, increasing farmer participation through socialization and training activities, and building synergy between irrigation managers.

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