Modernization readiness analysis of Belitang irrigation system at region level using analytic hierarchy process (AHP) method

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Abstract. Irrigation system management in the Belitang Irrigation System has some constraint that can be overcome by conducting irrigation modernization. Before implementing irrigation modernization, an irrigation system should be assessed to determine the level of irrigation modernization readiness stated by the readiness index of irrigation modernization (IKMI). The assessment of irrigation pillars was carried out in three regions including Belitang I, Belitang II and Belitang III. This study aimed to analyze the readiness of irrigation modernization in the Belitang Irrigation System and to determine the order of irrigation modernization development in three regions. Data was collected using 2 methods, namely walk through survey for irrigation infrastructure pillars and interviews for 4 other pillars including water availability, system management, institution and human resources. The assessment data was recapitulated and processed to obtain the IKMI. Then, decision making for the order of irrigation modernization development was conducted by using the analytic hierarchy process (AHP) method. The result of determining the IKMI was 69.05, so Belitang Irrigation System was categorized as less ready for modernization. This showed that the irrigation modernization needs to be postponed and the irrigation system is improved for 1-2 years. Furthermore, the results of the AHP analysis showed that the order of irrigation system development and improvement for irrigation modernization started from the Region of Belitang III, then Belitang I and Belitang II.

1. Introduction
The increase of agricultural productivity is basically influenced by many factors, one of which is fulfillment of crop water requirement. Irrigation has a function to provide water for agricultural land by flowing it so that water needs are fulfilled and excess water are drained. Irrigation supplied is used to fulfill crop water requirement and losses. The use of water for agriculture consumes 70% of total water use in the world [1]. Therefore, the increase of water use efficiency for agriculture by allocating irrigation water resources effectively, is expected to be an alternative effort to ensure and encourage the development of sustainable agriculture [2].

In the irrigation sector for agriculture, Indonesia is mostly dependent on surface irrigation for which the management of the irrigation system has some constraint. The reliability of irrigation water is low because the performance of irrigation systems depends on the condition of river basin. This was indicated by the surface irrigation area whose water was guaranteed by reservoirs at 76,542 ha (10.7%), whereas by river water discharges at 6,383,626 ha (89.3%) [3]. Condition of surface irrigation infrastructure was poor so that it affected the performance of the irrigation system. Based on the results of a performance audit of irrigation system in 2014 by the Directorate of Water Resources Operations and Maintenance, of the total surface irrigation in Indonesia measuring 7.1 million Ha, covering 46% or approximately 3.3 million Ha of irrigation infrastructure in damaged condition [4].
One of the irrigation systems in Indonesia that utilizes river water discharge for surface irrigation is the Belitang Irrigation Area. This irrigation area is located in Ogan Komering Ulu Timur Regency (OKU Timur), South Sumatera Province, which has a land area of 21,598 ha. Constraints that occurred were similar to the conditions of irrigation areas in Indonesia. Another constraint was that irrigation services performed were less than optimal due to the lack of quantity and quality of human resources for irrigation management. As an effort to overcome these constraints, it is necessary to have an effort made by the government that is conducting a thorough renewal by increasing the reliability of water supply, irrigation infrastructure, irrigation management, management institutions and human resources, known as irrigation modernization [5].

In line with the government's policy on irrigation modernization, the Belitang Irrigation System needs to be made a decision regarding the readiness of irrigation modernization planning or an improvement in the irrigation management system is needed first. Before irrigation modernization is carried out, an analysis of irrigation modernization readiness for the Belitang Irrigation System needs to be carried out. This readiness analysis begins with an assessment of the five pillars of irrigation modernization including water availability, infrastructure, irrigation management, management institutions and human resources. The assessment of irrigation area readiness is expressed by the readiness index of irrigation modernization (IKMI) which can be used to formulate and determine the next strategic steps [6].

An analysis of the irrigation modernization readiness index was discussed in several previous studies. Mulyadi et al. (2014) used the Analytical Hierarchy Process (AHP) method to obtain priority order of application of the irrigation modernization pillar in the Barubug Irrigation Area [7]. Pradipta et al. (2019) used the AHP method combined with K-Medoids Clustering for the analysis of irrigation modernization readiness in the Kedung Putri Irrigation System in groups according to secondary canal clusters of a similar type [6]. Sari et al. (2019) used a combination of Fuzzy Analytical Hierarchy Process (FAHP) and Simple Additive Weighting (SAW) methods to analyze the readiness of irrigation modernization in the Irrigation Area of Mojokerto Regency [8].

From some of the previous studies, this study would adopt the use of the AHP method for decision making related to irrigation modernization readiness. AHP method was used because it is one of the comprehensive decision-making methods that has the ability to solve problems by involving many criteria to rank alternative decisions in the form of priority scale [9]. The difference between this research and the previous one was that the research object (Belitang Irrigation System) had never been examined and the priority of irrigation modernization was determined based on the region of Irrigation System. This study aimed to analyze the readiness of irrigation modernization in the Belitang Irrigation System and to determine the order of irrigation modernization development in three regions.

2. Research methods

2.1. Study area

Belitang Irrigation System is located in Ogan Komering Ulu Timur Regency, South Sumatra Province, Indonesia. This irrigation area is used to irrigate 21,598 ha of agricultural land which is divided into 3 regions including Belitang I, Belitang II, and Belitang III which have 6,051 ha, 7,576 ha abd 7,971 ha command area, respectively. With a command area exceeding 3,000 ha, the Belitang Irrigation System is under the authority and responsibility of the central government both for the development and management of the irrigation system based on the Permen PUPR RI No. 14/PRT/M/2015. The competent authority to manage Belitang Irrigation System is the Sumatra VIII River Basin Organization (BBWS Sumatera VIII). The water resource for the Belitang Irrigation System is the Komering River abstracted through the Perjaya Dam which is flowed through the Belitang Secondary Canal. This canal starts from BB 0-BB 35 with the division of canal, BB 0-BB 8 into Belitang I, BB 8-BB 17 into Belitang II and BB 18-BB 35 into Belitang III. Each region has several secondary and sub secondary canals.
2.2. Data collection

2.2.1. Walk through survey. Walk through survey was performed to determine the percentage of the number of structures and the length of secondary canals, sub-secondary canals, tertiary canals, and drainage canals with good condition to the total number of buildings and total canal lengths. The results of data collection with this method were used to assess IKMI irrigation infrastructure pillar.

2.2.2. Interview. Interview using questionnaires were conducted to collect data on 4 other irrigation pillars namely water availability, system management, institution and human resources. Questionnaire forms and their weighted factors that represent certain pillars refer to the irrigation modernization guidelines issued by the Ministry of Public Work [10]. In this study, respondents used were Water Users’ Association (WUA), Federation of Water Users’ Association (WUAF) and regional officers. The respondents interviewed were 78 respondents consisting of 20 WUA and 5 WUAF in each region representing water users in the secondary and sub-secondary canals. For the regional officer, only 1 respondent was interviewed. The questionnaire form intended for respondents covering 4 irrigation pillars can be seen in Table 1, Table 2 and Table 3. Representation of answers from interviews with WUA, WUAF and Officers of each question submitted using an assessment on a scale of 1-5.

Table 1. List of questions along with weight values for WUA.

| Pillar                  | Weight value | Question number | Question                                                                 |
|------------------------|--------------|-----------------|--------------------------------------------------------------------------|
| Water availability     | 33.3         | 1               | Water availability in tertiary plots                                      |
| System management      | 2.78         | 2               | Adequacy to fulfill specified IP targets                                  |
|                        | 2.78         | 3               | The linking of cropping patterns in fulfilling the specified IP targets   |
|                        | 2.78         | 4               | Water distribution at tertiary level                                      |
| Institution            | 3.03         | 5               | WUA has been formed and is active                                        |
|                        | 9.09         | 6               | WUA's capacity and role in participating                                 |
| Human resources        | 10.00        | 7               | The number of farmers and owners of rice fields compared to the number of existing farmers |
|                        | 10.00        | 8               | Participation of WUA members                                             |
|                        | 10.00        | 9               | Percentage of farmers paying fee to WUA                                  |
|                        | 10.00        | 10              | Percentage of farmers who own land >2 Ha                                  |

Table 2. List of questions along with weight values for regional officers.

| Pillar                  | Weight value | Question number | Question                                                                                                                                 |
|------------------------|--------------|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| System management      | 2.08         | 1               | Availability and implementation of O&M manuals                                                                                         |
|                        | 2.08         | 2               | The O&M Manual is carried out in accordance with Permen PU No. 32/PRT/M/2007 or Permen PUPR No. 12/PRT/M/2015                            |
|                        | 4.17         | 3               | Availability and implementation of O&M Blanks                                                                                         |
|                        | 4.17         | 4               | Availability of supporting books                                                                                                     |
|                        | 8.33         | 5               | Implementation of O&M in the operation management system from secondary to tertiary                                                   |
|                        | 8.33         | 6               | Management of drainage systems                                                                                                        |
|                        | 2.78         | 7               | Carry out tertiary floodgate operations                                                                                               |
|                        | 2.78         | 8               | Special officers who carry out tertiary floodgate operations                                                                         |
|                        | 2.78         | 9               | Maintenance of tertiary floodgate                                                                                                     |
| Institution            | 3.03         | 10              | Regional performance capacity and real role in irrigation development and management as a developer or operator                          |
Table 3. List of questions along with weight values for WUAF.

| Pillar         | Weight value | Question number | Question                                                                 |
|---------------|--------------|----------------|-------------------------------------------------------------------------|
| Institution   | 4.5          | 1              | Institutional WUAF                                                       |
|               | 4.5          | 2              | WUAF has adequate capacity and a real role in participating to the development and management of irrigation at the main network |

2.3. Data processing

The determination of the IKMI value was based on the recapitulation of the assessment results from the questionnaire and walk through survey. Questionnaire data from 78 respondents were grouped by region, then the data was calculated on average so that an assessment of each region was obtained as a basis for assessing IKMI 4 irrigation pillars. The assessment on the 4 irrigation pillars was multiplied by the weight value of the questions in Table 1, Table 2 and Table 3. Data obtained from walk through survey of irrigation infrastructure in the three regions on a scale of 0-100% were combined, so that the recapitulation of the assessment of the 5 irrigation pillars can be obtained.

Then all 5 pillars assessment was multiplied by the main weight value of each pillar, which shows the level of importance of the pillar in an irrigation system. The main weight of the pillar were 20%, 25%, 15%, 20%, and 20% for water availability, infrastructure pillars, system management, institutions, and human resources respectively [6]-[10]. The weighted assessment results were summed to obtain the IKMI value of the irrigation area and each region. These IKMI can be classified into several categories as showed in Table 4.

Table 4. Classification of irrigation modernization readiness based on IKMI value.

| IKMI value | Category     | Application of irrigation modernization |
|------------|--------------|-----------------------------------------|
| >80        | Ready        | Modernization can be applied immediately |
| 50-80      | Less ready   | Modernization is postponed and needs to be improved in 1-2 years |
| 30-50      | Poorly ready | Modernization is postponed and needs to be improved in 2-4 years |
| <30        | Not ready    | Modernization is not necessary or fundamental improvements are made |

2.4. Analytical Hierarchy Process (AHP)

AHP was used because it provides a basic approach to get the best decision from a number of alternatives that are evaluated rationally and intuitively by multi criteria [7]. The first step of the analysis was to form a hierarchy with a direct hierarchical relationship between levels arranged from top to bottom, starting from the goal, continuing to the criteria and then to the final alternative (Figure 1). [11]. Determining pairwise comparison criteria was the next step in the analysis using the AHP method, which was making a matrix that contains a ratio of relative importance between one criteria and another that can be seen in Eq. (1) [12].

Choose the region with the best modernization readiness

- Water availability
- Irrigation infrastructure
- System management
- Institution
- Human resources

Figure 1. The AHP hierarchy chart.
Where $a_{ij}$ is the weight of the criteria $i$ divided by the weight of the criteria $j$

The relative importance of each element was calculated by normalizing the eigenvectors associated with the maximum eigenvalues of the pairwise comparison matrix. The making of pairwise comparison matrix criteria was based on the weight of each pillar contained in the Irrigation Modernization Guidelines [6]. Finally, consistency associated with a pairwise comparison matrix was estimated using a consistency ratio (CR). The allowable value for consistency ratio was smaller or equal to 10%. If it was more than 10%, then the matrix comparison value would be repeated. Determination of consistency ratio as follows Eq. (2):

$$CR = \frac{CI}{RC}$$

$$CI = \frac{\lambda_{\text{max}} - n}{n - 1}$$

Where CI is the consistency index, RI is the consistency index of a random square matrix of the same order, $\lambda_{\text{max}}$ is the largest eigenvalue "A", and $n$ is the square matrix sequence.

3. Results and discussion

3.1. The IKMI assessment of Belitang Irrigation System

The results of the IKMI assessment in the Belitang Irrigation System are presented in Table 5. Categories for each irrigation pillar were based on the collection and processing of results both walk through survey and interview. IKMI for each pillar was the total of three regions in Belitang Irrigation System.

Based on Table 5, the IKMI assessment of Belitang Irrigation System was categorized as enough, because it has an IKMI of 69.05 which is in the range of 50 to 80. Based on these results, irrigation modernization needs to be postponed and improved irrigation systems during 1-2 years.

| Irrigation pillar          | Pillar main weight (%) | Level | Category    | IKMI  |
|----------------------------|------------------------|-------|-------------|-------|
| Water availability         | 20                     | 77    | Less ready  | 15.40 |
| Irrigation infrastructure  | 25                     | 80    | Ready       | 20.00 |
| System management          | 15                     | 59    | Less ready  | 8.85  |
| Institution                | 20                     | 57    | Less ready  | 11.40 |
| Human resources            | 20                     | 67    | Less ready  | 13.40 |

IKMI of Belitang Irrigation System 69.05

Water availability pillar in Belitang Irrigation System was categorized as less ready with IKMI score of 77. Based on water balance, water discharge was adequate, but due to poor condition of irrigation network, water was not fluently flow to tertiary blocks and agricultural land. The IKMI score of the irrigation infrastructure pillar was 80, so that it was categorized as ready for modernization. This IKMI was obtained from walk through survey including main network buildings,
main canals (secondary and sub secondary), drainage canals and tertiary canals. For the system management, IKMI score was 59 which categorized as less ready for modernization. This was due to several factors including (1) manual and O&M forms were unavailable that have not been fully implemented, (2) maintenance of drainage canals has not been carried out routinely due to budget constraints, (3) there was water theft in the secondary and sub secondary canals, and (4) there was garbage in the canal.

The IKMI of institution was 57 which categorized less ready. Based on the results of the questionnaire, there were several WUAF and WUA that have been formed already and conduct activities but they were not yet effective in carrying out their roles. In addition, the empowerment activities carried out by the region officers have not been evenly distributed to the existing WUA. Finally, the IKMI score of the human resource pillar was 67, categorized as less ready for modernization. This could be seen from the required staff that were enough and most staffs were civil servants (PNS). However, there were shortcomings including (1) 20% lack of certified O&M and (2) WUA who had received training that was only around <40%.

3.2. IKMI assessment in three regions of Belitang Irrigation System

The results of the IKMI assessment at the regional level as a whole were not ready for irrigation modernization, because the IKMI score of three regions, Belitang I, Belitang II and Belitang III, were in the range of 50 to 80 categorized as less ready. IKMI score for each pillar for the region can be seen in Table 6.

| Region      | Water availability | Irrigation infrastructure | System management | Institution | Human resources | IKMI Total |
|-------------|--------------------|----------------------------|-------------------|-------------|-----------------|------------|
| Belitang I  | 16.80              | 20.00                      | 9.30              | 10.80       | 14.00           | 70.90      |
| Belitang II | 15.80              | 21.25                      | 8.85              | 11.40       | 14.60           | 71.90      |
| Belitang III| 13.60              | 18.50                      | 8.25              | 12.20       | 11.80           | 64.35      |

The distribution of IKMI in each region is shown in Figure 2. It can be seen that the performance of irrigation pillars in each region was different. Belitang I had an advantage in the pillar of water availability with the highest value among other regions. Belitang II had an advantage in the irrigation infrastructure pillar with the highest value among other regions. Belitang III has an advantage in the irrigation infrastructure pillar, but its value is lower than Belitang II.

3.3. IKMI assessment in three regions of Belitang Irrigation System

In the preparation of development priority at the region of Belitang Irrigation System, it should be structured hierarchy chart that includes goal, criteria and alternative. The goal was to rank the region

![Figure 2. Distribution of IKMI values for each region.](image-url)
from the least ready to the most ready for irrigation modernization development and improvement. The criteria used were 5 irrigation pillars, while the alternatives offered are 3 regions.

Determining criteria pairwise comparison is the first step in the analysis using the AHP method, which is making a matrix that contains the ratio of relative importance between criteria to one another. In this study, criteria pairwise comparison were made based on the main weights of each irrigation pillar listed in the irrigation modernization guidelines. The weights of each irrigation pillar were compared to each other against all irrigation pillars, so a pairwise comparison matrix will be obtained. Then the criteria eigenvector was determined by squaring the criteria pairwise comparison matrix and adding the numbers in one row of the obtained matrix, then normalized. In the next step, the pairwise comparison matrix was multiplied by the eigenvector criteria to produce the criteria ranking matrix. Ranking criteria can be seen in Figure 3.

| Criteria pairwise comparison | Criteria eigenvector | Criteria ranking |
|-----------------------------|----------------------|------------------|
| WA  | II  | SM  | I  | HR  |
| WA  | 1.00 | 0.80 | 1.33 | 1.00 | 1.00 |
| II  | 1.25 | 1.00 | 1.67 | 1.25 | 1.25 |
| SM  | 0.75 | 0.60 | 1.00 | 0.75 | 0.75 |
| MI  | 1.00 | 0.80 | 1.33 | 1.00 | 1.00 |
| HR  | 1.00 | 0.80 | 1.33 | 1.00 | 1.00 |

: Water availability   \(\text{CR} : 2.92\%\)
: Irrigation infrastructure
: System management
: Institution
: Human resources

**Figure 3.** Ranking of irrigation pillars by AHP method.

Based on the AHP analysis, first rank of irrigation pillars was irrigation infrastructure with weight value of 1.21. Three pillars namely water availability, management institutions and human resources came to the second rank with weight value of 0.96. The last rank was system management with weight value of 0.72. These results indicated that water availability, management institutions and human resources had the same importance in improving irrigation performance, while irrigation infrastructure became the highest importance and system management was the lowest importance.

The solution matrix was then determined to obtain a decision in the order of regional development and improvement before irrigation modernization is carried out (Figure 4). The preparation of the solution matrix was the result of multiplication between alternative pairwise comparison and criteria ranking. Whereas alternative pairwise comparison used IKMI score for each normalized pillar.

| Alternative pairwise comparison | Criteria ranking alternative |
|---------------------------------|-----------------------------|
| WA  | II  | SM  | I  | HR  |
| Belitang I  | 0.36 | 0.33 | 0.35 | 0.31 | 0.35 | 0.96 | 1.65 | 2 Belitang I |
| Belitang II | 0.34 | 0.36 | 0.34 | 0.33 | 0.36 | 0.72 | 1.67 | 1 Belitang II |
| Belitang III | 0.29 | 0.31 | 0.31 | 0.35 | 0.29 | 0.96 | 1.51 | 3 Belitang III |

**Figure 4.** Solution matrix.
Based on the solution matrix, the alternative ranking results revealed, the rank region namely Belitang II, Belitang I and Belitang III with weight values of 1.67, 1.65, and 1.51, respectively. From these results, the preparation of priority scales for irrigation system development and improvement before irrigation modernization in regional level was sorted from Belitang III, Belitang I and Belitang II. The development and improvement efforts that should include increasing water availability, routine maintenance, technical assistance, strengthening institutions and public campaigns [6].

4. Conclusions
Based on the assessment result of IKMI was 69.05, which was categorized as less ready for irrigation modernization, the irrigation modernization in Belitang Irrigation System needed to be within for 1-2 years for system improvements. The order of irrigation system development and improvement for irrigation modernization based on analysis by AHP started from Belitang III, Belitang I and Belitang II with weight values of 1.51, 1.65, and 1.67, respectively.

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