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# Optimization Balongganggang Reservoir Capacity for Irrigation

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**ABSTRACT**

Indonesian agriculture is the largest economic contributor after the non-oil and gas industry. However, ensuring stability in agriculture poses a significant challenge, as indicated by BPS data in 2020 and 2022, showing a decrease in the rice sector in crop area and productivity value by 2.3%. Therefore, this research aimed to increase agricultural output by optimizing planting patterns and reservoirs in Balongganggang Irrigation Area and Reservoir, Sukodadi District, Lamongan Regency, East Java. Optimization of planting patterns was carried out using rainfall and climatology data from 2013 – 2022, with a linear programming method, facilitated by POM-QM for Windows V5 program. The process of optimization focused on two objectives, namely considering maximum land area and maximizing profit. According to the analysis, optimization based on land area and profit provided the same optimal value, leading to a 9.98% increase in planting intensity from 120.57% to 130.55%, with a profit of Rp 33,967,000,000.00.

## 1. Introduction

Indonesian agriculture is characterized by unstable growth patterns, particularly in Lamongan Regency, with significant fluctuation in rice production over the last 5 years [1][2]. This fluctuation is often experienced in areas such as Balongganggang, where approximately 2256 Ha of land is not fully irrigated due to lack of water supply. Balongganggang is an irrigation area that depends on water supply from Embung Balongganggang, a small reservoir of the entire Gondang Irrigation Area. However, the main source of water in this area is derived from the Gondang Reservoir network. To address the issue of limited irrigation, there is a need to enhance rice productivity by ensuring a consistent water supply. A good irrigation network and constant water supply can provide water demands for agricultural land throughout fferent periods [2][3][4]. Therefore, empowering the construction and maintenance of irrigation systems is essential to maximize crop yields [5][6]. Based on the background above, this research aimed to optimize planting patterns in the Balongganggang Irrigation Area with a linear programming method.

The main objectives of this research consist of three point, first to determine the impact of Gondang Reservoir scharge on Embung Balongganggang inflow discharge. Second, to determine the right planting pattern by the capacity of Balongganggang Reservoir, and the last to determine the impact of the use of reservoir capacity volume on water requirements in planting patterns.

## 2. Research Method

The first stage of this research included a comprehensive review of relevant literature such as scientific books, journals, reports, laws, and regulations. After understanding several theoretical frameworks, data collection was carried out based on the theory's requirements that have been investigated [7][8], which included:

a. Irrigation area
b. Rainfall data
c. Climatological data
d. Hydrological data
e. Data on the volume of reservoirs and the area of reservoir inundation.

The calculation and analysis process was carried out after data collection, which included:

a. Climatological analysis [9]
b. Hydrological analysis [10]
c. Analysis of irrigation water needs [11]

Further analysis was carried out to determine water requirements for each type of plant, assessing the discharge availability in the irrigation area. Subsequently, the linear programming method was optimized to obtain optimal planting patterns.

## 3. Results and Discussions

### 3.1 Hydrology Analysis

a. FJ Mock Analysis

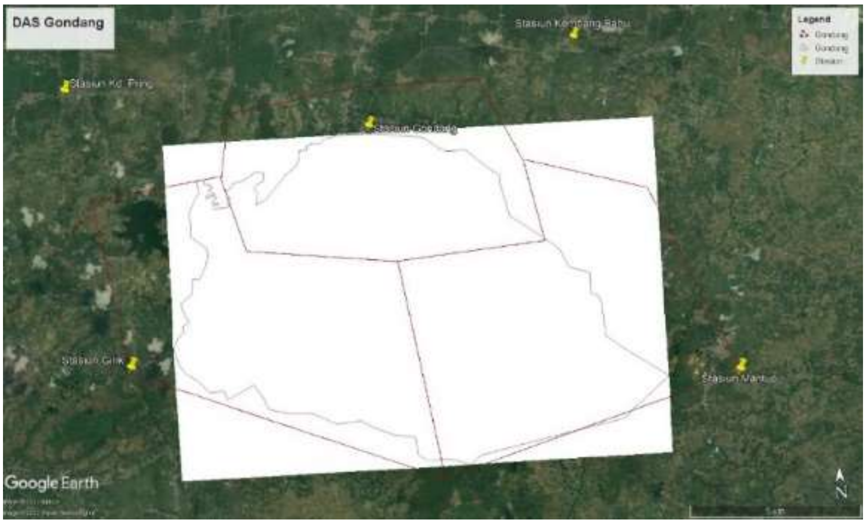
Hydrological data from FJ Mock analysis included rain stations and watershed areas [6][12]. The stations used included:

1. Gondang Station
2. Girik Station
3. Mantup Station

Subsequently, the weight factors of the three stations were calculated as shown in Table 1 [7].

**Table 1.** Ratio of Station to Watershed Areas

| | A ($m^2$) | Ratio |
|---|---|---|
| Girik | 26099261,12 | 0,37 |
| Mantup | 26071434,53 | 0,36 |
| Gondang | 19111321,54 | 0,27 |
| Total | 71282017,2 | 1 |




*Source: Research Data (2024).*

**Figure 1.** Map of the Gondang watershed and Polygon Thiessen Method subdivision

FJ Mock analysis was carried out to determine the price of actual evapotranspiration (Ep), water surplus (WS), base flow, and DSO to obtain the final value as the total runoff R. Subsequently, each analysis results from 10 years was ranked to obtain a discharge value with 80% reliability [5][6], and the final discharge, as shown in **Error! Not a valid bookmark self-reference.**.

**Table 2.** Recapitulation of discharge with FJ Mock Analysis

| Rank | Prob | Months | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 1 | 9.09% | 8.87 | 13.87 | 9.18 | 8.24 | 4.81 | 5.28 | 2.34 | 2.10 | 2.65 | 6.77 | 9.29 | 9.28 |
| 2 | 18.18% | 8.11 | 8.61 | 7.29 | 7.50 | 4.47 | 4.30 | 2.13 | 1.64 | 1.64 | 3.83 | 7.13 | 8.52 |
| 3 | 27.27% | 7.62 | 7.70 | 6.52 | 7.07 | 4.27 | 3.12 | 1.53 | 1.40 | 1.47 | 2.95 | 7.01 | 8.50 |
| 4 | 36.36% | 7.31 | 7.58 | 6.50 | 6.69 | 3.92 | 3.08 | 1.22 | 0.75 | 1.38 | 2.85 | 5.99 | 7.85 |
| 5 | 45.45% | 6.12 | 6.82 | 6.48 | 6.22 | 3.55 | 2.30 | 1.09 | 0.70 | 0.47 | 2.52 | 5.64 | 6.72 |
| 6 | 54.55% | 5.86 | 6.69 | 6.44 | 6.04 | 3.10 | 1.99 | 1.08 | 0.55 | 0.43 | 1.20 | 4.99 | 6.44 |
| 7 | 63.64% | 5.83 | 6.52 | 6.32 | 5.74 | 2.17 | 1.75 | 1.05 | 0.54 | 0.33 | 0.37 | 3.76 | 6.23 |
| 8 | 72.73% | 5.35 | 5.76 | 5.92 | 5.03 | 2.13 | 1.64 | 0.90 | 0.50 | 0.29 | 0.19 | 3.09 | 5.52 |
| 9 | 81.82% | 4.33 | 4.70 | 5.60 | 3.24 | 1.55 | 1.16 | 0.52 | 0.34 | 0.19 | 0.17 | 2.38 | 5.19 |
| 10 | 90.91% | 2.48 | 2.05 | 3.06 | 3.16 | 1.48 | 0.90 | 0.48 | 0.31 | 0.19 | 0.11 | 1.41 | 4.04 |
| Dependable flow 80% | | 4.54 | 4.91 | 5.66 | 3.60 | 1.67 | 1.26 | 0.60 | 0.37 | 0.21 | 0.18 | 2.53 | 5.26 |
| lt/dt | | 4535.11 | 4911.74 | 5659.57 | 3599.20 | 1670.58 | 1259.03 | 598.92 | 371.35 | 214.98 | 175.79 | 2525.54 | 5256.58 |
| Balong's Discharge (lt/s) | | 3150.01 | 3411.60 | 3931.03 | 2499.93 | 1160.36 | 874.50 | 416.00 | 257.93 | 149.32 | 122.11 | 1754.19 | 3651.13 |
| Balong's Discharge (m3/s) | | 3.15 | 3.41 | 3.93 | 2.50 | 1.16 | 0.87 | 0.42 | 0.26 | 0.15 | 0.12 | 1.75 | 3.65 |

*Source: Research Data (2024).*

Figure 2 shows illustrates the water flow from Gondang Reservoir to Balongganggang Reservoir.

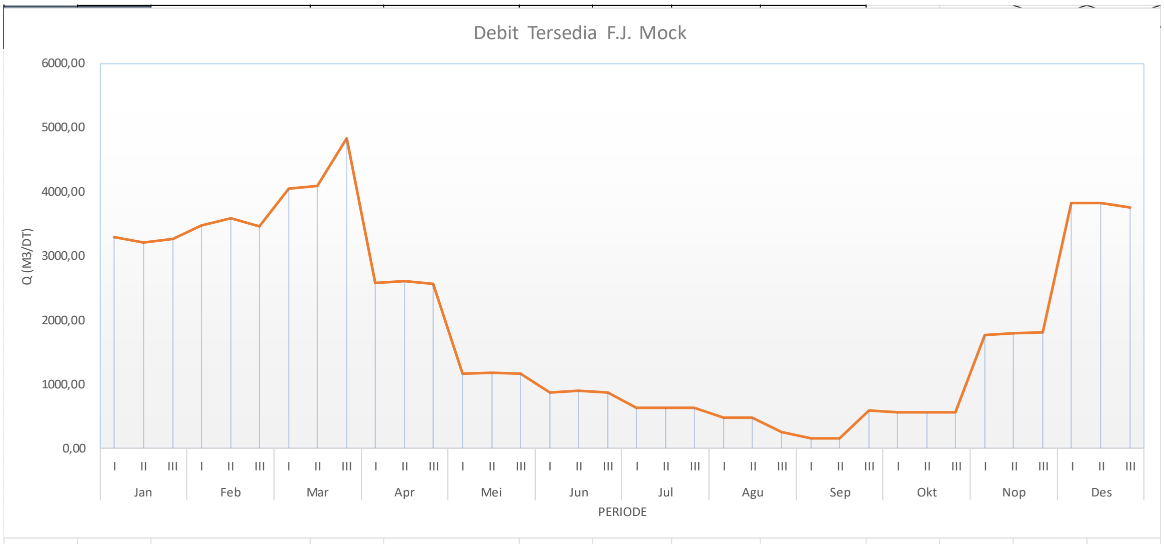

*Source: Research Data (2024).*
**Figure 2.** Water Flow diagram

The inflow value in Embung Balongganggang was [13]:

$Q_{Balongganggang}$ = $A_{Downstream}/(A_{Upstream} + A_{Downstream})$ x 100% x $Q_{80}$
= 2256/(992 +2256) x 100% x 4,54
= 69,46% x 4,54
= 3,15 m3/dt

b. Calculation of Reservoir Outflow discharge

In this research, reservoir outflow indicates discharge from the reservoir door. As shown in Figure 3, the graph of recapitulation of the total discharge used at the reservoir door has been added with the incoming discharge due to rain falling directly to the surface of the reservoir and the use of water reserves [14][15].

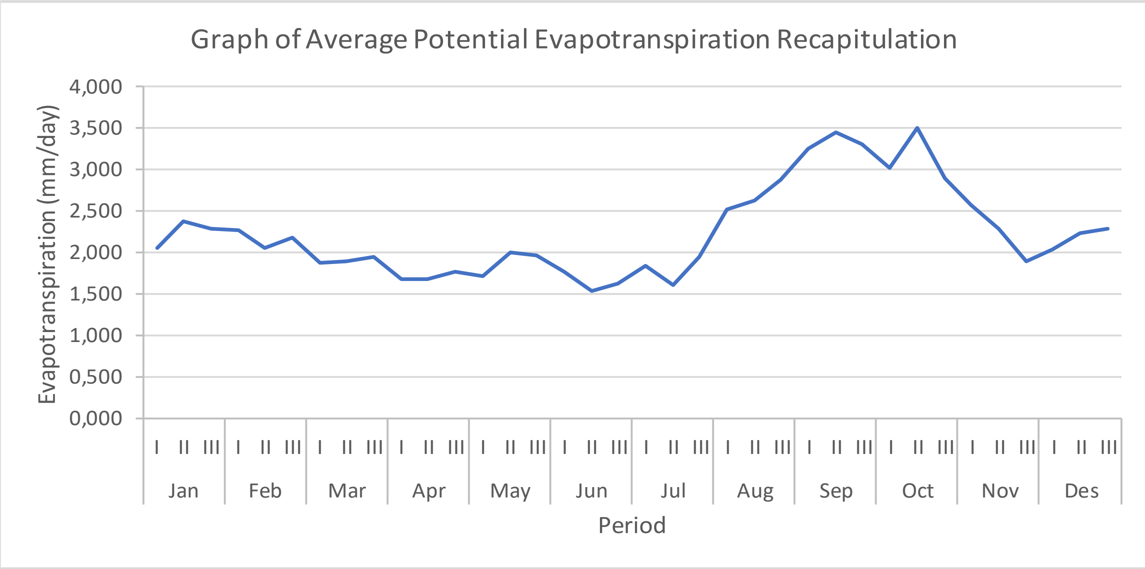



*Source: Research Data (2024).*
**Figure 3.** Discharge Available Chart with FJ Mock Analysis

### 3.2 Climatology Analysis

Climatological calculations were used to determine the amount of plant evapotranspiration, which included several data such as wind speed, air temperature, humidity, and solar irrigation [9][16]. This value served as a crucial input for analyzing runoff discharge using FJ Mock analysis and determining water needs for irrigation. The graph of recapitulation of the results obtained from evapotranspiration calculation is shown in Source*: Research Data (2024).*

**Figure**.




*Source: Research Data (2024).*

**Figure 4.** Average Potential Evapotranspiration Recapitulation Chart

### 3.3 Analysis of Irrigation Water Needs

Analysis of irrigation water needs was carried out in several stages

a. Average Rainfall

Average rainfall was calculated using the same method as FJ Mock analysis [6][14], which included two stations, namely Sukodadi Station and Pucuk Station [7].

$A_{\text{Sukodadi Station}}$ = 15.700.745 $m^2$

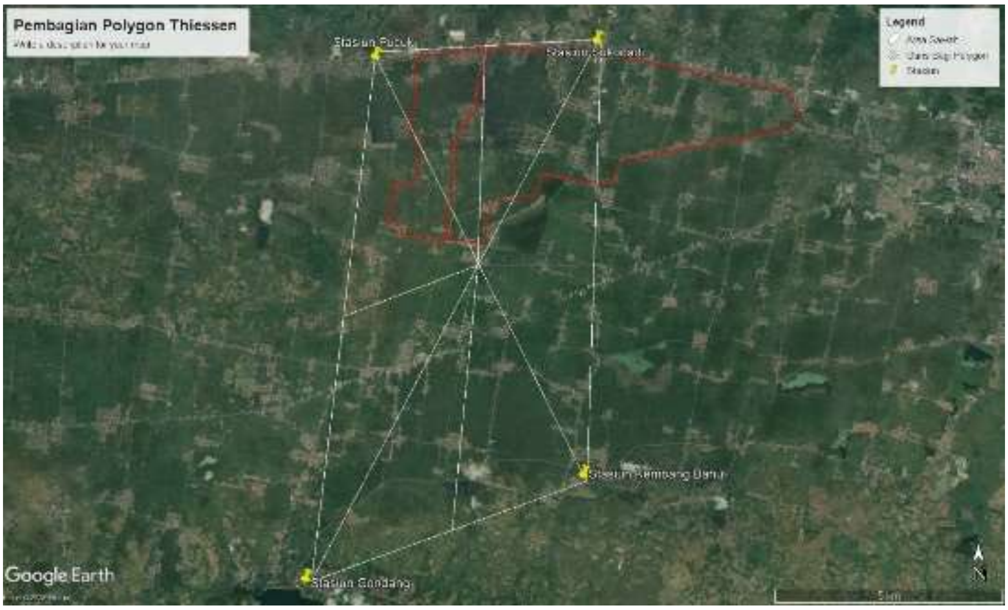
$A_{\text{Pucuk Station}}$ = 6.700.584 $m^2$

$A_{\text{Total}}$ = 22.401.329 $m^2$

$F_{\text{Sukodadi}}$ = 15.700.745 / 22.401.329 = 0,7

$F_{\text{Pucuk}}$ = 6.700.584 / 22.401.329 = 0,3

Based on the calculation, average rainfall results were obtained for each period. Subsequently, 10-year results were ranked and the value of $8^{th}$ rank, representing 80% was used for further analysis.

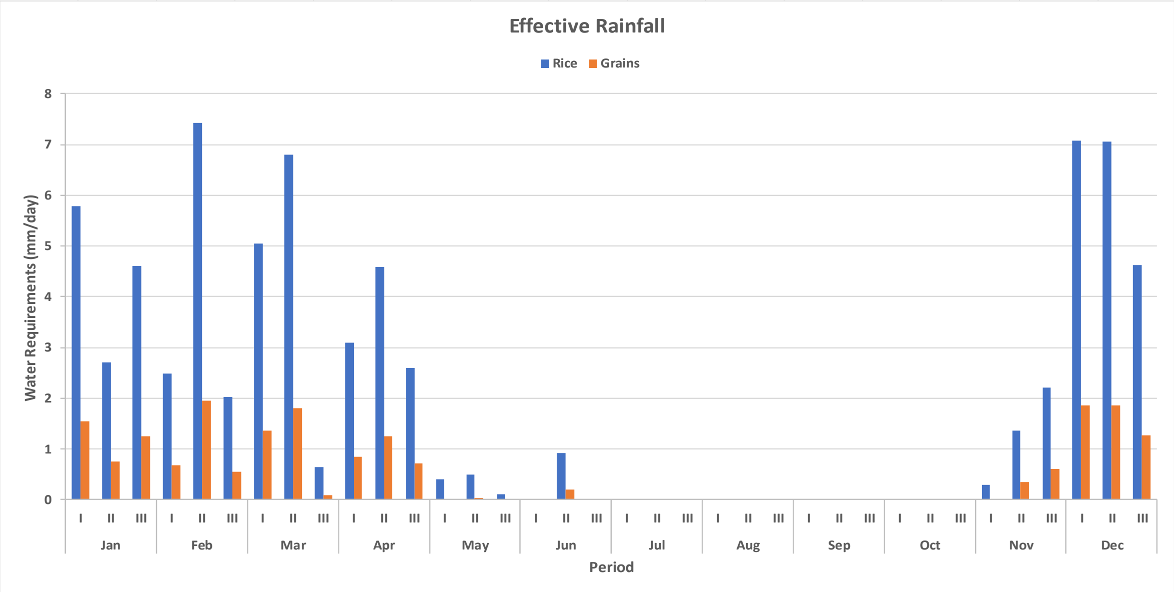



*Source: Research Data (2024).*

**Figure 5.** Thiessen Polygon vision in Rice Field Areas

b. Effective Rainfall

Effective rainfall is the probability of water adequately meeting the plant's needs, with a reliability threshold set at 80%. Moreover, Figure 6 shows recapitulation of the effective rainfall values for rice, corn, and mung beans [2][8].



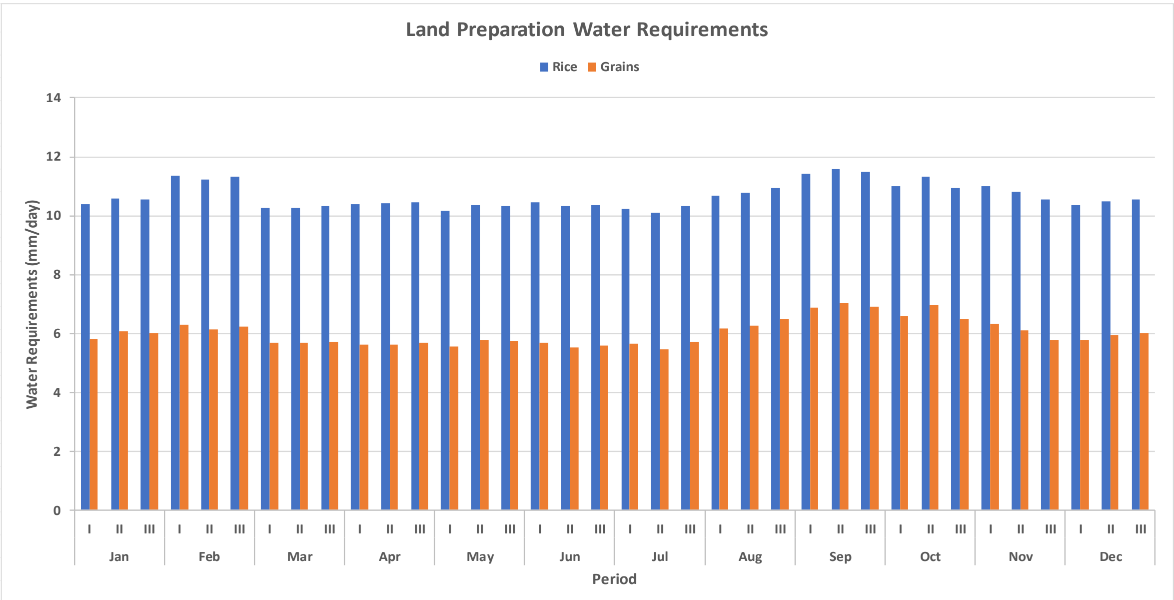

*Source: Research Data (2024).*

**Figure 6.** Chart of Effective Rainfall Recapitulation

c. Land Preparation

In this research, land preparation is carried out for 1.5 months, playing an essential role in effective growth by proving optimal soil and environmental conditions. However, when land has not been cultivated for more than 2.5 months, the irrigation process becomes more prolonged. The water requirements required before rice planting are described in the book "Planning Criteria for the Irrigation Section," where the equation was developed by Van de Goor and Ziljstra (1968) based on a constant water rate in liters per second during the land preparation period [17]. A summary of the calculation of water requirements for land preparation is presented in Source: *Research Data (2024).*

**Figure** .




*Source: Research Data (2024).*

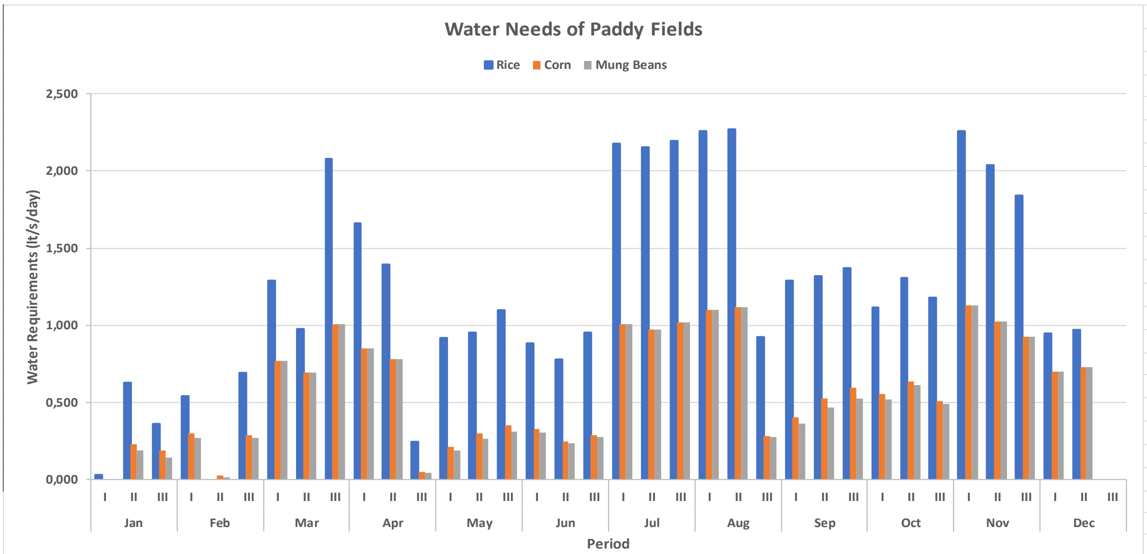
**Figure 7.** Chart of Preparation Water Requirements in 1 year

d. Plant Water Requirements

Plant water requirements are calculated accorng to planned alternative contions [14][18], namely:

Alternative 1 : At the beginning of the planting period in November I
Alternative 2 : At the beginning of the planting period in November II
Alternative 3 : At the beginning of the planting period in November III
Alternative 4 : At the beginning of the planting period in December I
Alternative 5 : At the beginning of the planting period in December II
Alternative 6 : At the beginning of the planting period in December III

Recapitulation of water needs in 1 year for alternative 4 is shown in Figure 8.




*Source: Research Data (2024).*

**Figure 8.** Chart of Water Needs of paddy fields in 1 year

### 3.4 Optimization of Crop Patterns

The results of agricultural business are determined by subtracting production costs from the net profit. This calculation details multiplying the net profit per area of rice fields by the total paddy land produced. Subsequently, the results are analyzed as a function of goals in optimization [19], as shown in Table 3.

**Table 3.** The Agricultural Product of Lamongan Regency

| No. | Description | Satuan | Rice | Corn | Mung Beans |
|---|---|---|---|---|---|
| 1 | Product Price | IDR/kg | 6,500 | 5,500 | 14,000 |
| 2 | Productivity | ton/ha | 7.70 | 9.48 | 1.48 |
| 3 | Production Results | IDR/ha | 50,064.024 | 52,130.862 | 20,755.631 |
| 4 | Production Cost | IDR/ha | 40,677.900 | 30,591.420 | 14,002.267 |
| 5 | Profitability | IDR/ha | 9,386.124 | 21,539.440 | 6,753.364 |

*Source: Research Data (2024).*

Optimization Model

The inequality planning for optimization process was based on the discharge requirements for each type of plant, along with limitations such as maximum land area. In the Balongganggang Irrigation Area, there is a maximum area of 2256 Ha and limitations in the form of availability of water discharge in the Balongganggang Reservoir. Therefore, this research aimed to maximize land area in one year of growing season and profits from agriculture [14][20]. The mathematical model that used for optimization is presented below.

- Purpose function

Maximize:

Based on land area

$$Z = X_{p1} + X_{j1} + X_{b1} + X_{p2} + X_{j2} + X_{b2} + X_{p3} + X_{j3} + X_{b3}$$

Based on profit

$$Z = 9386124(X_{p1} + X_{p2} + X_{p3}) + 21539440(X_{j1} + X_{j2} + X_{j3}) + 6753364(X_{b1} + X_{j3} + X_{b3})$$

Information:

$X_{p1}$ : Rice area in the rainy season (RS)
$X_{j1}$ : Corn area in the rainy season (RS)
$X_{b1}$ : Mung beans area in the rainy season (RS)
$X_{p2}$ : Rice area in dry season I (DSI)
$X_{j2}$ : Corn area in dry season I (DSI)
$X_{b2}$ : Mung beans area in dry season I (DSI)
$X_{p3}$ : Rice area in dry season II (DSII)
$X_{j3}$ : Corn area in dry season II (DSII)
$X_{b3}$ : Mung beans area in dry season II (DSII)

- Constraint Function

Dependable inflow

$$V_{p1}X_{p1} + V_{j1}X_{j1} + V_{b1}X_{b1} \leq Q_1 \text{ (Period 1 – 12)}$$
$$V_{p2}X_{p2} + V_{j2}X_{j2} + V_{b2}X_{b2} \leq Q_2 \text{ (Period 13 – 24)}$$
$$V_{p3}X_{p3} + V_{j3}X_{j3} + V_{b3}X_{b3} \leq Q_3 \text{ (Period 25 – 36)}$$

When :

$V_{pi}$ : Rice water needs in each period
$V_{ji}$ : Corn water needs in each period
$V_{bi}$ : Mung bean water needs in each period
$Q_i$ : Discharge used in each period

Maximum Area

$$X_{p1} + X_{j1} + X_{b1} \leq 2256 \text{ Ha}$$
$$X_{j1} + X_{b1} \leq 150 \text{ Ha}$$
$$X_{p2} + X_{j2} + X_{b2} \leq 2256 \text{ Ha}$$
$$X_{j2} + X_{b2} \leq 200 \text{ Ha}$$
$$X_{b2} \geq 50 \text{ Ha}$$
$$X_{p3} + X_{j3} + X_{b3} \leq 2256 \text{ Ha}$$
$$X_{b3} \leq 50 \text{ Ha}$$

Non-negativity

$$X_{p1}, X_{j1}, X_{b1}, X_{p2}, X_{j2}, X_{b2}, X_{p3}, X_{j3}, X_{b3} \geq 0$$

Input and Output Program

The mathematical model was inputted into the POM-QM for Windows V5 program according to the alternative, as shown in Source: *Research Data (2024).*

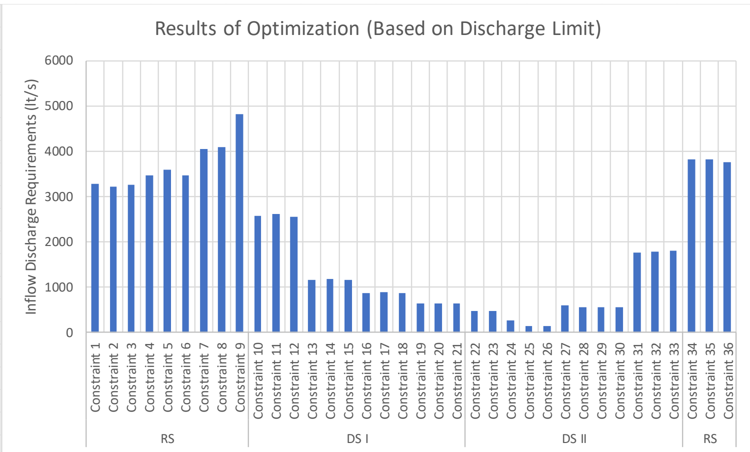
**Figure**

| | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 | X9 | | RHS | Equation form |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximize | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | Max X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 + X9 |
| Constraint 1 | ,03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | <= | 3285,65 | 0.03X1 <= 3285.65 |
| Constraint 2 | ,63 | ,16 | ,12 | 0 | 0 | 0 | 0 | 0 | 0 | <= | 3213,65 | 0.63X1 + 0.16X2 + 0.12X3 <= 3213.65 |
| Constraint 3 | ,36 | ,06 | ,02 | 0 | 0 | 0 | 0 | 0 | 0 | <= | 3258,21 | 0.36X1 + 0.06X2 + 0.02X3 <= 3258.21 |
| Constraint 4 | ,54 | ,23 | ,2 | 0 | 0 | 0 | 0 | 0 | 0 | <= | 3469,84 | 0.54X1 + 0.23X2 + 0.2X3 <= 3469.84 |
| Constraint 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | <= | 3586,07 | <= 3586.07 |
| Constraint 6 | ,69 | ,23 | ,22 | 0 | 0 | 0 | 0 | 0 | 0 | <= | 3459,29 | 0.69X1 + 0.23X2 + 0.22X3 <= 3459.29 |
| Constraint 7 | 1,29 | ,63 | ,63 | 0 | 0 | 0 | 0 | 0 | 0 | <= | 4049,38 | 1.29X1 + 0.63X2 + 0.63X3 <= 4049.38 |
| Constraint 8 | ,97 | ,52 | ,52 | 0 | 0 | 0 | 0 | 0 | 0 | <= | 4090,66 | 0.97X1 + 0.52X2 + 0.52X3 <= 4090.66 |
| Constraint 9 | 2,08 | ,99 | ,99 | 0 | 0 | 0 | 0 | 0 | 0 | <= | 4825,05 | 2.08X1 + 0.99X2 + 0.99X3 <= 4825.05 |
| Constraint 10 | 0 | 0 | 0 | 1,66 | ,77 | ,77 | 0 | 0 | 0 | <= | 2572,42 | 1.66X4 + 0.77X5 + 0.77X6 <= 2572.42 |
| Constraint 11 | 0 | 0 | 0 | 1,39 | ,66 | ,66 | 0 | 0 | 0 | <= | 2607,45 | 1.39X4 + 0.66X5 + 0.66X6 <= 2607.45 |
| Constraint 12 | 0 | 0 | 0 | ,24 | 0 | 0 | 0 | 0 | 0 | <= | 2560,99 | 0.24X4 <= 2560.99 |
| Constraint 13 | 0 | 0 | 0 | ,92 | ,21 | ,19 | 0 | 0 | 0 | <= | 1169,57 | 0.92X4 + 0.21X5 + 0.19X6 <= 1169.57 |
| Constraint 14 | 0 | 0 | 0 | ,95 | ,29 | ,26 | 0 | 0 | 0 | <= | 1171,88 | 0.95X4 + 0.29X5 + 0.26X6 <= 1171.88 |
| Constraint 15 | 0 | 0 | 0 | 1,1 | ,35 | ,31 | 0 | 0 | 0 | <= | 1162,66 | 1.1X4 + 0.35X5 + 0.31X6 <= 1162.66 |
| Constraint 16 | 0 | 0 | 0 | ,88 | ,32 | ,3 | 0 | 0 | 0 | <= | 874,5 | 0.88X4 + 0.32X5 + 0.3X6 <= 874.5 |
| Constraint 17 | 0 | 0 | 0 | ,78 | ,22 | ,21 | 0 | 0 | 0 | <= | 896,17 | 0.78X4 + 0.22X5 + 0.21X6 <= 896.17 |
| Constraint 18 | 0 | 0 | 0 | ,95 | ,29 | ,27 | 0 | 0 | 0 | <= | 874,5 | 0.95X4 + 0.29X5 + 0.27X6 <= 874.5 |
| Constraint 19 | 0 | 0 | 0 | 2,18 | 1 | 1 | 0 | 0 | 0 | <= | 635,76 | 2.18X4 + X5 + X6 <= 635.76 |
| Constraint 20 | 0 | 0 | 0 | 2,15 | ,97 | ,97 | 0 | 0 | 0 | <= | 635,76 | 2.15X4 + 0.97X5 + 0.97X6 <= 635.76 |
| Constraint 21 | 0 | 0 | 0 | 2,19 | 1,02 | 1,02 | 0 | 0 | 0 | <= | 635,76 | 2.19X4 + 1.02X5 + 1.02X6 <= 635.76 |
| Constraint 22 | 0 | 0 | 0 | 0 | 0 | 0 | 2,26 | 1,1 | 1,1 | <= | 477,7 | 2.26X7 + 1.1X8 + 1.1X9 <= 477.7 |
| Constraint 23 | 0 | 0 | 0 | 0 | 0 | 0 | 2,27 | 1,12 | 1,12 | <= | 477,7 | 2.27X7 + 1.12X8 + 1.12X9 <= 477.7 |
| Constraint 24 | 0 | 0 | 0 | 0 | 0 | 0 | ,92 | ,28 | ,27 | <= | 257,93 | 0.92X7 + 0.28X8 + 0.27X9 <= 257.93 |
| Constraint 25 | 0 | 0 | 0 | 0 | 0 | 0 | 1,29 | ,4 | ,36 | <= | 149,32 | 1.29X7 + 0.4X8 + 0.36X9 <= 149.32 |
| Constraint 26 | 0 | 0 | 0 | 0 | 0 | 0 | 1,32 | ,52 | ,47 | <= | 149,32 | 1.32X7 + 0.52X8 + 0.47X9 <= 149.32 |
| Constraint 27 | 0 | 0 | 0 | 0 | 0 | 0 | 1,37 | ,59 | ,52 | <= | 588,85 | 1.37X7 + 0.59X8 + 0.52X9 <= 588.85 |
| Constraint 28 | 0 | 0 | 0 | 0 | 0 | 0 | 1,12 | ,55 | ,52 | <= | 561,63 | 1.12X7 + 0.55X8 + 0.52X9 <= 561.63 |
| Constraint 29 | 0 | 0 | 0 | 0 | 0 | 0 | 1,3 | ,63 | ,61 | <= | 561,63 | 1.3X7 + 0.63X8 + 0.61X9 <= 561.63 |
| Constraint 30 | 0 | 0 | 0 | 0 | 0 | 0 | 1,17 | ,51 | ,49 | <= | 561,63 | 1.17X7 + 0.51X8 + 0.49X9 <= 561.63 |
| Constraint 31 | 0 | 0 | 0 | 0 | 0 | 0 | 2,26 | 1,13 | 1,13 | <= | 1761,11 | 2.26X7 + 1.13X8 + 1.13X9 <= 1761.11 |
| Constraint 32 | 0 | 0 | 0 | 0 | 0 | 0 | 2,04 | ,99 | ,99 | <= | 1786,24 | 2.04X7 + 0.99X8 + 0.99X9 <= 1786.24 |
| Constraint 33 | 0 | 0 | 0 | 0 | 0 | 0 | 1,84 | ,86 | ,86 | <= | 1806,03 | 1.84X7 + 0.86X8 + 0.86X9 <= 1806.03 |
| Constraint 34 | ,94 | ,52 | ,52 | 0 | 0 | 0 | 0 | 0 | 0 | <= | 3817,12 | 0.94X1 + 0.52X2 + 0.52X3 <= 3817.12 |
| Constraint 35 | ,97 | ,55 | ,55 | 0 | 0 | 0 | 0 | 0 | 0 | <= | 3816,81 | 0.97X1 + 0.55X2 + 0.55X3 <= 3816.81 |
| Constraint 36 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | <= | 3759,64 | <= 3759.64 |
| Constraint 37 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | <= | 2256 | X1 + X2 + X3 <= 2256 |
| Constraint 38 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | >= | 150 | X2 + X3 >= 150 |
| Constraint 39 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | <= | 2256 | X4 + X5 + X6 <= 2256 |
| Constraint 40 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | <= | 200 | X5 + X6 <= 200 |
| Constraint 41 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | >= | 50 | X6 >= 50 |
| Constraint 42 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | <= | 2256 | X7 + X8 + X9 <= 2256 |
| Constraint 43 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | <= | 50 | X9 <= 50 |

*Source: Research Data (2024).*

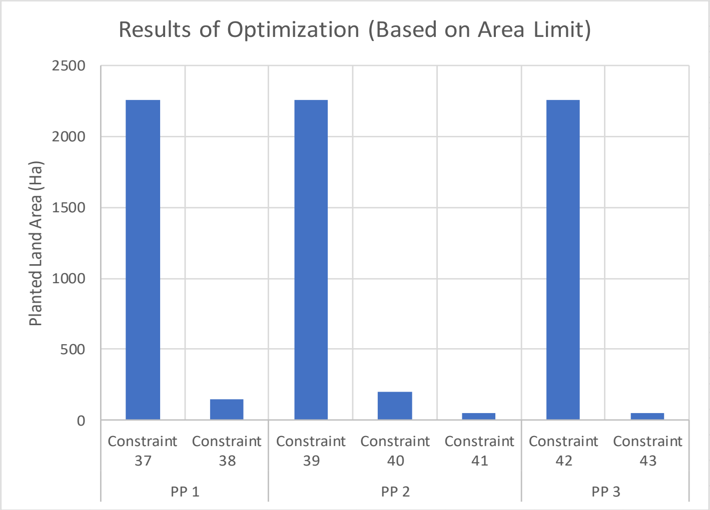
**Figure 9.** Input in POM-QM for Windows V5 Program

After inputting the entire mathematical model, the program was run and the final result of optimization was shown in**Error! Reference source not found.Error! Reference source not found.**




*Source: Research Data (2024).*

**Figure 10.** Optimization Results Graph Based on Discharge as a Constraint




*Source: Research Data (2024).*

**Figure 11.** Optimization Results Graph Based on Areas as a Constraint

Analysis of Optimization Results

The equations formulated in POM-QM for Windows V5 program would be run and iterated automatically by the program. Consequently, the output results are obtained in the form of numbers in the coefficient X, representing the area of each type of plant and the value of the destination function Z. Recapitulation of the output results by POM-QM for Windows V5 are shown in**Error! Reference source not found.** and **Error! Reference source not found.**.

**Table 4.** Recapitulation of Optimization Results Based on Land Area

| Alternative | Plant Period | Irrigation Area / Irrigation Intensity | | | | | |
|---|---|---|---|---|---|---|---|
| | | Rice | | Corn | | Mung Beans | |
| | | Ha | % | Ha | % | Ha | % |
| 1 | RS | 704.25 | 31.22 | 150 | 6.65 | 0 | 0.00 |
| | DS I | 302.93 | 13.43 | 150 | 6.65 | 50 | 2.22 |
| | DS II | 0 | 0.00 | 189.4 | 8.40 | 50 | 2.22 |
| 2 | RS | 802.81 | 35.59 | 150 | 6.65 | 0 | 0.00 |
| | DS I | 199.89 | 8.86 | 150 | 6.65 | 50 | 2.22 |
| | DS II | 0 | 0.00 | 190.19 | 8.43 | 50 | 2.22 |
| 3 | RS | 911.43 | 40.40 | 150 | 6.65 | 0 | 0.00 |
| | DS I | 199.89 | 8.86 | 150 | 6.65 | 50 | 2.22 |
| | DS II | 0 | 0.00 | 196.48 | 8.71 | 50 | 2.22 |
| 4 | RS | 2106 | 93.35 | 150 | 6.65 | 0 | 0.00 |
| | DS I | 197.15 | 8.74 | 150 | 6.65 | 50 | 2.22 |
| | DS II | 0 | 0.00 | 241.96 | 10.73 | 50 | 2.22 |
| 5 | RS | 1480.07 | 65.61 | 150 | 6.65 | 0 | 0.00 |
| | DS I | 114.03 | 5.05 | 150 | 6.65 | 50 | 2.22 |
| | DS II | 0 | 0.00 | 174.29 | 7.73 | 50 | 2.22 |
| 6 | RS | 1480.07 | 65.61 | 150 | 6.65 | 0 | 0.00 |
| | DS I | 111.76 | 4.95 | 150 | 6.65 | 50 | 2.22 |
| | DS II | 0 | 0.00 | 72.39 | 3.21 | 50 | 2.22 |

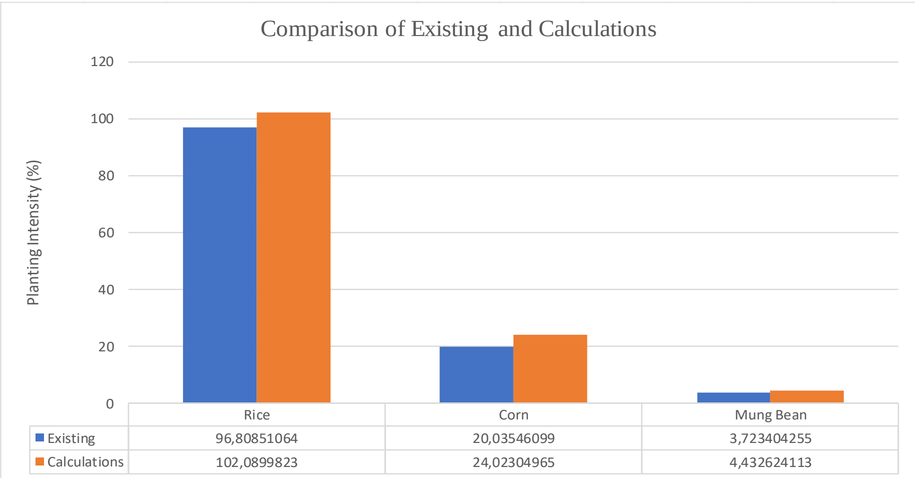
*Source: Research Data (2024).*

**Table 5.** Recapitulation of Optimization Results Based on Profitability

| Alternative | Plant Period | Planting Area/Planting Intensity | | | | | |
|---|---|---|---|---|---|---|---|
| | | Rice | | Corn | | Mung Beans | |
| | | Ha | % | Ha | % | Ha | % |
| 1 | RS | 704.25 | 31.22 | 150 | 6.65 | 0 | 0.00 |
| | DS I | 302.93 | 13.43 | 150 | 6.65 | 50 | 2.22 |
| | DS II | 0 | 0.00 | 189.4 | 8.40 | 50 | 2.22 |
| 2 | RS | 802.81 | 35.59 | 150 | 6.65 | 0 | 0.00 |
| | DS I | 199.89 | 8.86 | 150 | 6.65 | 50 | 2.22 |
| | DS II | 0 | 0.00 | 190.2 | 8.43 | 50 | 2.22 |
| 3 | RS | 911.43 | 40.40 | 150 | 6.65 | 0 | 0.00 |
| | DS I | 199.89 | 8.86 | 150 | 6.65 | 50 | 2.22 |
| | DS II | 0 | 0.00 | 196.5 | 8.71 | 50 | 2.22 |
| 4 | RS | 2106 | 93.35 | 150 | 6.65 | 0 | 0.00 |
| | DS I | 197.15 | 8.74 | 150 | 6.65 | 50 | 2.22 |
| | DS II | 0 | 0.00 | 242 | 10.73 | 50 | 2.22 |
| 5 | RS | 1480.1 | 65.61 | 150 | 6.65 | 0 | 0.00 |
| | DS I | 114.03 | 5.05 | 150 | 6.65 | 50 | 2.22 |
| | DS II | 0 | 0.00 | 174.3 | 7.73 | 50 | 2.22 |
| 6 | RS | 1480.1 | 65.61 | 150 | 6.65 | 0 | 0.00 |
| | DS I | 111.76 | 4.95 | 150 | 6.65 | 50 | 2.22 |
| | DS II | 0 | 0.00 | 72.39 | 3.21 | 50 | 2.22 |

*Source: Research Data (2024.)*

Both tables show the same intensity value for each alternative, with the maximum total intensity produced being 130.55% in alternative 4. Moreover, a comparison of alternative 4 with existing contions is shown in Figure 12.




*Source: Research Data (2024.)*

**Figure 12.** Irrigation Intensity Chart Between Existing and Analysis

The calculation results exceeding 9.98% of the existing conditions suggest greater optimality, leading to the conclusion that the optimal planting patterns were

Rainy Season : Rice – Grains

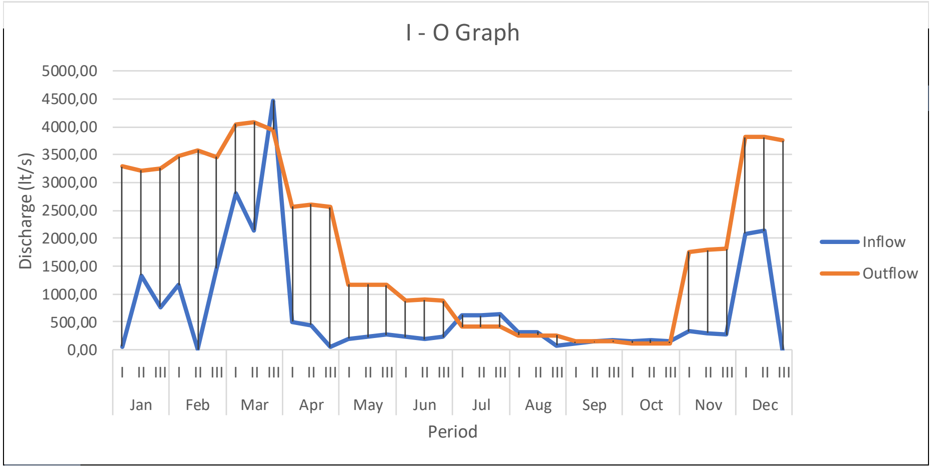
Dry season I : Paddy – Grains – Grains
Dry season II : Grains– Grains
The total planted area of each plant was

| | | |
|---|---|---|
| Rice | : 2303,2 | Ha |
| Corn | : 542,0 | Ha |
| Mung beans | : 100 | Ha |

Based on the analysis results, the income in one year for alternative 4 was IDR 33,967,000,000.

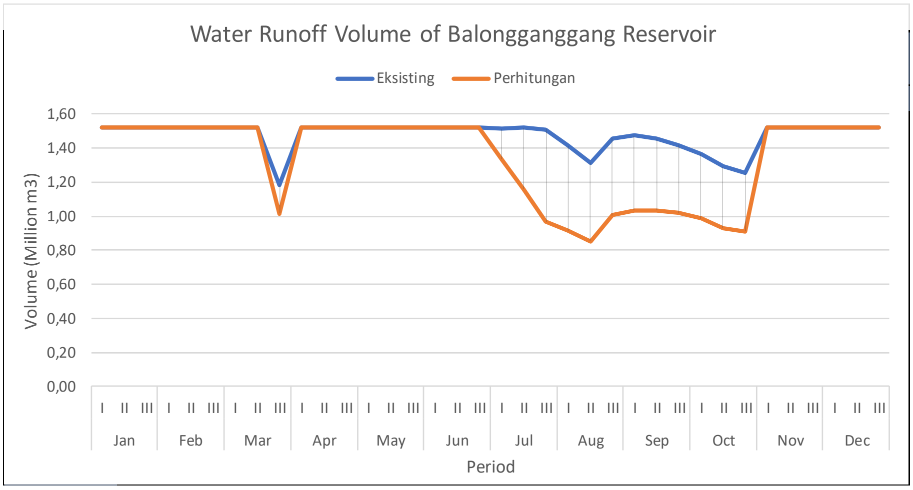
### 3.5 Reservoir Balance

Reservoir balance is the equilibrium of water between inflow and outflow discharge. In this research, inflow discharge was obtained from the calculation of F. J. Mock analysis and after reducing rice fields use before reaching Balongganggang Reservoir [2][18]. Meanwhile, outflow discharge was used for Balongganggang irrigation in the selected planting patterns, namely alternative 4. Further details on the water use graph are presented in Figure 13.




*Source: Research Data (2024.)*
**Figure 13.** Inflow and Outflow Graph

Figure 13 shows the difference between the inflow and outflow discharge, which is used to calculate the volume of water generated in 1 period. Changes in the volume of water runoff from Balongganggang Reservoir are shown in Figure 14.




*Source: Research Data (2024.)*
**Figure 14** Water Runoff Graph of Balongganggang Reservoir

## 4. Conclusion and Suggestion

### 4.1 Conclusions

In conclusion, the results obtained from the calculation and research analysis are as follows:

a. F. J. Mock analysis showed that the reliable discharge used for Gondang Reservoir inflow ranged from 5659.57 lt/s to 175.80 lt/s, with a reliability of 80%. Due to the presence of paddy fields along the route to Balongganggang Reservoir, the inflow into the reservoir was only 69.46% of the total discharge. Consequently, the largest and smallest discharges for Balongganggang Reservoir inflow were 3931.03 lt/s and 122.11 lt/s, respectively.
b. Optimization calculations considered alternative initial planting periods as well as area limits for corn and mung beans of 150 Ha and 50 Ha per planting season. Based on optimization results from alternatives 1 to 6 by the POM-QM for Windows V5 program iteration, the optimal planting pattern was found in alternative 4, in terms of land area and profit. For land area-based optimization results, the planting patterns during rainy season (RS), dry season I (DS I), and dry season II (DS II) were Rice (2106 Ha) - Grains (Corn - 150 Ha), Rice (197.15 Ha) - Grains (Corn - 150 Ha) - Grains (Mung Beans - 50 Ha), and Grains (Corn - 241.96 Ha) - Grains (Mung Beans - 50 Ha), respectively. Meanwhile, regarding profit-based optimization, the planting patterns during rainy season (RS), dry season I (DS I), and II (DS II) were Rice (2106 Ha) - Grains (Corn - 150 Ha), Rice (197.15 Ha) - Grains (Corn - 150 Ha) - Grains (Mung Beans - 50 Ha), and Grains (Corn - 241.96 Ha) - Grains (Mung Beans - 50 Ha). The maximum profit obtained based on land area and profit optimization was Rp 33,967,000,000.00 in alternative 4.
c. The use of Balongganggang Reservoir storage water occurred in several periods due to high water needs and low rainfall. However, the smallest volume was observed in October period III, at 0.85 million cubic meters.

### 4.2 Suggestions

Based on the results, several suggestions were made for further research, focusing on Balongganggang Irrigation Area and Balongganggang Reservoir:

a. The method used in this research was F. J. Mock’s analysis of Gondang Reservoir, which was the primary reservoir of Balongganggang Reservoir. The analysis suggested that energy loss along the channel between the two structures could be neglected. Therefore, the use of inflow discharge according to the records available at the Balongganggang Reservoir was recommended.
b. Before conducting optimization, there is a need to investigate the existing land conditions. Additionally, collaboration with farmers and local institutions is essential to understand plant varieties, appropriate water usage according to regulations, and annual planting patterns
c. The network efficiency used in this optimization is based on worst-case scenario assumption. Consequently, further research is expected to calculate efficiency correctly for accurate results.
d. Optimization of mung bean plants can be replaced with other grains or crops. The decision to include mung beans in this optimization is based on historical data recorded by the *Badan Statistik Indonesia* (BPS). However, a better approach can be made by analyzing current agricultural product trends.

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