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Prioritization of Irrigation Areas Based on the Analytical Hierarchy Process (AHP) at the Rokan Hulu Regency, Riau, Indonesia

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ABSTRACT

The Riau Province, Indonesia has launched a Program of Food Self-Sufficiency (Operasi Pangan Riau Mandiri program) since 2013, which the main objective was to achieve self-sufficiency in the rice production. Under the local government budget constraints, only small numbers of the existing irrigated areas were able to be further developed. The Analytical Hierarchy Process (AHP) method was applied in assisting the local government of the Rokan Hulu regency in selecting and prioritizing which irrigated areas will be developed. This study identified five significant criteria for the development of irrigated area, such as: (i) institutional capacity building criteria (weight value = 45.6%), (ii) technical one (21.3%), (iii) economic (19.2%), (iv) social/culture (8.1%), and (v) environmental criteria (5.8%). The higher the weighted value of the criteria, the more important it will be. The priority irrigation areas in need to be developed were as the following order: (i) Kaiti Samo irrigation area (weight value = 56%), (ii) Menaming irrigation area (20%), (iii) Palis (14%), and (iv) Perak (10%). These criteria may fit the research objective in selecting the most important irrigated location to be developed.

Keyword: decision, analytical hierarchy Process, irrigation areas, priority

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1. INTRODUCTION

For many years rice as the major carbohydrate resources for population living in Riau province, was supplied from the neighboring provinces such as West Sumatra, Jambi and from the Java Island. In 2015, Riau produced 247,000 ton of rice (38%), approximately 403,000 ton (62%) was imported from other areas to fulfill the demand. In order to achieve self-sufficiency in rice production for the province of Riau, this province launched a food self-sufficiency program (OPRM), 2013.

In order to support the implementation of the OPRM, the Rokan Hulu regency seeks opportunity to develop existing irrigation areas for rice fields such as in Kaiti Samo, Menaming, Palis, and Perak [1], [2]. Under the local government's budget constraints (APBD) and the limited central government budget (APBN), it is necessary to prioritize the development of the existing irrigation areas based on a systematic decision-making process in accordance with the local conditions and the region's potential [3].

This research objectives were to identify and prioritize the most important irrigated areas to be developed from 4 identified locations in Rokan Hulu, such as; (i) Palis River, (ii) Perak River, (iii) River Menaming, and (iv) Kaiti Samo, at Rokan Hulu Regency, Riau Province, Indonesia, and to establish development criteria which met stakeholders' objectives.

Hierarchy is defined as a representation of a complex problem in a multi -level structure consists of; first level is a goal, second level is a number of criteria, third level is some sub-criteria, and so on. The final level is defined as alternatives or options [4]. By structuring the hierarchy, complex problems can be decomposed into relatively a small number of groups. Then these groups were then organized into a hierarchical form. Finally, the problem would appear in a relative simple structure to be any further analysed [3], [4], [5].

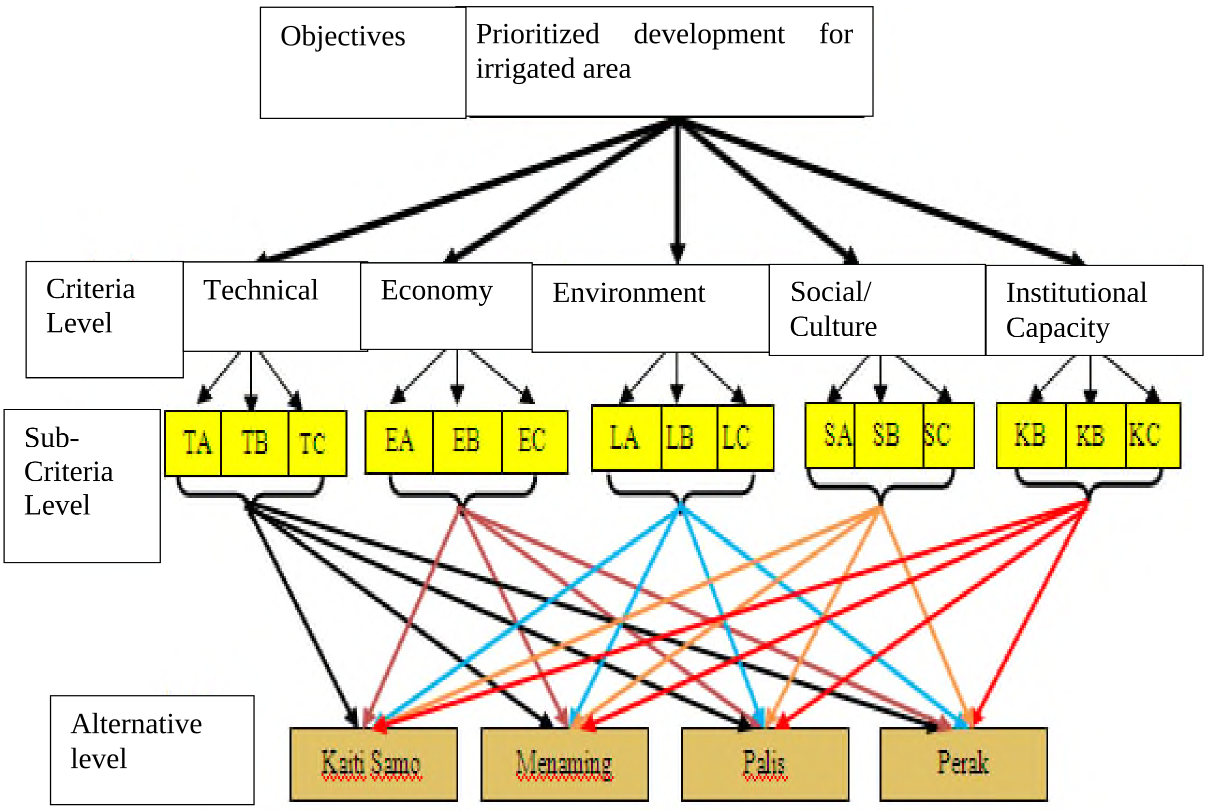
4. METODOLOGY

The hierarchical structure of the irrigated areas planned for the Rokan Hulu, Riau province was developed as the following Figure 1.

At least 2 main steps required in the developing of the AHP for this case study [6], [7], [8], [9], [10]. They are:

1. Defining the Problem.

It is essential to determine the problem clearly, in detail, and understandable. The main problem in this study is to determine which irrigated area is prioritized to develop. Four irrigated areas were then investigated, such as irrigated area in Kaiti Samo, Menaming, Palis and Perak.



2. Developing Hierarchy Structure

Firstly, determine the main objectives of this study, namely "top-level prioritization of irrigation area development plan". Secondly, develop five significant criteria i.e.; (i) technical criteria, (ii) economic criteria, (iii) environmental, (iv) cultural and social, and (v) institutional. Thirdly, develop hierarchy of sub-criteria levels. At the initial stage, there were identified 21 sub-criteria. Then, these sub-criteria were reduced to 15 criteria, because this study restricted to review 3 sub-criteria for each single criterion (5 x 3 = 15 sub-criteria). Finally, choose the best alternatives of irrigation area based on the AHP [11], [12]. This study also used application for presenting the final results [13].

Descriptions:
(i) Technical:
TA = the presence of a person in charge as the water regulator
TB = Irrigation network functionality
TC = Coordination with irrigation agency (Public Work Department. and Agricultural Department.).
(ii) Economy:
EA = Direct cost to construct and rehabilitate the irrigation construction.
EB = Operation and maintenance cost.
EC = Field productivity rates
(iii) Environment:
LA = Existing construction of irrigation infrastructure
LB = Availability of water resources
LC = Water storage capacity
(iv) Social/Culture:
SA = Capacity institutional of farmers
SB = Capacity building of individual farmers
SC = Coordination performances among farmers' in their group (P3A)
(v) Institutional Capacity:
KA = Capacity institutional of farmers
KB = Capacity building of individual farmers
KC = Coordination performances among

Fig. 1. Hierarchy Criteria to Define Priority in the Development of Irrigated Areas in Rokan Hulu Regency, Riau Province, Indonesia

A. Pairwise Comparison Matrix

The advantage of AHP is its ability to combine both qualitative and quantitative elements. In order to quantify the qualitative elements (e.g. which one is more importance between technical and economy criteria), a pairwise comparison scale can be applied.

According to Saaty [4], the grading scale of 1 to 9 is the best option to apply in AHP (Table 2). For this case study, matrix 5x5 was

Table 1. The Fundamental Scale in AHP

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment moderately favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Very strong importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Extremely importance	The evidence favouring one activity over another is the highest possible order of affirmative
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
reciprocals	If activity i has one of above number assigned to when compared with activity j, then j has reciprocal value when compared with i.	
rational	Ratios arising from the scale. If consistency were to be forced by obtaining n numerical value to spin the matrix.	

applied (Table 1).

1. Weighted the Calculated Elements

a. Mathematical calculation process in the AHP method is done by using a comparison matrix. If in a subsystem operation is n elements of A1, A2, ..., An, then the comparison of the elements of the operation will form a matrix of size nxn with a shape as shown in Table 2.

b. Changing value A12 using the rules as follow:

- If $a_{12} = \alpha$, then $a_{21} = 1/\alpha$.
- If operated A_1 and A_2 have equal importance then $a_{12} = a_{21} = 1$.

A diagonal matrix = 1.

Table 2. Pair Wise Comparison Matrix for this case study (matrix of 5x5)

	A1	A2	A3	A4	A5
A1	1.00	a12	a13	a14	a15
A2	1/a12	1.00	a32	a42	a52
A3	1/a31	1/a23	1.00	a43	a53
A4	1/a41	1/a24	1/a34	1.00	a54
A5	1/a51	1/a25	1/a35	1/a45	1.00

B. The Calculation of Consistency and the Priority Factors

According to Saaty, 1990, a consistency value of 100 % is not mandatory in the AHP method, since the calculation of the elements according to the decision makers are sometimes changed. The theory of this comparison matrix accommodates a small error in the coefficients. This will lead to small deviations as well to the eigenvalue ones. If the main diagonal of the matrix A is worth one, and if it is consistent, it will then yield a small deviation from aij. However, this is still showing the largest eigenvalue λ maximum. This value will approach the eigenvalues n and the rest will be zero. The deviations from the declared consistency are calculated as Consistency Index (CI), by the following equation:

CI = lmax – n / (n-1) (i)

Where: max l = eigenvalue maximum,

n = matrix dimension

Consistency Index (CI) at above equation is a random matrix with a rating scale of 1 to 9 and its opposite as Random Index (RI). The RI values are specified in Table 3.

Table 3. Values of Random Index (RI) Based n Matrix Dimensions

Number of Matrix (n)	Random Index / RI (inconsistency)
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

This study used 5x5 matrix dimension (with RI of 1.12).

The comparison between CI and RI for a matrix is defined as the ratio of consistency (CR) as shown in the following equation:

CR = CI/ RI (2)

Where: CR = ratio of consistency

RI = random index

The acceptable value of consistency ratio (CI) is ≤ 0.1.

The case study for this research is located in four irrigation areas, encompassing; (i) Palis River in District of Rokan IV Koto covering a-potential field of rice plantation area of 220 hectares, (ii) Perak River in District Bangun Purba covering 43 hectares, (iii) River Menaming in District Rambah covering 250 hectares, and (iv) Kaitisamo River in the district Samo Rambah covering area of 738 hectares (Fig. 2).

Two phases of site investigations were conducted in this research; preliminary survey, and detailed investigation. These investigations involved four main groups of respondents. They were 11 experts from; the Department of Agriculture Rokan Hulu, Department of Horticulture and Irrigation Rokan Hulu, Department of Highways and Irrigation (BMPU) Rokan Hulu, and a group of local farmers (P3A).

3. RESULT AND DISCUSSION

A. Data Analysis for Preliminary Investigation

The main objective of this preliminary investigation was to identify the most significant sub-criteria affecting to each single criterion. Initially, there were identified 5 criteria compromising 28 sub-criteria. Then this paper simplified and reduced these sub-

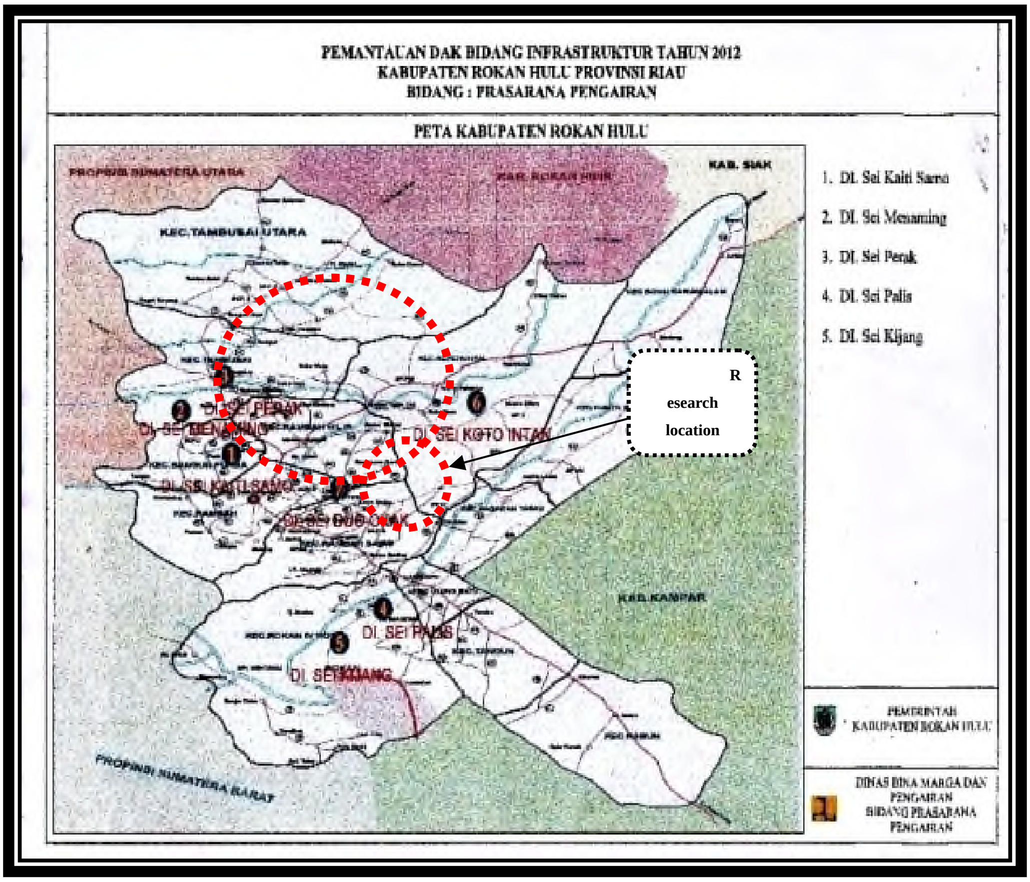


Figure 2. Location Map of Rokan Hulu Regency

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criteria to become 15 significant sub-criteria using Lickers scale of: 1 (low effect), 2 (medium), 3 (high), and 4 (very high)). For example, for sub-criteria of irrigated channel performance was considered as highly effected to the technical criteria (scale 3) by 7 responders, and 4 responders considered this is will yield very high effect to the existing technical criteria (scale 4). Total responders= 11 persons. The relative value of sub-criteria of irrigated channel performance = (7x3) + (4x4) = 37.

1. Technical criteria

There were identified 3 significant sub-criteria under technical criteria, namely: (i) condition and function of the existing irrigation network, (ii) irrigated channel performances, and (iii) the presence of a person in charge (PIC) as the water usage regulator. These sub-criteria are considered very important to yield the best quality performances for this technical criterion (Fig. 3).

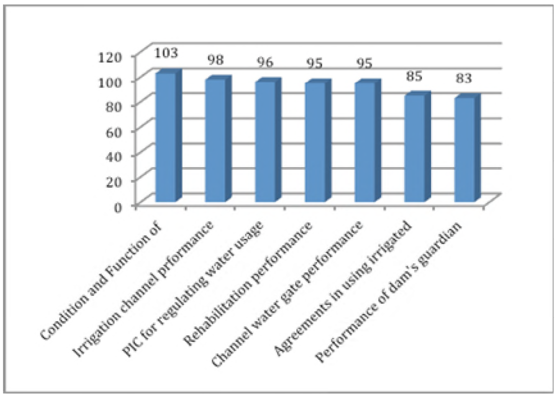

Fig. 3. Scoring of Sub-Criteria Effecting to the Technical Criteria

This is because of during an early planting season, rice fields need adequate water. Hence the condition and function of irrigation networks as well as water channels are very crucial to ensure adequate water supply to the rice fields continuously (Eryani I.GST AG PT, Indayati Lanya, Santosa I GST NGR, I Nyoman Norken, 2014). In order to maintain adequate amount and continuity of the water flow in the water channels, it is required the presence of persons in charge (PIC) who were responsible for managing and distributing water channel fairly to all rice field areas.

2. Economy Criteria

An availability of government budget is considered very important factors in ensuring sustainability of irrigation infrastructure investment, operation and maintenance, as the main financial resources were obtained from the local government budgets (APBD) and the Central Government budgets (APBN). The productivity rates of rice fields within a certain area are also considered is as an important sub-criterion prior to establish decision (in the development of rice fields) (Fig. 4).

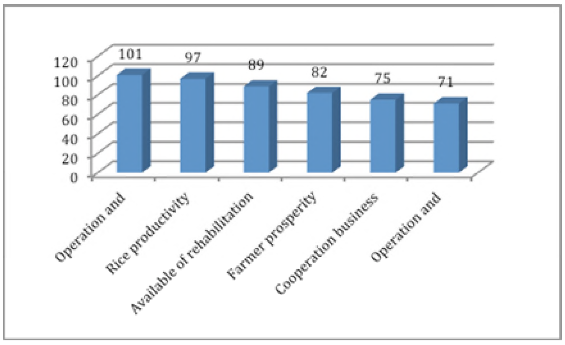

Fig. 4. Scoring of Sub-Criteria Effecting Economic Criteria

3. Environmental Criteria

Environmental criteria may include three main sub-criteria, namely: vast of rice field areas, the availability of water resources, and adequacy volume of water resources (Fig. 5).

Obviously, the magnitude scale of the rice field areas as the main sub-criterion need to be put into consideration, prior to finance the irrigation systems. The larger the rice field areas, the more significant they are to be. This consideration should be in line with the availability of water resources as well as its debit in meeting agriculture water demand especially during the dry seasons [15].

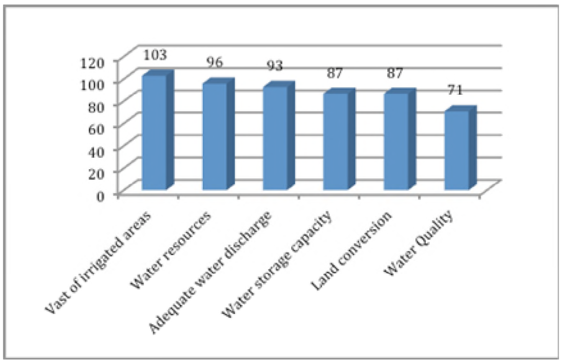

Fig. 5. Scoring of Sub-Criteria Effecting Environment Criteria

There were identified 3 significant social culture sub-criteria, such as: (i) local and social culture of the local farmers, (ii) adequate number of farmers in the irrigated areas as local labours, and (iii) legal factor of land use and land ownership. According to the regulations Rokan Hulu No. 6 year 2010, the development of agricultural lands including rice field areas, should follow the existing spatial plans. This regulation is made to guarantee the legal ownership of the agricultural lands. Once disputes of land ownership occur among the local farmers, these problems would hinder the development of the existing irrigation areas.

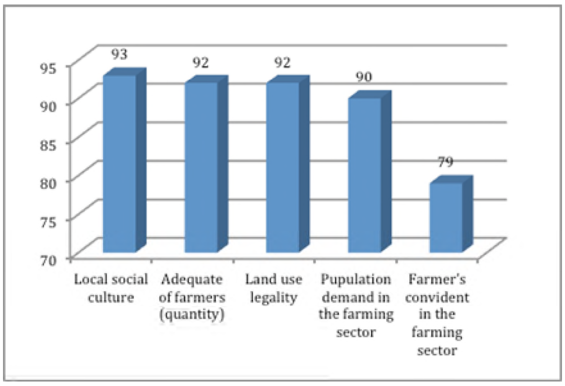

Fig. 6. Scoring of Sub-Criteria Effecting Social/Culture Criteria.

5. Institutional criteria

Prior establishing a decision in the development of irrigation areas, it is required some sub-criteria readiness to take place, including; (i) the existing farmers' institution capacity building (P3A). The main function of this institution was to organize its farmer members in maintaining of the existing irrigation network, (ii) adequacy of farmers' organization performance in managing its members in utilizing fertilizer, planting the rice, and harvesting the rice, and (iii) strong

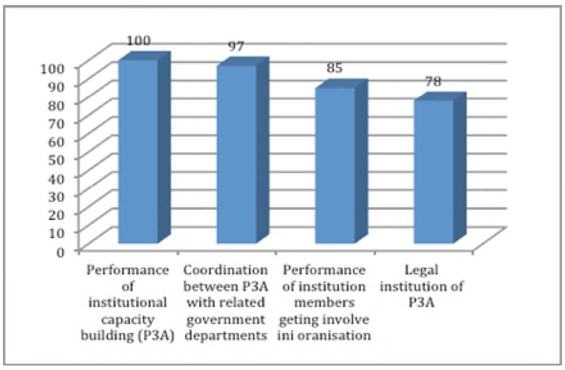

Fig. 7. Scoring of Sub-Criteria Effecting Institutional Criteria

Table 3. Comparison Matrix of Criteria

	Technical (A1)	Economic (A2)	Environmental (A3)	Social Cultural (A4)	Institutional (A5)
Technical (A1)	1.00	1.00	3.00	5.00	1.00/3.00=0.33
Economic (A2)	1.00	1.00	3.00	3.00	1.00/3.00=0.33
Environmental (A3)	1.00/5.00=0.20	1.00/3.00=0.33	1.00	0.33	1.00/5.00=0.20
Social Cultural (A4)	1.00/5.00=0.20	1.00/3.00=0.33	3.00	1.00	1.00/5.00=0.20
Institutional (A5)	3.00	3.00	5.00	5.00	1.00
Sum	5.53	5.67	15.00	14.33	2.07

coordination between P3A with the local Public Work Department and Agricultural Department in order to improve rice production rates.

B. Analysis of Detail Survey

The detail survey objectives were to compare each element based on (i) criteria levels, (ii) sub-criteria levels, and (iii) alternative levels.

Based on the interviewed data obtained from the experts, the following results were drawn; Relationship between; (i) technical (A1) and economic (A2) is equal importance (1.00), (ii) relation between technical (A1) and environmental (A3) is moderate importance of one over another (3.00), (iii) relation between technical (A1) and social cultural (A4) is strong importance (5.00), and (iv) relation between technical (A1) and institutional (A5) is also moderate importance of one over another (1.00 / 3.00 = 0.33). The following matrix 5x5 shows the comparison matrix of criteria:

This comparison matrix was then normalized by dividing value of each single column with the amount of the pertinent column, for example: relationship between A1 and A1 is 1.00 / 5.53 = 0.18, relation between A1 and A2 is 1.00 / 5.67 = 0.18, relation between A1 and A3 is 3.00 / 15.00 = 0.20, relation between A1 and A4 is 5.00 / 14.33 = 0.35, and relation between A1 and A5 is 0.33 / 2.07 = 0.16 (Table 4).

In order to obtain Eigenvector of this matrix, it is necessary to calculate the total value criteria each single line of the normalized matrix and divide them with 5 (the amount of matrix lines), for example; Eigenvector for technical criteria (A1) is (0.18 + 0.18 + 0.20 + 0.35 + 0.16)/5 = 0.21.

Table 4 Normalization matrix and Eigenvector criteria

	Technical (A1)	Economic (A2)	Environmental (A3)	Social Cultural (A4)	Institutional (A5)	Sum	E-Vector
Technical (A1)	0.18	0.18	0.20	0.35	0.16	1.07	0.21
Economic (A2)	0.18	0.18	0.20	0.21	0.16	0.93	0.19
Environmental (A3)	0.06	0.06	0.07	0.02	0.10	0.31	0.06
Social Cultural (A4)	0.04	0.06	0.20	0.07	0.10	0.46	0.09
Institutional (A5)	0.54	0.53	0.33	0.35	0.48	2.24	0.45
Sum	1.00	1.00	1.00	1.00	1.00	5.00	1.00

This Eigenvector was then multiplied by the comparison matrix in order to yield the following results.

The results of each single parameter above, were then divided by the Eigenvector matrix in order to obtain Eigenvalues, for example: 1.19 : 0.21 = 5.59, 1.01 : 0.19 = 5.44, 0.31 : 0.06 = 5.14, 0.47 : 0.09 = 5.09, and 2.41 : 0.45 = 5.39. An average of Eigenvalues above was then calculated and it was 5.33.

Then Consistency Index (CI) is calculated by using the following equation:

$$CI = \frac{\lambda_{max} - n}{n-1} = \frac{5.33 - 5}{5 - 1} = 0.08$$

Based on the Random Index (RI) Table 3, it was identified that RI was 1.12.

Then the Consistency Ratio (CR) of this calculation was defined as the following equation

$CR = \frac{CI}{RI} = \frac{0.08}{1.12} = 0.07$ < 0.10 (the comparison matrix was accepted as the maximum acceptable CR=0.10). This can be seen in Fig. 8.

Matrix integrity was then check as the following calculation:

1. Technical (A1) = (A1A1 x A1A2 x A1A3 x A1A4 x A1A5) $^{1/5}$
   = (1.00 x 1.00 x 3.00 x 5.00 x 0.33) $^{1/5}$
   = 1.380
2. Economic (A2) = (A2A1 x A2A2 x A2A3 x A2A4 x A2A5) $^{1/5}$
   = (1.00 x 1.00 x 3.00 x 3.00 x 0.33) $^{1/5}$
   = 1.246

Table 5 Multiplication of the comparison matrix and Eigenvector criteria

1.00	1.00	3.00	5.00	0.33		0.21		1.19
1.00	1.00	3.00	3.00	0.33		0.19		1.01
0.33	0.33	1.00	0.33	0.20	X	0.06	=	0.31
0.20	0.33	3.00	1.00	0.20		0.09		0.47
3.00	3.00	5.00	5.00	1.00		0.45		2.41

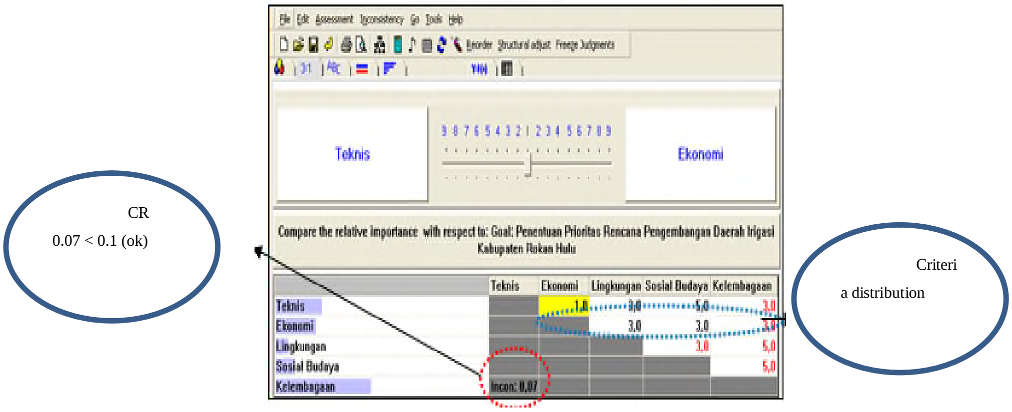

Fig. 8. Consistency Ratio of the AHP results.

3. Environmental (A3) = (A3A1 x A3A2 x A3A3 x A3A4 x A3A5) $^{1/5}$
   = (0.33 x 0.33 x 1.00 x 0.33 x 0.20) $^{1/5}$
   = 0.375
4. Social Cultural (A4) = (A4A1 x A4A2 x A4A3 x A4A4 x A4A5) $^{1/5}$
   = (0.20 x 0.33 x 3.00 x 1.00 x 0.20) $^{1/5}$
   = 0.525
5. Institutional(A5) = (A5A1 x A5A2 x A5A3 x A5A4 x A5A5) $^{1/5}$
   = (3.00 x 3.00 x 5.00 x 5.00 x 1.00) $^{1/5}$
   = 2.954

Total = 1.380 + 1.246 + 0.375 + 0.525 + 2.954
= 6.480

Then in order to identify the prioritize criteria (in percentage), it was then calculated as follow:

1. Technical (A1) = (1.380/6.480) x 100 = 21.29 %
2. Economic (A2) = (1.246/6.480) x 100 = 19.22 %
3. Environmental (A3) = (1.380/6.480) x 100 = 5.79 %
4. Social Cultural (A4) = (1.380/6.480) x 100 = 8.11 %

Institutional (A5) = (1.380/6.480) x 100 = 45.59 %

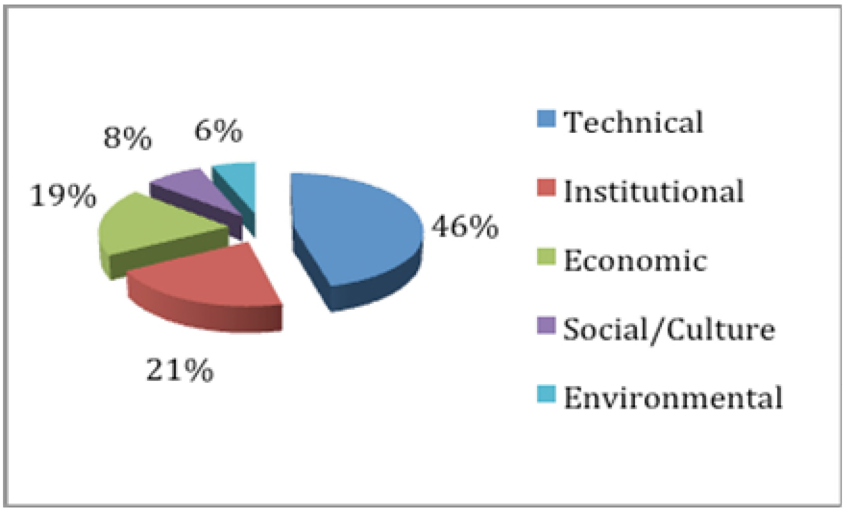

Fig. 9. Priority criteria obtained from the AHP results.

Based on Figure 9, the AHP analysed the level of prioritize criteria for the development of irrigation system in the research location, was as the following list ; (i) institutional capacity building criteria (compromising 45.6 % of the total existing criteria), (ii) technical criteria (21.3 %), (iii) economic criteria (19.2 %), (iv) social and cultural criteria (8.1%), and (v) environmental criteria (5.8%). The higher the percentage, the more important the criteria will be. The consistency ratio (CR) for these criteria was 0.07 (< 0.1), which it means that this calculation is consistent. Then, the results are acceptable.

Based on the above analysis, the most important criteria in determining the priority of the development plan is institutional capacity criterion. It is very obvious that, as a strong farmer institution and capacity building may ensure sustainability operation of irrigation systems. As a consequence, this may also improve the rice production rate. A relative importance of each criterion is shown in Figure 9.

It was identified that, first priority for the development of irrigation areas in Rokan Hulu, was Kaiti Samo (57%), second priority was Menaming (20%), third priority Palis (14%), and the last one was Perak (9%) (Table 6 and Fig. 10).

Table 6. Criteria Significant to Develope the Existing Irrigation Areas in Rokan Hulu

Alternative Location	*Priority Preferences (%)*
Kaiti Samo	*57%*
Menaming	*20%*
Palis	*14%*
Perak	*9%*
Total	*100%*

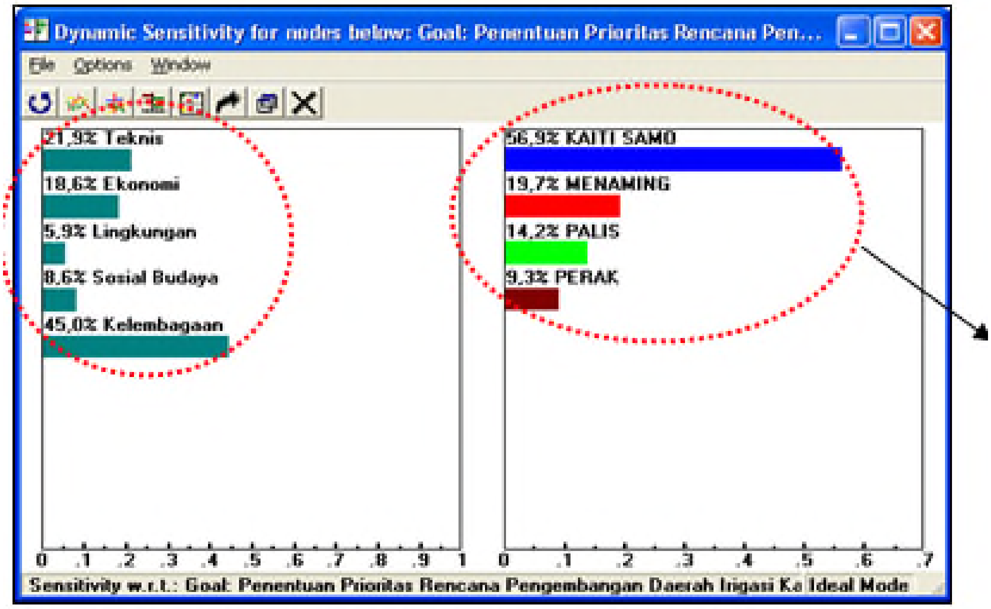

Fig. 10. Prioritized irrigated area needs to develope based on the significant development criteria (in Percentage)

The Kaiti Samo area has adequate readiness criteria to develop such as well establish of the existing farmers' institutional capacity building (P3A), the condition of irrigation networks were relatively functioning, adequate of the government budget allocations (from APBD and APBN) to maintain and operate the irrigation systems, adequate number of farmers as local labours, sufficient water resources from Kaiti Samo rivers, vast rice field areas (>700 ha), and relative high rice production rates. Hence, based on the implementation of AHP the decision for developing irrigated area has been done systematically and achieving its paper objectives.

4. CONCLUSION

The significant criteria for the development of irrigation areas in Rokan Hulu were established as the following order; firstly institutional criteria, secondly technical, thirdly economic, fourthly social/cultural, and the last one was environmental criteria. The first prioritized irrigated location in need to be developed was Kaiti Samo area as this location yield the highest alternative level (57%).

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