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Development of Irrigation Networks Based on Priorities Using the Multiple Attribute Decision Making Method

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ABSTRACT

Development of irrigation networks is a crucial element in increasing the efficiency and effectiveness of water distribution for agriculture. This research aims to determine priorities for developing irrigation networks in the Bedadung Irrigation Area, Jember Regency, using the Multiple Attribute Decision Making (MADM) method. This method consider various criteria influencing decision-making, such as physical condition of the channel, land area, water requirements, and level of infrastructure damage. This research involved collecting primary and secondary data through field surveys, interviews with interpreters, as well as reviewing technical and administrative documents related to irrigation networks. Data was analyzed using several MADM techniques, such as Simple Additive Weighting (SAW), Weighted Product (WP), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to obtain the weight of each criterion and determine development priorities. The results show that the main priority for developing irrigation networks in the Bedadung Irrigation Area is repairing primary, secondary, and tertiary canals that are badly damaged, followed by increasing canal capacity to meet water needs in the dry season. Implementation of the results of this research is expected to increase the efficiency of irrigation water distribution, reduce water losses, and increase agricultural productivity.

1. INTRODUCTION

One of the most important infrastructures in increasing food security and productivity is the irrigation network (Kurnianingrum *et al*., 2023). The construction of an irrigation network covering an area of approximately 1.5 million hectares. Then, for the 15 million hectares of irrigation network that is in less than prime condition due to its age, it is necessary to carry out rehabilitation and maintenance of infrastructure in stages until 2044 (PUPR, 2024). An irrigation network consists of additional channels, structures, and buildings used for the supply, distribution, grant, use, and disposal of irrigation water (Ministry of PUPR, 2015).

One of the factors that determines the performance of irrigation networks is physical ability because physical damage hinders the flow of irrigation water (Buya, 2019). The physical condition of the irrigation network is very important to increase agricultural productivity and help achieve food sovereignty to increase agricultural production and ensure national food security and the welfare of the community, especially farmers (Astutik & Suhardi, 2021). The increasing demand for better irrigation performance cannot be separated from several factors of irrigation management such as water resources themselves, human resources, and infrastructure where these factors are the main factors that will later become the success index of irrigation services (Arif *et al*., 2019).

The success of irrigation services is not spared the development and management of irrigation networks, where development and management cannot be carried out simultaneously due to problems with fund allocation and implementation time (Rusli & Febriani, 2015). This makes it difficult to me*et al*l existing needs so Priority analysis is needed in the development and management of irrigation networks. Analyze. Priority this using the Multi-Attribute Decision Making (MADM). MADM analysis can also be used to solve problems with various criteria and alternatives. Some of the methods that can be used to solve MADM problems include the Simple Additive Weighting Method (SAW), Weighted Product (WP), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Pradipta *et al*., 2020). The research that has been carried out has various significant benefits, both theoretically and practically. This research is expected to be able to make a real contribution to the management and development of irrigation networks to increase effectiveness, and efficiency and is expected to be the basis for decision-making for the development, rehabilitation, and improvement of irrigation networks in the Bedadung Irrigation Area.

2. MATERIALS AND METHODS

The selection of the research location is determined by the researcher intentionally or by *Purposive methods* where the selection of the location is a direct consideration based on the characteristics and objectives of the study (Lenaina, 2021). The research location is in the Bedadung Irrigation Area, Jember Regency. Astronomical position, Bedadung Irrigation Area is located at the coordinates of Latitude - 8º13'49" and Longitude +113º53'03" with an area of 13,245 Ha and water discharge of 8,950 m^3/sc.

2.1. Determination of Research Location

The irrigation networks included in the development and management were selected through an analysis of priority location determination where data on primary, secondary, and tertiary irrigation networks were obtained. The selected irrigation area had a service area of 13,245 ha, consisted of 3 Technical Implementation Unit or UPT, namely UPT Curah Malang, UPT Balung, and UPT Wuluhan which were under the authority of the Dinas Pekerjaan Umum Bina Marga dan Sumber Daya Air, Jember Regency (Jatmiko *et al*., 2022). This research was conducted at 19 secondary channel location points which is a priority for development and management as detailed in Table 1.

2.2. Data Collection and Assessment of Irrigation Networks

The data collected includes the evaluation of irrigation networks carried out through network inventory and tracing. The assessment criteria for irrigation canals was shown in Table 2. Each analysis weight parameter has an approach with the priority of maintenance and rehabilitation operations by the regulation of the Minister of PUPR Number 47/PRT/M/2015. The weighting parameters of the irrigation network used in this study are shown in Table 3.

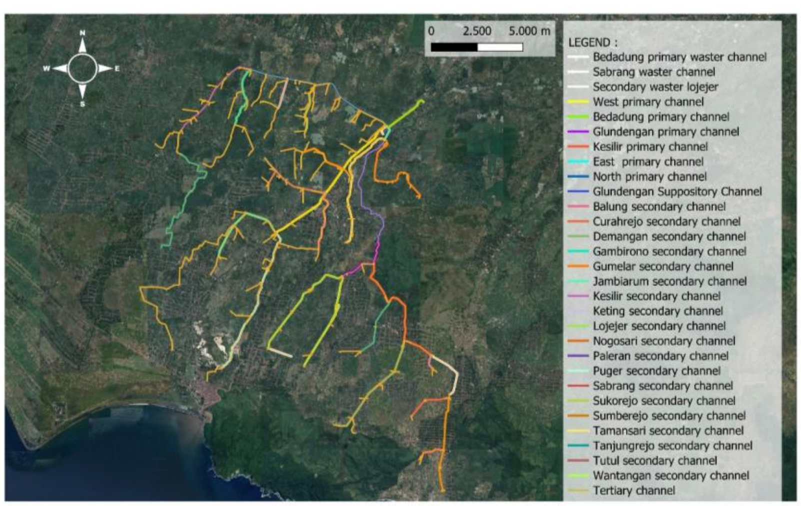

Figure 1. Map of Bedadung Irrigation Area

Table 1. Irrigation areas observed for this research

UPT (Technical Implementation Unit)	Service Area	Service Area (ha)
UPT Wuluhan	Secondary channel Tanjung Rejo	310
	Secondary channel Taman Sari	657
	Secondary channel Lojejer	741
	Secondary channel Ampel Bloh	811
	Secondary channel Bunder Nogosari	561
	Secondary channel Demangan	965
	Secondary channel Kesilir	177
	Secondary channel Sabrang	378
	Secondary channel Sumberejo	586
	Secondary channel A1	214
UPT Balung	Secondary channel Tutul	658
	Secondary channel Balung	411
	Secondary channel Jambearum	734
	Secondary channel Puger	1251
UPT Curah Malang	Secondary channel Sukorejo	747
	Secondary channel Keting	216
	Secondary channel Gambirono	509
	Secondary channel Paleran	885
	Secondary channel Gumelar	419

Source: Dinas Pekerjaan Umum dan Sumber Daya Air (2020)

Table 2. Criteria for assessing the condition of irrigation networks

	Parameters	Category
1	Good	Both functionally and physically
2	Minor Damage	The duct plaster is peeling, there is light vegetation
3	Moderately damaged	The channel is all dirt, some of it is dirt, there are cracks and shifts
4	Heavily damaged	channel lining collapsed, collapsed

Table 3. Parameters and weights of irrigation network assessment (Pradipta *et al*., 2020)

	Parameters	Category	Value	Weight (%)
1	Main irrigation network infrastructure	Good	3	25
		Minor damage	2	
		Heavily damaged	1	
2	Tertiary irrigation network infrastructure	Good	1	35
		Minor damage	2	
		Moderately damaged	3	
		Heavily damaged	4	
3	Water availability		Within a month	15
4	Wide range of services		In ha	10
5	Productivity		In ton/ha	15

2.3. Method for Priority Location Determination

The decision-making method used Multiple Attribute Decision Making (MADM) to determine priority locations in the Bedadung irrigation area. This study applies three MADM methods explained in the following.

1) Simple Additive Weighting (SAW) Method

The SAW method stands for Simple Additive Weighting, which is a weighted addition method used in decision support systems. This method is used to find the weighted sum of the performance ratings on each alternative on all attributes (Kusumadewi *et al.,* 2006).

1. Determining criteria (C_i) and alternatives (A_i)
2. Determining the weight of each criterion (W)

3. Create a decision matrix with rows and columns represent the alternatives being evaluated and the criteria used
4. Normalize the decision matrix by calculating the numbered performance rating value (r_{ij})) of the A_i alternative in criterion Cr_{ij}. i. The formula for the normalization process is as follows:

$$r_{ij} = \begin{cases} \dfrac{x_{ij}}{\underset{i}{Max}\, x_{ij}} & \text{if } j \text{ is a profit attribute (benefit)} \\ \dfrac{\underset{i}{Min}\, x_{ij}}{x_{ij}} & \text{if } j \text{ is a cost attribute (cost)} \end{cases} \tag{1}$$

where r_{ij} is normalized performance rating, $Max\ x_{ij}$ is maximum value, $Min\ x_{ij}$ is minimum value, and x_{ij} is rows and columns of the matrix.

5. The sum of the normalized matrix row elements multiplied by the preference weight (W) is the result of the preference value (V_i). The largest value (V_i) is the best alternative. The value (V_i) is obtained as the following:

$$V_i = \sum_{j=1}^{n} w_j\ r_{ij} \tag{2}$$

where: V_i is final value (ranking) for each alternative, w_j is predefined preference weights for each criterion, and r_{ij} is normalized performance rating value.

2) Weighted Product (WP)

This method is a method to determine a decision, namely by multiplying to be able to relate the value of the attribute, in this case, the value of the attribute will be ranked first by the weight of the attribute (Anastasya *et al*., 2023).

1. Determination of W_j weight value

$$W_j = \frac{W_j}{\sum W_j} \tag{3}$$

where W_j is a positive value rank for the profit attribute and a negative value rank for the cost attribute.

2. Determination of the S weight value

$$S_i = \prod_{j=1}^{n} X_{ij}^{wj} \tag{4}$$

where S_i is *h* result of normalization of the decision on the i^{th} alternative, X_{ij} is *h* rating alternative per artifact, *I* is alternative, and *j* is attribute.

3. Determination of the weight value of V

$$V_i = \frac{\prod_{j=1}^{n} X_{ij}^{wj}}{\prod_{j=1}^{n} X_{ij*Wj}} \tag{5}$$

where V_i isrelative preference of each alternative analogized as a vector, X_{ij} is variable value of the alternative on each attribute, W_j is criterion weight value, * is the number of criteria that have been assessed on the S vector, n is number of criteria, i is alternative value, and j is criterion value.

3) Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

The TOPSIS multi-criteria method combines the relative weights of important criteria to find solutions from alternative sets (Olson, 2024). This method relies on minimizing the distance between the ideal and lowest points simultaneously (Suryandini, 2014) according to the following steps:

a. Determining criteria (C_i) and alternatives (A_i)
b. Determining the weight of each criterion (W) with the highest weight value on the criterion determines the level of importance of a criterion in the assessment
c. Create a normalized decision matrix with the equation:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{6}$$

where r_{ij} is normalized performance rating value, and x_{ij} is rating each alternative.

d. Creating a weighted normalized decision matrix with the equation:

$$y_{ij} = w_j\, r_{ij} \tag{7}$$

where y_{ij} is weighted value of the i^{th} alternative in the j^{th} criterion, and w_j is weight of the j^{th} criterion

e. Determining the matrix of positive ideal solutions using the equation:

$$A^+ = (,,...,) \text{ and } = (,,...,) y_1^+ y_2^+ y_n^+ A^- y_1^- y_2^- y_n^- \tag{8}$$

where A^+ is positive ideal solution, and A^- is negative ideal solution with the following conditions:

$$y_j^+ = \begin{cases} \underset{i}{Max}\, y_{ij} & \text{if } j \text{ is a profit attribute (benefit)} \\ \underset{i}{Min}\, y_{ij} & \text{if } j \text{ is a cost attribute (cost)} \end{cases} \tag{9}$$

$$y_j^- = \begin{cases} \underset{i}{Min}\, y_{ij} & \text{if } j \text{ is a profit attribute (benefit)} \\ \underset{i}{Max}\, y_{ij} & \text{if } j \text{ is a cost attribute (cost)} \end{cases} \tag{10}$$

f. Determine the distance between the weighted values to the positive ideal solution with the following equation:

$$D_i^+ = \sqrt{\textstyle\sum_{j=1}^{n} (y_i^+ - y_{ij}^-)^2} \tag{11}$$

where D_i^+ is distance from the i alternative to the positive ideal solution.

g. Determine the distance (D_i^-) between the weighted values to the negative ideal solution as the following equation:

$$D_i^- = \sqrt{\textstyle\sum_{j=1}^{n} (y_{ij}^+ - y_{ij}^-)^2} \tag{12}$$

h. Calculate the final value (V_i) of preference for each alternative with the equation:

$$V_i = \frac{D_i^-}{D_i^- + D_i^+} \tag{13}$$

Table 4. Initial assessment of the research location in each parameter

No.	Secondary channel	Assessment Parameters				
		MINI	**TINI**	**Water availability**	**Service Area (ha)**	**Productivity**
1	Tanjung Rejo	3	2	12	310	6
2	Tamansari	3	2	12	657	6
3	Lojejer	3	2	12	741	6
4	Ampelbloh	3	4	12	811	6
5	Bunder Nogosari	3	2	12	561	6
6	Demangan	3	2	12	965	6
7	Kesilir	3	1	12	177	6
8	Sabrang	3	2	12	378	6
9	Sumberejo	3	2	12	586	6
10	A1	3	3	12	214	6
11	Tutul	2	1	8	658	6
12	Balung	2	2	8	411	6
13	Jambearum	2	1	8	734	6
14	Puger	2	1	8	1251	6
15	Sukorejo	3	2	7	747	6
16	Keting	3	4	7	216	6
17	Gambirono	3	1	7	509	6
18	Paleran	3	3	7	885	6
19	Gumelar	3	2	7	419	6

Note: MINI = Main irrigation network infrastructure, TINI = Tertiary irrigation network infrastructure

3. RESULTS AND DISCUSSION

This analysis was carried out using the MADM method where there are five parameters, namely the main irrigation network infrastructure, tertiary, water availability, service area, and productivity. By the analysis in the field, the initial data was obtained which is shown in Table 4. It can be seen directly that the primary channel in Bedadung is in good condition, but for the tertiary irrigation network, many are categorized as being in a slightly damaged position.

3.1. Simple Additive Weighting Method (SAW)

The assessment of the physical condition of the irrigation network is carried out by direct field surveys on the main, secondary, and tertiary channels. Observation is one way of collecting data through a careful and systematic recording process of objects directly observed (Muhlis & Yuliana, 2011). The SAW method can help in decision-making where it produces the greatest value to be chosen as the best alternative. Based on the normalization assessment (Table 5), the

Table 5. Normalized matrix in the SAW method

Secondary channel	MINI	TINI	Water availability	Service Area (ha)	Productivity
Tanjung rejo	1.00	0.75	1.00	0.25	1.00
Tamansari	1.00	0.75	1.00	0.53	1.00
Lojejer	1.00	0.75	1.00	0.59	1.00
Ampelbloh	1.00	0.75	1.00	0.65	1.00
Bunder Nogosari	1.00	0.75	1.00	0.45	1.00
Demangan	1.00	0.75	1.00	0.77	1.00
Kesilir	1.00	0.75	1.00	0.14	1.00
Sabrang	1.00	0.75	1.00	0.30	1.00
Sumberejo	1.00	0.75	1.00	0.47	1.00
A1	1.00	0.75	1.00	0.17	1.00
Tutul	0.67	0.50	0.67	0.53	1.00
Balung	0.67	0.50	0.67	0.33	1.00
Jambearum	0.67	0.50	0.67	0.59	1.00
Puger	0.67	0.50	0.67	1.00	1.00
Sukorejo	1.00	1.00	0.58	0.60	1.00
Keting	1.00	0.50	0.58	0.17	1.00
Gambirono	1.00	0.25	0.58	0.41	1.00
Paleran	1.00	1.00	0.58	0.71	1.00
Gumelar	1.00	0.50	0.58	0.33	1.00

Note: MINI = Main irrigation network infrastructure, TINI = Tertiary irrigation network infrastructure

Table 6. Priority value of development and management of irrigation networks with the SAW Method

No.	Secondary channel location	Total Value	Priority Location Ranking	Recommendations
1	Paleran	0.908	1	Management
2	Sukoharjo	0.897	2	Management
3	Demangan	0.890	3	Development
4	Ampelbloh	0.877	4	Development
5	Lojejer	0.872	5	Development
6	Tamansari	0.865	6	Development
7	Sumberejo	0.859	7	Management
8	Bunder Nogosari	0.857	8	Development
9	Sabrang	0.843	9	Development
10	Tanjung rejo	0.837	10	Development
11	A1	0.830	11	Development
12	Kesilir	0.827	12	Management
13	Gumelar	0.696	13	Development
14	Puger	0.692	14	Management
15	Keting	0.680	15	Development
16	Jambearum	0.650	16	Development
17	Tutul	0.644	17	Development
18	Balung	0.625	18	Development
19	Gambirono	0.616	19	Management

resulting matrix is processed to form rankings. The final value of the preference comes from the multiplication of the normalized matrix row elements by the preference weights corresponding to the matrix column elements (Table 6).

3.2. Weighted Product (WP)

Method Weighted Product is a method is a simple method using multiplication to connect attribute ratings, where each attribute rating must be raised to the power of the weight of the attribute in question (Setyabudi & Mustafidah, 2020). The first thing that is processed in this data is to add up the assessment results for each parameter by giving the relative weight values that have been determined in Table 3 then dividing by the total weight. The priority values are presented in Table 7.

Table 7. Priority value of development and management of irrigation networks with the WP method

Secondary channel	Si	Total Value	Priority Ranking	Recommendations
Paleran	7.382	0.062	1	Management
Demangan	7.300	0.062	2	Management
Sukorejo	7.258	0.061	3	Development
Ampelbloh	7.174	0.061	4	Development
Lojejer	7.110	0.060	5	Development
Tamansari	7.025	0.059	6	Management
Sumberejo	6.945	0.059	7	Development
Bunder Nogosari	6.915	0.058	8	Development
Sabrang	6.647	0.056	9	Development
Tanjung Rejo	6.516	0.055	10	Development
A1	6.279	0.053	11	Development
Kesilir	6.161	0.052	12	Management
Puger	5.528	0.047	13	Development
Gumelar	5.375	0.045	14	Management
Jambearum	5.241	0.044	15	Development
Balung	5.184	0.044	16	Development
Tutul	5.030	0.043	17	Management
Balung	4.945	0.042	18	Development
Gambirono	4.300	0.036	19	Development

Table 8. Weighted normalized matrix from TOPSIS method

Secondary channel	Weighting				
	MINI	TINI	Water availability	Service size	Productivity
	0.25	0.35	0.15	0.10	0.15
Tanjung rejo	1.2207	1.7321	0.8171	0.2182	0.6882
Tamansari	1.2207	1.7321	0.8171	0.4625	0.6882
Lojejer	1.2207	1.7321	0.8171	0.5216	0.6882
Ampelbloh	1.2207	1.7321	0.8171	0.5709	0.6882
Bunder Nogosari	1.2207	1.7321	0.8171	0.3949	0.6882
Demangan	1.2207	1.7321	0.8171	0.6793	0.6882
Kesilir	1.2207	1.7321	0.8171	0.1246	0.6882
Sabrang	1.2207	1.7321	0.8171	0.2661	0.6882
Sumberejo	1.2207	1.7321	0.8171	0.4125	0.6882
A1	1.2207	1.7321	0.8171	0.1506	0.6882
Tutul	0.8138	1.1547	0.5448	0.4632	0.6882
Balung	0.8138	1.1547	0.5448	0.2893	0.6882
Jambearum	0.8138	1.1547	0.5448	0.5167	0.6882
Puger	0.8138	1.1547	0.5448	0.8806	0.6882
Sukorejo	1.2207	2.3094	0.4767	0.5258	0.6882
Keting	1.2207	1.1547	0.4767	0.1521	0.6882
Gambirono	1.2207	0.5774	0.4767	0.3583	0.6882
Paleran	1.2207	2.3094	0.4767	0.6230	0.6882
Gumelar	1.2207	1.1547	0.4767	0.2950	0.6882

Note: MINI = Main irrigation network infrastructure, TINI = Tertiary irrigation network infrastructure

3.3. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

Data processing with the TOPSIS method in this study also produces ranking values like the previous method, where the results of the evaluation can be seen in Table 8. The TOPSIS method was first introduced by Hwang & Yoon (1981), and this method is one of the techniques for making decisions based on multiple criteria. This method has a simple but complex concept in problem-solving. The concept of solving this method, which means choosing the best alternative that not only has the shortest distance from the positive ideal solution but also has the longest distance from the negative ideal solution, is the reason why this method was chosen by the researcher (Utama, 2017).

Table 9 shows the final results of the calculation of the priority values for each secondary channel based on their proximity to the positive (D^+) and negative (D^-) ideal solutions. The priority values are used to determine the recommended action, namely Management or Development. The separation between management and development recommendations provides more targeted technical policy direction and budget allocation.

Table 9. Priority value of irrigation network development and management with the TOPSIS Method

Secondary channel	D+	D-	Priority Values	Priority Ranking	Recommendations
Paleran	1.84	1.848	0.812	1	Management
Sukorejo	1.41	1.824	0.788	2	Management
Demangan	1.39	1.387	0.694	3	Development
Ampelbloh	1.34	1.347	0.673	4	Management
Lojejer	1.32	1.331	0.662	5	Management
Tamansari	1.31	1.315	0.648	6	Development
Sumberrejo	1.25	1.303	0.637	7	Development
Bunder Nogosari	0.95	1.299	0.633	8	Development
Sabrang	0.93	1.279	0.603	9	Development
Tanjung Rejo	0.88	1.274	0.592	10	Development
A1	0.84	1.271	0.577	11	Management
Kesilir	0.75	1.271	0.572	12	Development
Puger	0.74	0.954	0.432	13	Development
Gumelar	0.71	0.727	0.352	14	Management
Jambearum	0.68	0.707	0.349	15	Development
Tutul	0.66	0.701	0.337	16	Development
Keting	0.61	0.673	0.334	17	Development
Balung	0.49	0.604	0.304	18	Development
Gambirono	0.43	0.469	0.203	19	Development

3.4. Priority Analysis and Relationship between Methods

The priorities for the development and management of 19 secondary channels with this method result in different sequences. However, 3 secondary channels are always in the top 3 rankings, namely the secondary channels Peleran, Sukorejo, and Demangan. Based on Table 10, it can be seen that the SAW, WP, and Topsis methods show the ranking of priority results on the three secondary irrigation canals assessed. According to the Regulation of the Minister of PUPR No.30/PRT/M/2015 which discusses the development and processing of irrigation systems, it states that management includes operation, maintenance, and rehabilitation activities while development includes new construction activities or repairs and improvements to existing irrigation networks. In simple terms, management means operation, maintenance, and rehabilitation which are maintenance to repair and maintain irrigation infrastructure. Meanwhile, development means new development and improvements that improve the performance of irrigation infrastructure.

Table 10. Comparison of priority ratings between MADM methods

Method	Paleran	Sukorejo	Demangan
SAW	1	2	3
WP	1	3	2
TOPSIS	1	2	3

Figure 2. Condition of the secondary channels with high priority: (a) Paleran, (b) Sukorejo, and (c) Demangan

Based on field observations (Figure 2a), the tertiary network in the secondary canal of Paleran has value of severely damaged, the channel is filled with plants and weeds, and the wall of the channel is still in the form of soil, while the availability of water in the Paleran channel is only for 7 months with a service area of 885 Ha. Other channels that are still in the highest ranking are the Sukorejo (Figure 2b) and Demangan (Figure 2c) channels where these channels serve the availability of water in an area of 747 Ha and 965 Ha. In the secondary channel of Sukorejo there is damage to the channel where it is in the form of walls that are holes, collapsed, and broken, besides that there is also a collection of garbage that covers the Sukorejo channel. Because the irrigation canal was previously only used to irrigate rice fields, the surrounding community used it as a garbage dump because it was needed to develop and manage where the youth organization had to play a role (Susanto, 2014). Based on these conditions, it is necessary to make efforts to improve and cooperate well with the surrounding community to restore irrigation assets according to needs.

Recommendations for the three channels are development and management efforts. Actions that must be taken include development activities in the form of high sediment removal, cleaning of wild plants, and repairing damaged canal walls. Meanwhile, management activities such as the removal of sediment, garbage, and weeds and the repair of channel walls are to the needs of the Sukorejo channel. In the Demangan Canal, it is necessary to carry out development activities such as the construction of channel walls, repair of channel walls, and the removal of sediment and weeds in the channel. Public awareness of the importance of maintaining irrigation networks is the main thing that must be done by P3A (Agustyawan & Sabilla, 2021).

4. CONCLUSION

The evaluation of priority location determination using the SAW and Topsis methods shows the same priority order. It can be concluded that the secondary channel Paleran, the secondary channel Sukorejo, and the secondary channel Demangan are in the top 3 channels, where the irrigation canal has suffered moderate to severe damage. The channel requires priority recommendations in the form of periodic development and management activities such as repairs and construction of damaged irrigation assets.

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