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Optimization of water distribution for channel irrigation networks Krueng Baro Kiri scheme (Aceh-Indonesia)

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Abstract. The standard area of Krueng Baro irrigation scheme is 11.950 Ha, divided into *Baro Kanan* irrigation (8,920 Ha) and *Baro Kiri* irrigation (3.030 Ha). This irrigation focuses on increasing the productivity of food crops in Pidie District. Previous research reported that the distribution efficiency of the *Baro Kiri* primary channel (74,1%) was smaller than the *Baro Kanan* (86,8%). The decreasing efficiency level of the channel results in a large number of unirrigated paddy fields that which in turn decrease the rice productivity. This study aimed to determine the optimum area of the rice fields that can be irrigated and examine the amount of discharge distributed to each channel by minimizing water loss. The method used was the optimization linear program. The optimization had the objective function of minimizing water loss. The land area was a decision variable, while the water loss in each channel and the water availability in each weir were the constraint function. The optimization results created an area of 2.810 Ha out of 3.030 Ha total area of rice fields in *Krueng Baro Kiri* by minimizing water loss in each channel based on the efficiency value of each channel. The rice field terrace that had highly reduced from the standard area in the *Krueng Baro Kiri* were the ones in the channel section of R4 and R5, 10 Ha of the standard rice field area. This occurred because these two channel sections (R4 and R5) had the smallest efficiency value of 47,26%, and 58,03%, respectively.

1. Introduction

The *Krueng Baro* irrigation scheme focuses on increasing the productivity of food crops in Pidie District, which has a total area of 11.950 Ha divided into the *Baro Kanan* (8.920 Ha) and the *Baro Kiri* irrigation scheme (3.030 Ha). The location of the *Krueng Baro* irrigation scheme is presented in figure 1. Some efforts to increase the productivity of food crops include expanding the planting area and implementing the intensive method on the existing land. One of the efforts to increase food production is establishing good water allocation to evenly distribute the water to each rice field terrace [1]. However, various current water allocation systems require to be reviewed because of the water supply is not optimal for each rice field terrace. One of the factors influencing this condition is a large amount of water loss, causing the rice fields not to obtain enough water in the irrigation scheme. A large amount of water loss can be resulted from the damaged and leaking primary and secondary channels. Thus, it is necessary to optimize the irrigation water allocation spatially (between the terrace).

The irrigation water distribution is problematic if the available discharge is smaller than the water requirement (especially during the dry season). Thus, the efficient use of irrigation water is required.



The harvest is not only influenced by the fulfillment level of water needs but by way of providing water [2].

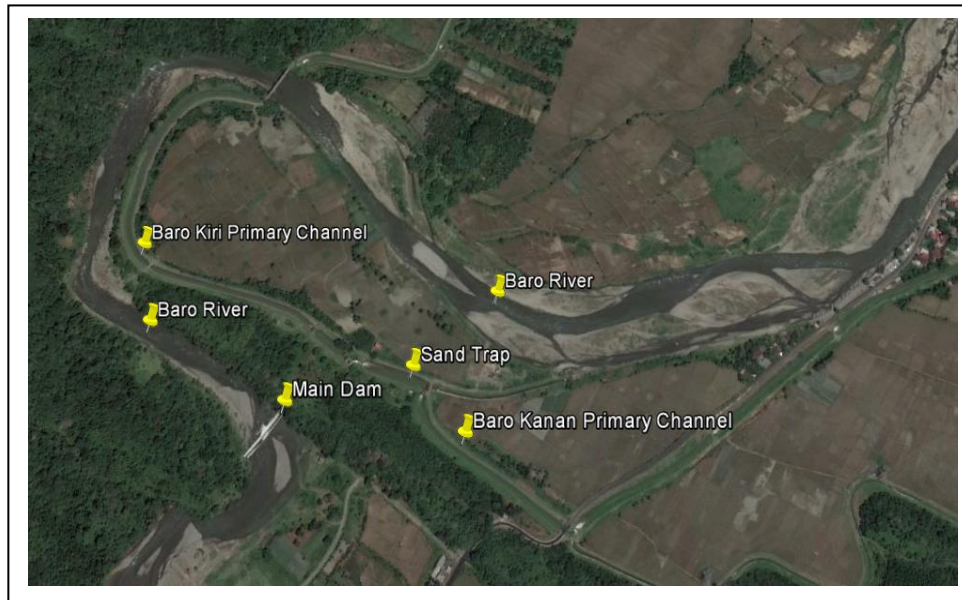


Figure 1. *Krueng Baro* irrigation scheme.

Efficiency is an examination of water provision compared to the needs. From an engineering point of view, the definition of irrigation efficiency is based on the fact that not all water supplied or tapped into the canal can be channeled to the tapping place/ irrigated land; some are lost [3].

Agricultural production, especially the paddy fields in the upstream of Krueng Baro irrigation scheme, has met the agriculture's target, around 5 to 6 tons/ha. However, those in the downstream areas did not reach the goal because of the lack of water. The planting intensity in Baro irrigation scheme is currently twice a year, Paddy-Paddy. The planting realization in MT I and MT II are 9.015 Ha and 8.030 Ha, respectively. The total planting realization is 17.046 Ha. The Planting Index (PI) in Baro irrigation scheme is 143%, while the percentage of planting realization area is 71% [4].

According to Azmeri et al. [5] the distribution efficiency of the Baro Kiri primary channel is smaller than the distribution efficiency of Baro Kanan channel. The actual efficiency level of Baro Kiri primary channel is 74,1%, meaning that the water loss along the Baro Kiri primary channel is 15,9% from the efficiency of the design conditions (90%). On the other hand, Baro Kanan primary channel has a distribution efficiency of 86,8%, indicating that the water loss along the channel is 3,2% of the efficiency of design conditions (90%). A large amount of water loss in the irrigation channel of Baro Kiri is due to the damage and leakage leading to the number of unirrigated rice terrace. Thus, it is necessary to optimize the water allocation in each channel by minimizing water loss.

Azmeri et al. [6] stated that an optimization model is usually formed by combining the system behavior and the objective function of the system. The constraint system objective is created by being the objective function. Next, suitable mathematical algorithms will be selected to be applied to the optimization. Sometimes, the optimization model of a system requires to be simplified the form of the optimization algorithm used, to meet the requirements of one optimization algorithm.

The results of a research conducted by Azmeri et al. [5] showed that the implementation of cropping patterns in Krueng Baro Kiri irrigation scheme is not optimal. The cropping pattern consists of only two planting seasons yearly, namely MT I and MT II. The best and ideal planting schedule in Baro Kiri irrigation scheme is October II as it produces the largest planting area.

Based on the problem statement above, this study aimed to analyze the optimum area of the Baro Kiri Irrigation scheme that can be irrigated, the discharge distributed to each channel by optimizing the water loss minimizing.

2. Methodology

Problems concerning irrigation water allocation often occur if the amount of available discharge is smaller than the water required (especially during the dry season); thus, efficient use of irrigation water is needed. This study conducted the water allocator process employing the Linear Program using Solver in Microsoft Excel for optimization and its stages. The optimization was carried out to obtain the land area and the discharge distributing into each primary and secondary channel. The limitation, an obstacle in optimization, is the water availability that must be greater or equal to the water requirements for each rice field terrace.

The optimization using linear program is undertaken by creating mathematical equation model based on the objective function, constraint function, and non-negative mathematical model function built according to the objective function to achieve. The stages of optimization are:

2.1. Initial optimization variable

The creation of the optimization algorithm must consider the variables of the objective function and the constraint function. This study had several primary variables that were used to solve the optimization, as presented in table 1.

2.2. Optimization using linear program

The optimization solutions of several alternatives and scenarios were obtained using the Solver program. The solver was activated through the Manage Excel Add-Ins feature and displayed in the Data Analysis menu. This study analyzed basic solutions in linear programs to find the best combination of resources and constraints to obtain the optimal results/conditions so that they can be interpreted and used for decision-making. The mathematical model in this linear program was created based on the objective function to achieve. The formulation of the optimization analysis consisted of:

2.2.1. The objective function. The objective function to achieve was to minimize the water loss in the irrigation channel, aiming to irrigate all rice field as needed. This objective function was an equation consisting of the independent variable which will be optimized, and the form of its function is to minimize water loss.

Minimum water loss:

$$\sum_{i=1}^n (Q_{Ri} * E_i) \quad (1)$$

Where:

Q_{Ri} = Distribution discharge of each channel in Baro Kiri irrigation scheme (m³/sec);

E_i = The water loss in each irrigation channel (%); and

n = The number of irrigation channels.

2.2.2. The constraint function. This constraint function was an equation limiting the main use, and the form of this function is the water availability in the Krueng Baro river and the sufficient amount of water reaching the related place.

Constraint:

➤ Irrigation water demand:

$$\sum_{i=1}^n Q_{Ri} \leq Qsj \quad (2)$$

➤ The water distributed:

$$\sum_{i=1}^n (Q_{Ri} * Ei) + Q_{Ri} \leq Q_{sj} \quad (3)$$

Where

$$Q_p = DR \times A_i \quad (4)$$

Decision Variable: the land area (A)

Where:

Q_{Ri} = distribution discharge of each channel in *Baro Kiri* irrigation scheme (m³/s);

Q_{sj} = the availability discharge in the weir (m³/s);

Ei = the water loss in each channel (%);

A_i = the coverage of each channel (Ha); and

DR = the water demand at the intake valve (m³/s).

Table 1. Initial variables in each channel in Krueng Baro Kiri irrigation scheme.

No	Channel Section	Efficiency (%)	Initial
1	BBrkr 1 - BBrkr 2	88.83	R1
2	BBrkr 2 - BBrkr 3	70.25	R2
3	BBrkr 3 - BBrkr 4	67.39	R3
4	BBrkr 4 - BBrkr 5	47.26	R4
5	BBrkr 5 - BBrkr 6	58.03	R5
6	BBrkr 6 - BBrkr 7	84.92	R6
7	BBrkr 7 - BBrkr 8	84.42	R7
8	BBrkr 8 - BBrkr 9	78.3	R8
9	BBrkr 9 - BBrkr 10	87.26	R9
10	BBrkr 10 - BRb 1	80.03	R10
11	BRb 1 - BRb 2	64.27	R11
12	BRb 2 - BRb 3	85.51	R12
13	BRb 3 - BRb 4	77.95	R13
14	BBrkr 10 - BLk 1	78.24	R14
15	BLk 1 - BLk 2	88.27	R15
16	BLk 2 - BLk 3	75.72	R16
17	BLk 3 - BLk 4	88.44	R17
18	BLk 4 - BLk 5	87.83	R18
19	BLk 5 - BLk 6	81.77	R19
20	BBrkr 6 - Bla 1	90.69	R20
21	Bla 1 - Bla 2	91.29	R21
22	Bla 2 - Bla 3	88.53	R22
23	Bla 3 - Bla 4	89.54	R23
24	Bla 4 - Bla 5	89.13	R24
25	Bla 5 - Bla 6	89.33	R25
26	Bla 6 - Bla 7	61.03	R26
27	Bla 7 - Bla 8	67.89	R27

3. Results and discussion

The optimization process and stages in this study employed the Linear Program using Solver in Microsoft Excel. The optimization was used to obtain the optimum land area by minimizing the water loss in each channel in the *Krueng Baro Kiri* irrigation scheme. The constraints in the optimization calculation were the land area and the water availability in the weir that serves the *Baro Kiri* irrigation scheme. Table 2 presents the optimization results of optimum rice field area by minimizing water loss in each channel in the *Baro Kiri* irrigation scheme.

Table 2 shows that the planned rice field is smaller than the standard area of the rice fields served by *Krueng Baro Kiri* Dam. The discharge available at this weir was 4,469 m³/sec, while the discharge required was 4,814 m³/sec. The total standard area of rice fields that should be irrigated by *Keumala Kiri* Dam was 3,030 Ha, while the total of rice fields that can be irrigated based on the water availability in the optimization results was 2,810 Ha. This finding indicates that 220 ha of rice field terrace that cannot be served due to lack of water available in the weir.

The channel section of R4 had the smallest efficiency value in *Krueng Baro Kiri* irrigation scheme (47.26%), with the water loss of 52.74%. The optimization results showed that R1, R20, R21, R23, R24, and R25 channel section were reduced by 7 Ha of the total standard area, while R2, R3, R11, R26, and R27 channel sections were decreased by 9 Ha of the standard area. The rice field terrace with the highest area reduction compared to the standard area in the *Krueng Baro Kiri* irrigation scheme were R4 and R5 channel section, 10 Ha decline of the standard area. This occurs because R4 and R5 were the channel sections with the smallest efficiency values (47, 26% and 58.03% respectively), indicating that these channel section had the highest water loss.

Table 2. The optimization results of optimum rice field area by minimizing water loss in each channel in the *Baro Kiri* irrigation scheme.

No	Channel Section	Initial	Efficiency (%)	Water Loss (%)	Water Demand (m ³ /s)	Total Standard Area (Ha)	Optimization of Total Area (Ha)
1	BBkr 1 - BBkr 2	R1	88.83	11.17	0.193	154	147
2	BBkr 2 - BBkr 3	R2	70.25	29.75	0.229	160	151
3	BBkr 3 - BBkr 4	R3	67.39	32.61	0.080	70	61
4	BBkr 4 - BBkr 5	R4	47.26	52.74	0.236	147	137
5	BBkr 5 - BBkr 6	R5	58.03	41.97	0.301	189.5	180
6	BBkr 6 - BBkr 7	R6	84.92	15.08	0.146	119	111
7	BBkr 7 - BBkr 8	R7	84.42	15.58	0.180	141	133
8	BBkr 8 - BBkr 9	R8	78.3	21.7	0.027	39	31
9	BBkr 9 - BBkr 10	R9	87.26	12.74	0.262	200	192
10	BBkr 10 - BRb 1	R10	80.03	19.97	0.500	247	239
11	BRb 1 - BRb 2	R11	64.27	35.73	0.383	210	201
12	BRb 2 - BRb 3	R12	85.51	14.49	0.017	40	32
13	BRb 3 - BRb 4	R13	77.95	22.05	0.040	49	41
14	BBkr 10 - BLk 1	R14	78.24	21.76	0.013	37	29
15	BLk 1 - BLk 2	R15	88.27	11.73	0.053	55	47
16	BLk 2 - BLk 3	R16	75.72	24.28	0.163	103	95
17	BLk 3 - BLk 4	R17	88.44	11.56	0.038	49	41
18	BLk 4 - BLk 5	R18	87.83	12.17	0.116	81	73
19	BLk 5 - BLk 6	R19	81.77	18.23	0.323	170	162
20	BBkr 6 - Bla 1	R20	90.69	9.31	0.136	89	82
21	Bla 1 - Bla 2	R21	91.29	8.71	0.005	36	29
22	Bla 2 - Bla 3	R22	88.53	11.47	0.053	55	47
23	Bla 3 - Bla 4	R23	89.54	10.46	0.018	41	34
24	Bla 4 - Bla 5	R24	89.13	10.87	0.131	87	80
25	Bla 5 - Bla 6	R25	89.33	10.67	0.309	160	153
26	Bla 6 - Bla 7	R26	61.03	38.97	0.274	160.5	151
27	Bla 7 - Bla 8	R27	67.89	32.11	0.241	141	132

4. Conclusion

Based on the optimization results of the land area by minimizing the water loss in *Krueng Baro Kiri* Irrigation scheme, it can be concluded that The total area of optimized rice field by minimizing the water loss in each channel section based on the efficiency value of each channel is 2810 Ha out of 3.030 Ha total area of rice fields in *Krueng Baro Kiri*.

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