Income Optimization by Utilizing Rotiklot Dam Irrigation and Marginal Agricultural Land in Border Area

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Abstract. The study aims to (1) build a linear programming model and determine the optimal volume of dam water that maximizes farmers' income based on plant types and field area for two growing seasons; (2) modify the linear programming model by incorporating marginal land, (3) test model sensitivity to obtain information about farmers' income when the government program "planting corn and harvesting cows" is implemented. The research was conducted in Fatuketi Village, which is the only area irrigated by Rotiklot Dam for agricultural purposes, with a land area of 159 ha in 2021. Agricultural commodities cultivated by the farmers consist of rice and corn. The data analysis is based upon a linear programming model for income maximization and its simulation with 300 ha of marginal land having the potential to be managed into new agricultural land, as well as testing the sensitivity of corn cultivation models covering 10%, 20%, 25%, and 50% of the area. The model analysis suggests that maximum income can be achieved when farmers cultivate only rice on the land, with a total income of Rp.1,270,070,000. The model also recommends planting rice on all marginal lands (300 ha) so that the total income increases to Rp.3,666,428,000. The sensitivity analysis suggests that cultivating maize on 10%, 20%, 25% and 50% of the 159-ha land will result in income decrease, namely to Rp.1,228,923,000, Rp.1,144,846,000, Rp.1,102,807,000 and Rp.1,067,682,000 respectively, while for the marginal land, the income will decline to Rp.3,547,645,000, Rp.3,428,862,000, Rp.3,369,471,000, and Rp.3,075,861,000 respectively.

Keywords: Dam Irrigation · Income Optimization · Linear Programming · Marginal Agricultural Land · Sensitivity Analysis

1 Introduction

The Indonesian government seeks to create justice within the framework of a unitary state by encouraging Indonesia's development from the periphery (border areas). One of the efforts made is to build supporting infrastructure that can drive strategic sectors of the domestic economy. [1] states that the construction of service facilities and infrastructure

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is one of the important components of development. This effort is expected able to realize the economic independence of each region and accelerate the improvement of the quality of life of the people of the border areas. The research of [2] explains that regular infrastructure development can increase the economic growth of the region.

Water resource infrastructure is urgently needed to be built in the NTT region because the problem of drought is a challenge for the NTT government in increasing agricultural production. In general, the NTT region is an area that has a dominant dry climate. This also causes the use of land for agriculture to be less than optimal because some of the lands is not processed and becomes critical land.

Belu Regency as the territory of the Unitary State of the Republic of Indonesia bordering the Democratic State of Timor Leste (RDTL) is a special concern of the Indonesian government. The government's priority in the border areas in Belu Regency is regional structuring and improving the quality of the economy through the agricultural sector and infrastructure development that further supports food security. The agricultural sector in Belu Regency is a strategic sector because it has the largest contribution to GRDP, which is 22% [3] so it becomes one of the export-oriented food barns development areas based on the Keputusan Menteri Pertanian No. 215/Kpts./OT.050 /2/2017 [4].

Farmers in the Belu Regency area have been planting rice only once a year with a rainfed farming system because the rainy season lasts from November to April and there is no source of irrigation water to meet water needs during the summer. Sufficient water resources are urgently needed to irrigate agricultural land, thus encouraging the Indonesian government to build the Rotiklot Dam as an effort to meet agricultural water needs around the border areas.

The Rotiklot Dam is one of the solutions carried out by the central government to overcome the drought problem in the Belu Regency, especially in the agricultural sector. Rotiklot Dam is the third largest dam in NTT Province, located in Fatuketi Village, Kakuluk Mesak District, Belu Regency. This dam has a catchment area of 12.56 km^2 with a storage capacity of 2.79 million cubic meters to serve the population's raw water needs, develop irrigation areas for rice and corn, for hydroelectric power plants and become a tourist attraction and deal with floods. The Rotiklot Dam can irrigate 159 ha of agricultural land and is planned to irrigate 300 ha of marginal agricultural land [5]. The construction of the Rotiklot Dam has changed the farming habits of farmers around the dam. The planting season, which was previously held only once a year, has now increased to twice a year.

The availability of water in the Rotiklot Dam must be managed properly in order to optimize the agricultural production and income of border communities. In line with the findings of [6] in their research which states that irrigation development can increase agricultural production. Water from the dam that flows into agricultural land needs to consider the area of land, cropping patterns, water requirements for land preparation, water requirements for plant growth (evapotranspiration), water requirements for percolation (seepage), and water requirements for water layer replacement. One way to get optimal dam water management decisions is to use optimization mathematical models, such as linear programming, nonlinear programming, dynamic programming, and goal programming.

A study on the optimization of the impact of the Rotiklot Dam construction was carried out to obtain optimal solutions for agricultural production and income. A linear programming model is built and analyzed to determine the amount of dam water that can be utilized to provide maximum income to farmers based on the types of plants planted and the area planted during the two growing seasons [7]. Furthermore, the model is modified by involving marginal land that has the potential to be managed as agricultural land. Sensitivity analysis was carried out at the end of this study to determine the farmers' benefits when implementing the government program "planting corn and harvesting cows".

2 Research Method

This research was conducted in Fatukatei Village as the service area of the Rotiklot Dam for the agricultural sector. The area of agricultural land in Fatuketi Village is 159 ha and the area of marginal land that has the potential to be managed as agricultural land is 300 ha [5] The map of the research location is shown in Fig. 1.

Agricultural crops cultivated by farmers in Fatuketi Village are rice and corn which are cultivated twice a year, in November–April as the first planting season and May – October as the second planting season. In the first planting season, farmers use rainwater, while in the second planting season, farmers only use irrigation from the Rotiklot Dam because the average dry season rainfall is very small, which is 10.6 mm [8].

This study uses the following data: production, income, land area, and irrigation water needs. Agricultural production data and land area are primary data from interviews;

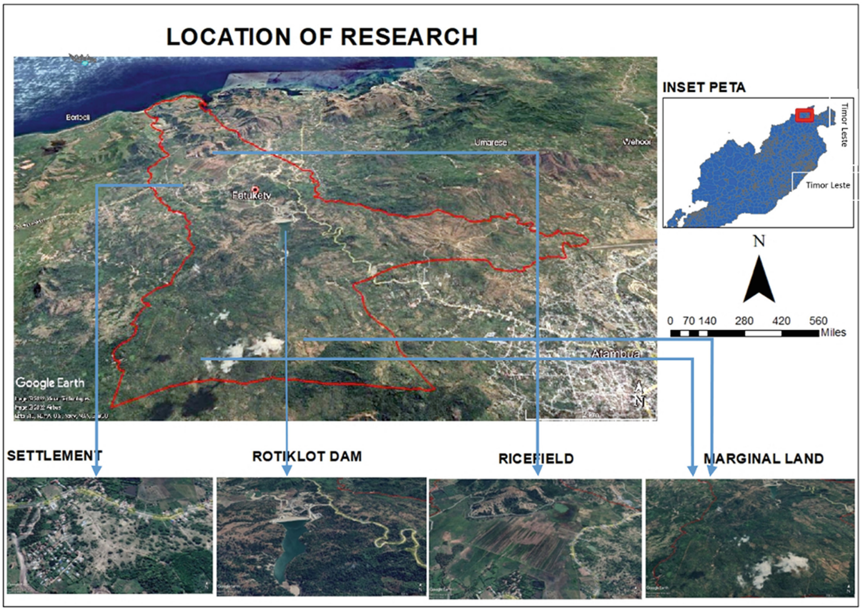

Fig. 1. Location of Research.

while data on agricultural income and water needs are obtained from the pre-analysis. Data requirements for income analysis include price, cost, and production data. Data for water needs analysis includes dam water volume, crop coefficient, and climatological data (such as rainfall, solar radiation, wind speed, humidity, and temperature).

The data analysis used in this research is to build a linear programming model for optimizing agricultural production and income using the constraints of existing land and water resources. Followed by an analysis of optimization of production and income using the constraint function of irrigation water resources and the accumulation of existing land with marginal land. Each optimization analysis is carried out as well as a sensitivity test. The stages of data analysis are shown in Fig. 2.

The stages of analysis are as follows:

1. The linear programming model for optimizing agricultural income and production is
   a. Objective Function

$$\max Z = \sum_j \sum_i C_i P_i X_{ij} \tag{1}$$

where:

i = commodity index, i.e. $i = 1, 2$; $i = 1$ for rice, and $i = 2$ for corn

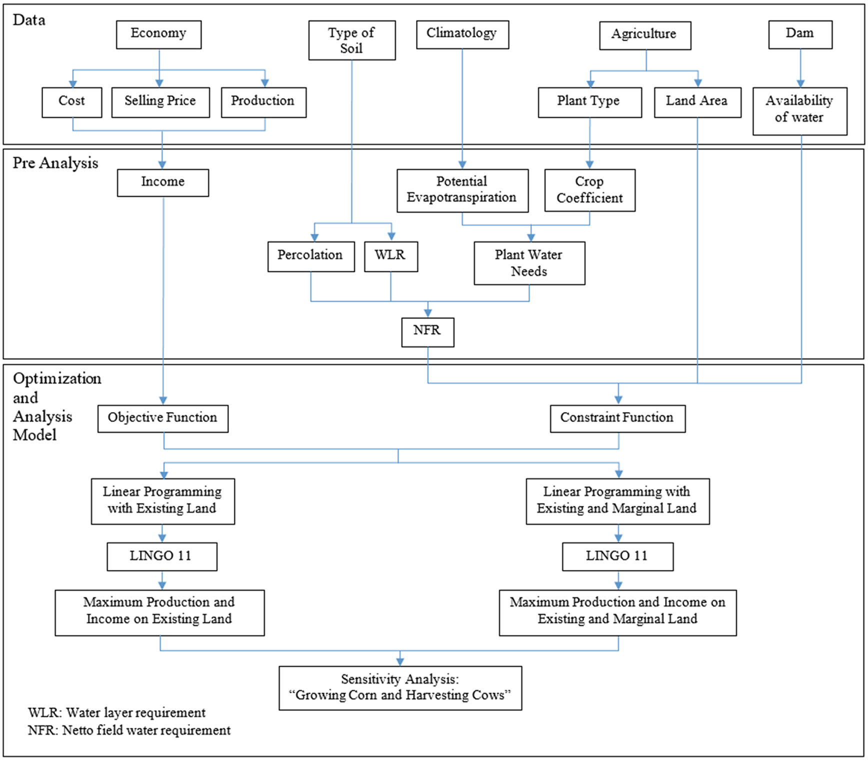

Fig. 2. Stages of Data Analysis.

j = planting season, i.e. $j = 1, 2$; $j = 1$ for first planting season, and $j = 2$ for second planting season
Z = maximum profit to be achieved (Rp)
C_i = net profit of commodity (Rp/kg)
P_i = crop production i per ha (rice = 2,218.85 kg/ha, corn = 2,700 kg/ha)
X_{ij} = area of existing land used to plant commodity i in planting season j.

b. Constraint Functions
 (i) Water Volume Constraint Function

This constraint is to ensure that the use of dam water for agricultural irrigation does not exceed the volume of dam water available for agricultural land. The model of this constraint function is

$$\sum_i V_i X_{ij} \leq V, \text{ for } j = 2 \tag{2}$$

Where:
V_i = volume of water requirement per hectare for the type of agricultural crop i (l/ha),
V = volume of available dam water (l).

The volume of water requirement per hectare for rice and corn is obtained by the formula [9]:

$$NFR = ET_c + WLR + P - R_e \tag{3}$$

and

$$NFR = ET_c + P - R_e \tag{4}$$

Where
NFR = Netto field water requirement (mm/day),
ETc = Water consumption for agricultural crops (mm/day),
P = Percolation (mm/day),
WLR = Water layer requirement (mm/day),
IR = water needs for land preparation (mm/day)
R_e = effective rain (mm/day).
with $ET_c = k_c \cdot ET_o$.
k_c = crop coefficient,
ET_o = Potential evapotranspiration (mm/day).

The water requirement for land preparation is calculated using the method developed by Van De Goor and Zijlstra [9]. The stages of determining water requirements for land preparation are formulated as follows:

Determine the water requirement (mm/day) to replace water loss due to evaporation and percolation in saturated rice fields (M):

$$M = ET_c + P \tag{5}$$

Determine the exponential constant of irrigation water requirements for land preparation (k):

$$k = \frac{M \cdot T}{S} \tag{6}$$

where
T = land preparation period (days)
S = water required for saturation (mm) plus 50 mm
Determine the water requirement (mm/day) for land preparation (IR):

$$IR = M \cdot \frac{e^k}{e^k - 1} \tag{7}$$

Where
e is an exponential number.

(ii) Planting Area Constraint Function

This constraint is to ensure that the total land area used for agricultural land in the dry season does not exceed the total available agricultural land area. The model of this constraint function is

$$\sum\nolimits_i X_{ij} \le A, \forall j \tag{8}$$

where A is the total of available agricultural land area (159 ha)

(iii) Non-negatives Constraint Function

This constraint is to ensure that the land area per hectare is not negative.

$$X_{ij} \ge 0, \ \forall i, j \tag{9}$$

2 The linear programming model to maximize the use of marginal land as agricultural land is

a. Objective Function

$$\max Z = \sum\nolimits_j \sum\nolimits_i C_i P_i (X_{ij} + Y_{ij}) \tag{10}$$

Where:
Y_{ij} = area of marginal land used to plant commodity i in planting season j

b. Constraint Function

(i) Water Volume Constraint Function

This constraint is to ensure that the use of dam water for agricultural irrigation on existing and marginal land does not exceed the volume of dam water available for agricultural land. The model of this constraint function is

$$\sum\nolimits_i V_i (X_{ij} + Y_{ij}) \le V, \ \text{for } j = 2 \tag{11}$$

Water needs analysis uses data that has been previously analyzed in the optimization model to answer the first problem.

(ii) Planting Area with Marginal Land Constraint Function

This constraint is to ensure that the total land area used for agricultural land in the dry season does not exceed the total available agricultural land area and the marginal land area used for agricultural land does not exceed the available land. The model of this constraint function is

$$\sum\nolimits_i X_{ij} \le A, \forall j \tag{12}$$

$$\sum_i Y_{ij} \leq B, \forall j \tag{13}$$

Where:
A = Available area of agricultural land (159 ha)
B = Available area of marginal land (300 ha)

(iii) Non-negatives Constraint Function
This constraint is to ensure that the land area per hectare is not negative.

$$X_{ij}, Y_{ij} \geq 0, \ \forall\, i, j \tag{14}$$

3. Sensitivity Analysis
This analysis was carried out by increasing the corn planting area by 10%, 20%, 25%, and 50%.

3 Results and Discussion

The analysis of the optimization of production and income of farmers in Fatuketi Village as a state border area that utilizes water from the Rotiklot Dam is carried out using the constraint functions of land area and water needs. Based on the results of the pre-research, the constraint function of the area of land cultivated by farmers by utilizing irrigation from the Rotiklot Dam in the second planting season is 159 ha. In addition, there is 300 ha of marginal land that can be used for the cultivation of food crops (rice and corn) using irrigation water from the Rotiklot Dam.

Water needs are the result of data analysis by considering the coefficient of plants and consumptive use of water for plants. It also considers the percolation of paddy fields based on soil type and rice-corn cropping patterns.

The results of the study found that in the first planting season the use of water came entirely from rainwater, while the second planting season came entirely from the irrigation water of the Rotiklot Dam, because there was almost no rainfall in the summer. Farmers in the border areas cultivate rice and corn on paddy fields with several combinations of cropping patterns. The combination of rice and corn cropping patterns on paddy fields in border areas that utilize water from the Rotiklot Dam is shown in Table 1.

The results also show that the soil texture on rice fields in the border area is classified as loam sandy. The percolation rate (P) for soil with loam sandy texture is 3 mm/day. The water requirement for soil saturation is 300 mm for a time (T) of 31 days.

Based on these data, an analysis of irrigation water needs for land preparation (IR) for rice plants was carried out, and water requirements for rice and corn plant growth in the second planting season. The results of the analysis found that the volume of water needed for rice plants is 8,548,416 mm^3 per hectare and 3,792,096 mm^3 per hectare for corn.

The average availability of water in the Rotiklot Dam for irrigation needs during the months of July–October is 2,935,000 m^3. The results of the analysis of the water requirements of each plant (rice and corn) and the data on the availability of water from the Rotiklot Dam were then used for optimization analysis.

Table 1. The Choice of Cultivate Patterns.

No.	Cultivate Patterns per Year	
	First Season	Second Season
1.	Rice	Rice
2.	Rice	Rice – Corn
3.	Rice	Corn
4.	Rice – Corn	Rice – Corn
5.	Rice – Corn	Corn

3.1 Analysis of Agricultural Production and Income Optimization Models Using Existing Land

Problems in the agricultural sector are the low level of productivity and climatic conditions that are difficult for farmers to control [10]. The low level of agricultural productivity has a direct impact on the low income of farmers so it is necessary to maximize agricultural production and income in Belu Regency. The development of rice and corn commodities needs to be carried out by utilizing irrigation water from the Rotiklot Dam and expanding agricultural land by utilizing marginal land so as to increase agricultural production and income in border areas.

The objective function of the optimization model is to maximize agricultural production and income based on the constraint function of the planting area for each type of plant and the availability of water in the Rotiklot Dam. The objective function is built based on the income per kilogram of each product, namely corn Rp. 1,000 per kg and rice Rp. 1,800 per kg. The constraint function is built based on the existing land area (159 ha), the availability of dam water for irrigation (2,935,000 m^3), as well as consumptive water needs for rice (8,548.416 mm^3 per hectare) and corn (3,792.096 mm^3 per hectare).

This model was completed with the help of the LINGO 11 software. The results obtained are the model recommends planting rice on the entire available land (159 ha) in the first and second planting seasons. The type of plant that is recommended to be cultivated is rice on the whole land with a total production of 705.6 t and an income of Rp. 1,270,070,000. These results indicate that farmers in Fatuketi Village need to cultivate rice commodities to obtain maximum income.

3.2 Analysis of Agricultural Production and Income Optimization Models by Utilizing Marginal Land

The importance of using marginal land is a priority for agricultural management planning in Fatuketi Village because there is excess water coming from the Rotiklot Dam. The marginal land area available in Fatuketi Village is 300 ha which can be used as agricultural land so that it has an impact on increasing agricultural production and income. As the results of previous studies by [11] state that the optimization strategy for the development of marginal land use to support the development of food crop commodities can be carried out by improving soil fertility and selecting various types of suitable and profitable food crops.

The objective function of the marginal land use optimization model is to maximize agricultural production and income based on the constraint function of planting area for each type of plant and the availability of water in the Rotiklot Dam. The objective function is built based on the income per kilogram of each product, namely corn Rp. 1,000,- per kg and rice Rp. 1,800,- per kg. The constraint function is built based on the existing land area (159 ha) and marginal area (300 ha), the availability of dam water for irrigation (2,935,000 m^3), as well as consumptive water needs for rice (8,548.416 mm^3 per hectare) and corn (3,792.096 mm^3 per hectare).

This model was completed with the help of LINGO 11 software. The results obtained are the model recommends all existing land (159 ha) and marginal land (300 ha) be used for rice cultivation with a maximum total production of 2,036.9 t/year and a maximum income of Rp. 3,666,428,000.

3.3 Sensitivity Analysis

Agricultural development efforts by the government are adjusted to the conditions and potential of the region that lead to integrated agriculture. The NTT Provincial Government has launched a program of "planting corn and harvesting cows". This program aims to improve the farmer's economy through the integration of corn – cattle. Corn and cattle commodities were chosen because these two commodities are inseparable from the dry land farming system in NTT, including Belu Regency, especially Fatuketi Village. The combination of corn - cattle can improve the economy of farmers as stated by [12, 13] that livestock plays a role as the backbone of the regional economy and an important source of income for farmers, while corn is the staple food for most people in NTT.

Sensitivity Analysis on Existing Land Model

Sensitivity analysis was carried out to determine agricultural production and income if farmers in Fatuketi Village implemented the government program "plant corn and harvest cows". This analysis was carried out by increasing the planting area of maize from the model recommendations, namely 0 ha, to 10%, 20%, 25%, and 50% of the existing land area (159 ha). The results of the sensitivity analysis are presented in Table 2.

The results of the sensitivity analysis found that if farmers in Fatuketi Village implemented the government program "plant corn and harvesting cows" by diverting part of the land to plant corn covering an area of 10%, corn production would increase to 85.9 t/year with a total income of Rp. 1,228,923,000. If the corn planting area is increased to 50% of the available land area, the corn production will increase to 430.7 t/year while the total income will decrease to Rp 1,067,682,000.

Although the income of farmers has decreased, this income does not include the income obtained by farmers from the cattle business, because the corn crop is used as quality cattle feed. Corn is a multipurpose commodity because almost all parts of the

Table 2. Sensitivity Analysis on Existing Land Model.

Percentage of Corn Cultivated Area Corn	Cultivated Area (ha)	Paddy Cultivated Area (ha)	Corn Production in a Year (ton)	Rice Production in a Year (ton)	Total Income (Rp)
10%	15.9	143.1	85.9	635.0	1,228,923,000
20%	31.8	127.2	171.7	564.5	1,144,846,000
25%	39.75	119.25	214.7	529.2	1,102,807,000
50%	79.75	79.75	430.7	353.9	1,067,682,000
10%	15.9	143.1	85.9	635.0	1,228,923,000

corn plant have potential economic value [14, 15] so further studies can be carried out to maximize farmers' income in Fatuketi Village with a combination of corn – cattle.

Sensitivity Analysis on Existing and Marginal Land Model

Sensitivity analysis of the existing and marginal land use optimization model to determine agricultural production and income when implementing the government program "plant corn and harvesting cows" is carried out by increasing the corn planting area by 10%, 20%, 25%, and 50%. The results of the sensitivity analysis are presented in Table 3.

The results of the sensitivity analysis found that if 10% of the existing (159 ha) and marginal (300 ha) land accumulation was used for corn cultivation, the corn production in Fatuketi Village would increase to 45.9 t/year with a total income of Rp. 3,547,645,000. If the additional corn planted area reaches 50%, the corn production will increase to 229.5 t/year with a total income of Rp. 3,075,861,000. The research of [16] stated that the "planting corn and harvesting cows" program was able to provide sufficient raw material biomass for animal feed production in NTT.

Table 3. Sensitivity analysis on existing and marginal land model.

Percentage of Corn Cultivated Area Corn	Cultivated Area (ha)	Paddy Cultivated Area (ha)	Corn Production in a Year (ton)	Rice Production in a Year (ton)	Total Income (Rp)
10%	45.9	413.1	247.9	1,833.2	3,547,645,000
20%	91.8	367.2	495.7	1,629.5	3,428,862,000
25%	114.75	344.25	619.7	1,527.7	3,369,471,000
50%	229.5	229.5	1,239.3	1,018.5	3,075,861,000
10%	45.9	413.1	247.9	1,833.2	3,547,645,000

4 Conclusion

The results of the optimization model analysis show that the availability of dam water is sufficient to meet the water needs of all agricultural land in Fatuketi Village throughout the year. Farmers are recommended to manage the entire existing land for rice cultivation for two growing seasons. The maximum income that can be obtained is Rp. 1,270,070,000.

The availability of marginal land of 300 ha can also be converted into agricultural land with the commodity being planted is rice for two growing seasons. The income to be obtained is Rp. 3,666,428,000 or 189% of the income without marginal land use.

The involvement of farmers in the "plant corn and harvest cow" program by planting corn on some land will reduce farmer's income from the sale of rice and corn production. However, farmer's income are predicted to increase further because corn yields can be used as quality cattle feed. Therefore, it is necessary to do further research to optimize agricultural income with a combination of corn – cattle.

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