The Evaluation of Palasari Reservoir Water Balance for Palasari Irrigation Area by Using RIBASIM

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ABSTRACT

One of the attempts to manage water resources is to build dams. One of the large dams in Indonesia, the Palasari Dam, which is located in Bali Province, was built in 1987 - 1989. The utilization purpose of the Palasari Dam is to irrigate the planned Palasari Irrigation Area in the amount of 1,300 Ha. However, the Palasari Reservoir challenges sedimentation and a lowering of storage water level, especially during the drought. This condition inflicts disruption of water availability. In the face of scarcity of water resources, it is necessary to explore water availability for efficient and effective distribution. In optimizing reservoirs, operational simulation analysis to determine the reliability of reservoir operations can use RIBASIM (River Basin Simulation) software by evaluating the results of the composition and distribution of water discharge. This research aims to evaluate the irrigation inflow released by the operation of the Palasari Reservoir to serve the Palasari Irrigation Area. Calculations for irrigation water demand in the Palasari Irrigation Area were carried out by the existing global crop plan, as well as modeling simulations with six rice field plots that were irrigated directly by the Palasari Reservoir using RIBASIM. Based on the results of model simulations, the existing discharge cannot fulfill water demands in the Palasari Irrigation Area. Hereafter, with the simulated annual average irrigation water demand of the Palasari Irrigation Area of 9.915 Mcm (0.314 m^3/s), it still runs into a water shortage of 4.049 Mcm (0.128 m^3/s) with a shortage rate of 40.76%.

Keywords: irrigation, reservoir, RIBASIM.

INTRODUCTION

One attempt to manage water resources is to build dams. A dam is a building in the form of earth fill, rock fill, and concrete, which is built not only to hold and hold water, but can also be constructed to hold and accommodate mining waste, or to hold sedimentation to form a reservoir. Dams function to supply raw water, irrigation inflow, flood control, and/or generate hydroelectric power [1]. One of the large dams in Indonesia, namely the Palasari Dam, which is located in Ekasari Village, Melaya District, Jembrana Regency, Bali Province, was built in 1987 - 1989. The utilization purpose of the Palasari Dam is to irrigate the planned Palasari Irrigation Area in the amount of 1,300 Ha [2]. The Palasari Reservoir challenges sedimentation and a lowering of storage water level, especially during the drought. The research results show that sedimentation in the Palasari Dam is caused by environmental damage and land use not covered by plants [3]. Sedimentation is also the biggest challenge in reservoir operations. Utilization of reservoir storage capacity is the main factor in fulfilling the benefits of a dam [4]. Reservoir operation rule curve is a benchmark operational period for a reservoir in which the water discharge produced must comply with provisions to maintain the reservoir elevation by the design [5].

On the other hand, one effort to increase agricultural output is to build an irrigation network. The construction of an irrigation network to support the provision of national food is necessary so that water availability on the land will be fulfilled even though the land is far from surface water sources (rivers). This cannot be separated from irrigation engineering efforts, namely supplying water with the precise quality, the precise space, and the right time effectively and economically [6]. However, based on the results of the Irrigation Asset Management survey and the Irrigation System Performance Index of the Palasari Irrigation Area using the e-PAKSI application, an index value for

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the operation and maintenance conditions of irrigation networks and non-irrigation networks was obtained based on an assessment of six components in the Palasari Irrigation Area, namely infrastructure by 24.65%, planting productivity by 12.13%, supporting facilities by 4.75%, personnel organization by 6.50%, documentation by 1.90%, and farmers organization by 7.00%. Therefore, the total index of irrigation system performance for the Palasari Irrigation Area is 56.92%, with an index of 55% - 69% indicating that the Palasari Irrigation Area has poor performance and needs consideration [7]. If the decline in the storage capacity of the Palasari Dam gets worse, it is feared that massive land conversion will occur in the Palasari Irrigation Area which could threaten the sustainability of agriculture in Jembrana Regency.

In optimizing reservoirs formed by water infrastructure (dams), operational simulation analysis to determine the level of reliability of reservoir operations can use RIBASIM (River Basin Simulation) software. RIBASIM users can evaluate various measurements, strategies, development, and adaptation pathways related to infrastructure, operational management, and water needs, to determine results related to water quantity, water quality, as well as the composition and distribution of water discharge [8].

Several studies related to reservoir optimization with RIBASIM have been carried out previously. Darsono et al.'s (2014) research is optimizing the Jatigede Reservoir to fulfill the water demand of the Rentang Irrigation Area and the Cirebon City, Cirebon Regency, Indramayu, and Majalengka areas by simulating the water balance of the Jatigede Reservoir system with the support of RIBASIM software. The reliability of the reservoir rule curve is tested by reservoir simulation analysis which produces zero (0) operating failures during operation using fifty (50) synthetic inflow data series. As a conclusion from that study, the volume of reservoir water utilization (demand) can still be increased [9].

Based on the problems that occurred both at the Palasari Reservoir and the Palasari Irrigation Area, concerning related research that had been carried out previously, this research was carried out to evaluate the water balance of the Palasari Reservoir in fulfillment of the water demand of the Palasari Irrigation Area. It is expected that the results of this research can later be developed to become a consideration in decision or policy-making for governments that have the authority to manage the Palasari Reservoir and the Palasari Irrigation Area so that the utilization of water and agricultural resources can be optimal for the society.

RESEARCH METHODS

Materials

Palasari Reservoir is located at coordinates 8°15'14" S 114°33'02" E or in Ekasari Village, Melaya District, Jembrana Regency, Bali Province. With a catchment area of 40.75 km^2, the land use of the Palasari catchment area is categorized by forests and plantations.

Figure 1. The location of Palasari Reservoir [10]

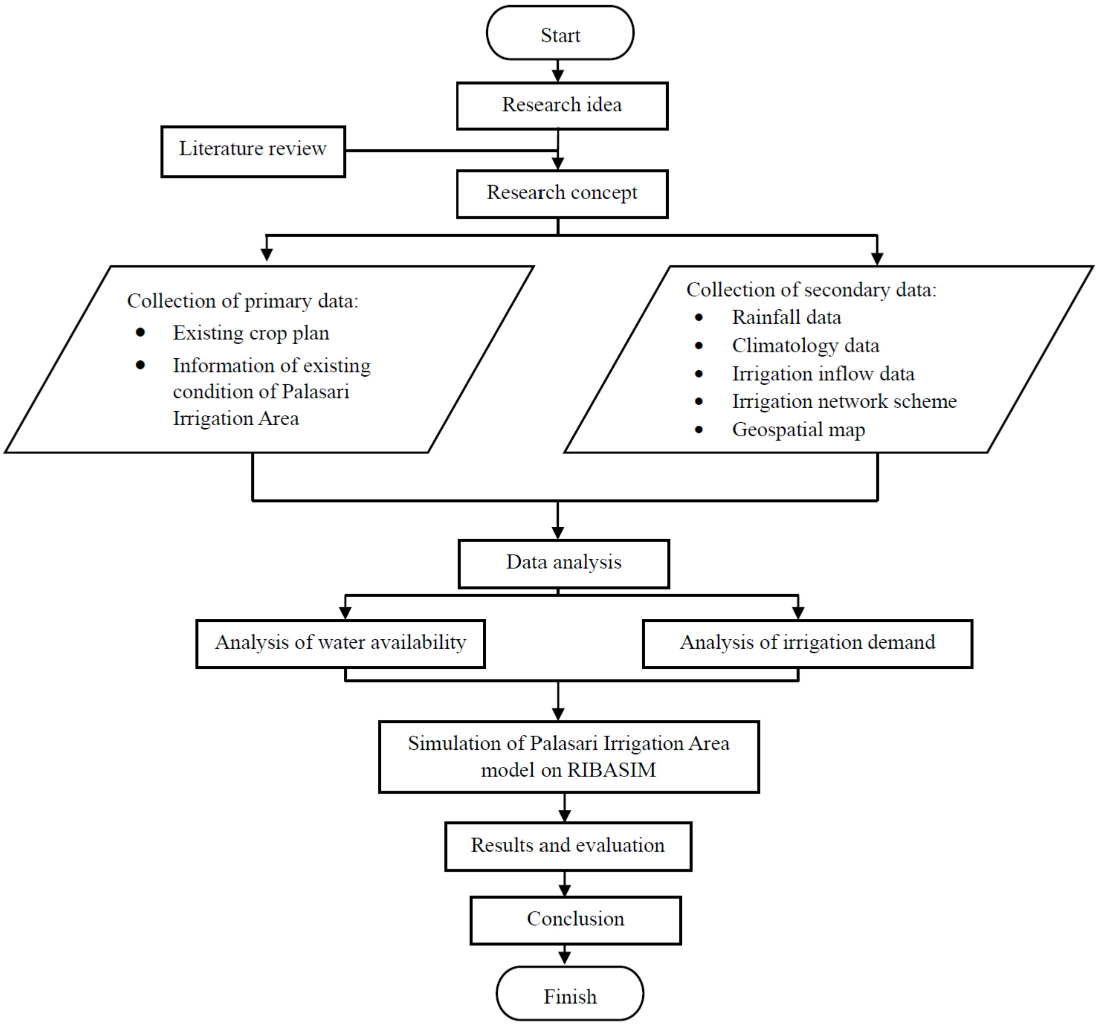
This research aims to analyze the water balance of the Palasari Dam catchment area and simulate irrigation inflow to evaluate the performance of the Palasari Dam in irrigating the Palasari Irrigation Area. It requires supporting data in the form of primary and secondary data obtained from several relevant authorized agencies. The following is a list of required data and flow chart for showing the research steps sequentially and clearly.

Table 1. List of required data

No.	Required data	Data Type
1	Existing crop plan and the condition of Palasari Irrigation Area	Primary data
2	Rainfall data	Secondary data
3	Climatology data	Secondary data
4	Irrigation inflow data	Secondary data
5	Design data of Palasari Dam	Secondary data
6	Irrigation network scheme of Palasari Irrigation Area	Secondary data
7	Geospatial map of Palasari Irrigation Area	Secondary data

Figure 2. Flow chart

Related to data availability, the conducted data in this research respectively: rainfall data in 20 years period (2004 – 2023); climatology data in 11 years period (2013 – 2023); and Palasari irrigation



inflow in 2 years period (2022 – 2023). Data processing in this research is divided into two steps,

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namely secondary data processing numerically using the Microsoft Excel application and irrigation water optimization simulation with data on the functional area of rice fields using RIBASIM software. Data processing follows the procedure (Figure 2) so that research can be carried out systematically and precisely.

Methods

In the data processing stage, analytical methods are used to obtain research results. The analysis methods used are:

1. Analysis of rainfall data

   The rainfall data used in this research was tested first for evaluating the data consistency. The methods used to test rainfall data include the Rescaled Adjusted Partial Sums (RAPS) method, the absence of trend test, and the outlier test.

   The RAPS method is a test for the consistency of rainfall data that uses data from the station itself, namely in the form of testing the cumulative deviation of the average value divided by the cumulative square root [11]. The formulas are:

   $$S_o^* = 0 \quad (1)$$

   $$S_k^* = \sum_{i+1}^{k} (Y_i - \bar{Y}) \quad (2)$$

   by k = 1, 2, …, n

   $$S_k^{**} = \frac{S_k^*}{Dy} \quad (3)$$

   $$Dy^2 = \sum_{i=1}^{n} \frac{(Y_i - \bar{Y})^2}{n} \quad (4)$$

   Statistic values of Q and R:

   $$Q = \max |S_k^{**}| \text{ for } 0 \leq k \leq n \quad (5)$$

   $$R = \max |S_k^{**}| \min |S_k^{**}| \text{ for } 0 \leq k \leq n \quad (6)$$

   With:

   S_o^* = initial deviation;

   S_k^* = absolute deviation;

   S_k^{**} = value of data consistency;

   n = number of data;

   Dy = average of deviation;

   Q = statistic value of Q; and

   R = statistic value (*range*).

   If a periodic series shows a trend, then the data is not recommended for use in hydrological analysis, especially frequency analysis, which is a function of probability. Trends can be viewed as a correlation between time and the variation of a hydrological variable. The absence of a trend test is a statistical analysis aimed at finding out whether data is randomly distributed or follows a certain trend [12]. One way is to use the rank correlation coefficient based on the Spearman Method as follows [13].

   $$KP = 1 - \frac{6\sum_{i=1}^{n}(dt)^2}{n^3 - n} \quad (7)$$

   $$t = KP \left[\frac{n-2}{1-KP^2}\right]^{\frac{1}{2}} \quad (8)$$

by:

KP = n rank correlation from Spearman

n = number of data

dt = Rt – Tt

Tt = rank from time period

Rt = rank of hydrology variable

t = distribution number of t, degree of freedom = n – 2 generally with level of significance of 5%

Outliers are data points that deviate far enough from the group trend. The existence of outliers is usually considered to interfere with the selection of the type of distribution for a data sample, so these outliers need to be removed [13]. Data outliers, besides causing data not normally distributed, can also have an effect on failure of conclusions or decisions making in research [14]. The formulas to determine upper and lower limits of outliers test are:

$$y_H = \bar{y} + K_n \cdot s_y \qquad (9)$$

$$y_L = \bar{y} - K_n \cdot s_y \qquad (10)$$

with:

y_H = upper limit value

y_L = lower limit value

$\bar{y}$ = average value

s_y = standard deviation from the logarithm of the sample

K_n = value depends on number of data sample

n = number of data sample

2. Analysis of evapotranspiration

In determining the evapotranspiration value, two terms must be considered: reference evapotranspiration (ETo*) and potential evapotranspiration (ETp). Potential evapotranspiration describes the need for the environment, a group of vegetation, or an agricultural area to carry out evapotranspiration, which is determined by several factors, such as the intensity of solar radiation, wind speed, leaf area, air temperature, and air pressure. Potential evapotranspiration also describes the energy obtained by the area from the sun. On the other hand, transpiration is proportional to how much carbon the vegetation absorbs because transpiration also plays a role in transferring CO_2 from the air to the leaves [15]. The used formula for calculating evapotranspiration is Penman Method as follows:

$$ETp = C \,.\, ETo^* \qquad (11)$$

with C = correction number → the condition difference between day and night weather.

3. Analysis of irrigation water demand

Irrigation water demands are the volume of water needed to fulfill evaporation needs, water loss, and water needs for plants by taking into account the amount of water supplied by nature through rain and the contribution of groundwater. The amount of irrigation water demand also depends on how the land is processed. In planning the amount of water demand for the rice field area as a whole, an analysis of water demand must be carried out starting from the irrigation channels, namely primary channels, secondary channels and tertiary channels to the amount of demand in the rice fields, in this case it needs to be supported by complete data related to this analysis to get optimal results [16].

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The formula is:

$$KAI = \frac{(Etc+IR+RW+P-ER)}{IE} \times A \quad (12)$$

with:

KAI = irrigation water demand (l/s)

Etc = consumptive water demand (mm/day)

IR = irrigation water demand at the rice field level (mm/day)

RW = water demand for replacing the water layer (mm/day)

P = percolation (mm/day)

ER = effective rainfall (mm/day)

IE = irrigation efficiency (%)

A = irrigation area

4. Simulation by using RIBASIM

RIBASIM software is used for water allocation modeling, which can be used at the planning stage of water resources development as well as operationally to assist in making management policies, for example, as a means of optimizing irrigation water in a watershed.

This research is conducted by nodes that are representing river basin components in a model. The used nodes for simulation model in this research as follows:

a) Layout nodes
- Variable inflow node
  This node is used to simulate the *inflow* of Palasari Reservoir.
- Confluence node
  This node is a confluence of some waterways.
- Terminal node
  This node is a downstream outlet boundary of a system.

b) Demand node
- Fixed irrigation node
  This node is used to model the irrigation network scheme with the water demand that has been calculated by user outside RIBASIM. The water demand on this node is supplied by irrigation inflow of Palasari Reservoir.

c) Control node
- Diversion node
  In this research, diversion node is used to represent Palasari Weir.

d) Link types
- Surface flow link data
  This link represents a river branch (no constraint), canal, or pipeline (flow capacity constraint).
- Diverted flow link data
  This link represents a canal supplying water users for irrigated area or canals for an inter-basin transfer of water. The canal is fed via a weir and gate in the river or the other canal.

Data Analysis

Data analyses were carried out by numerical analysis using Microsoft Excel and simulation using RIBASIM software. The procedure of secondary data analysis using Microsoft Excel generally analyse numerical data by utilizing the available features on it. The input data as numbers in secondary data is processed based on the formulas from literature review with the result obtained the water supply and water demand for irrigation.

Thereafter, the analysis takes the next step into simulation of irrigation water optimization using RIBASIM. The result from simulation model in the forms of map, chart, and report is being analyzed as the evaluation of Palasari Reservoir water balance in irrigating Palasari Irrigation Area.

RESULT AND DISCUSSION

In certain seasons, the Palasari Reservoir encounters overflows and reductions of water that are difficult to predict. When the Jembrana area experiences high-intensity rain, the water in the Palasari Reservoir tends to be excessive. However, it does not overflow, which could be detrimental to the surrounding ecosystem. On the other hand, when the intensity of rain in the Jembrana area is very low, the Palasari Reservoir will certainly experience quite worrying drought conditions. The reduction in water discharge during the dry season ranges up to 15 meters from the reservoir banks, this condition can result in drought in forest areas and reduced groundwater reserves for plants [17].

Rainfall data analysis is carried out as a series of required hydrological analyses. The rain data in this research comes from the CHIRPS Satellite through the extraction of daily rain data in the Palasari Reservoir watershed area, covering an area of 40.75 km^2. The analysis carried out includes testing the consistency of annual rainfall data and calculating effective rainfall.

Based on the rainfall data consistency test by three methods respectively RAPS method, the absence of a trend test, and outliers test, the used rainfall data in this research is reliable. Results of rainfall data consistency test can be seen in Table 2.

Table 2. Results of rainfall data consistency test

No.	Type of test method	Result	Annotation
1	RAPS	$Q/\sqrt{n}$ require = 1.220 $R/\sqrt{n}$ require = 1.430 $Q/\sqrt{n}$ calculate = 0.097 $R/\sqrt{n}$ calculate = 0.162	$Q/\sqrt{n}$ calculate < $Q/\sqrt{n}$ require → OK $R/\sqrt{n}$ calculate < $R/\sqrt{n}$ require → OK The rainfall data is consistent
2	The absence of trend	n = 20 $\sum D^2$ = 1486 Kp = −0.11 t = −0.501 with level of significance: 5%, degree of freedom n−2 → 18, it can be used tc values as follows. Lower limit −tc = −1.734 Upper limit tc = 1.734	For −1.734 < t < 1.734, with t = −0.501 → The rainfall data does not show any trend and fulfills the requirement
3	Outliers	Q1= 1675.67 Q3= 2278.25 IQR= 602.57 Upper limit= 3182.11 Lower limit= 771.81	From the raindall data set of 2004 – 2023, there are no *outlier* data outside the normal value range in the data set

The reference evapotranspiration value (ETo*) can be calculated using climatological data. It should be noted that the estimate of the average ETo* value for a watershed is more complex because the variety of watershed conditions can be very different. Reference evapotranspiration values are used in calculating irrigation water demands.

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Calculation of potential evapotranspiration (ETo) using the Modified Penman method. Climatology data was taken from the Palasari Climatology Station in Jembrana Regency. The climatological data used is a data series for eleven (11) years, namely 2013 to 2023. Result of evapotranspiration analyses can be seen in Table 3.

Table 3. Result of evapotranspiration analysis

No.	Month	ETo (mm/day)
1	January	6.29
2	February	6.33
3	March	5.72
4	April	4.85
5	May	4.56
6	June	4.13
7	July	4.56
8	August	5.39
9	September	6.29
10	October	5.78
11	November	6.02
12	December	6.45

Water demand for plants is the amount of water needed for plants in optimal growth conditions without water shortages, which is expressed as the net water requirement in rice fields (Net Field Water Requirement/NFR). The net value of water demand in rice fields is analysed using an agroclimatology approach based on the type and stage of plant growth, soil characteristics, and climatology. Plant water needs are reviewed based on the water balance, which depends on the following parameters.

a. Percolation;
b. Land preparation;
c. Consumptive use of plants;
d. Change of water layers; and
e. Effective rainfall.

The demand for irrigation water is the net demand for irrigation in rice fields covering the area of the tertiary plot (6 plots) that is directly flowed by Palasari Reservoir inflow divided by the efficiency value of the irrigation canal. Irrigation water demands are calculated based on the existing global crop plan for the Palasari Irrigation Area, namely Rice - Rice - Secondary Crops (Corn) with the start of planting in April. Result of water irrigation demand analysis can be seen in Table 4.

Table 4. Result of water irrigation demand analysis

No.	Month	NFR (mm/day)
1	January	1.16
2	February	1.16
3	March	2.81
4	April	5.55
5	May	7.66
6	June	6.66
7	July	5.96
8	August	6.86
9	September	9.04
10	October	8.97
11	November	7.06
12	December	1.54

After the numerical data analysis stage is completed, the research is continued by modeling in RIBASIM. The irrigation network scheme of the Palasari Irrigation Area is compiled at the stage of editing the data base network on the map in RIBASIM. The layout of nodes and links is carried out based on the existing irrigation network scheme and can be seen in Figure 3.

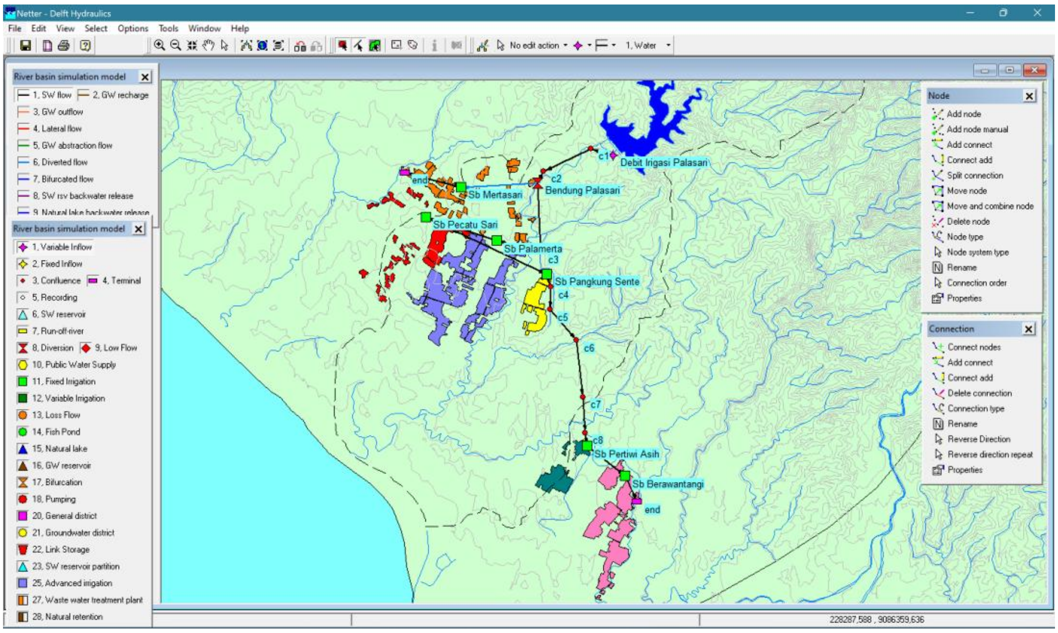

Figure 3. Simulation model of Palasari Irrigation Area network scheme in RIBASIM

Based on results of the modeling simulation in RIBASIM, it can be seen that the irrigation inflow of Palasari Reservoir cannot fulfill the irrigation water demands throughout the simulation period. The results of the modeling simulation in RIBASIM are presented in the form of graphs and reports. The graph of simulation result for each tertiary plot can be seen in Figure 4 – Figure 9, with the blue bar illustrates the supply from Palasari Reservoir and red line illustrates the demand of water irrigation.

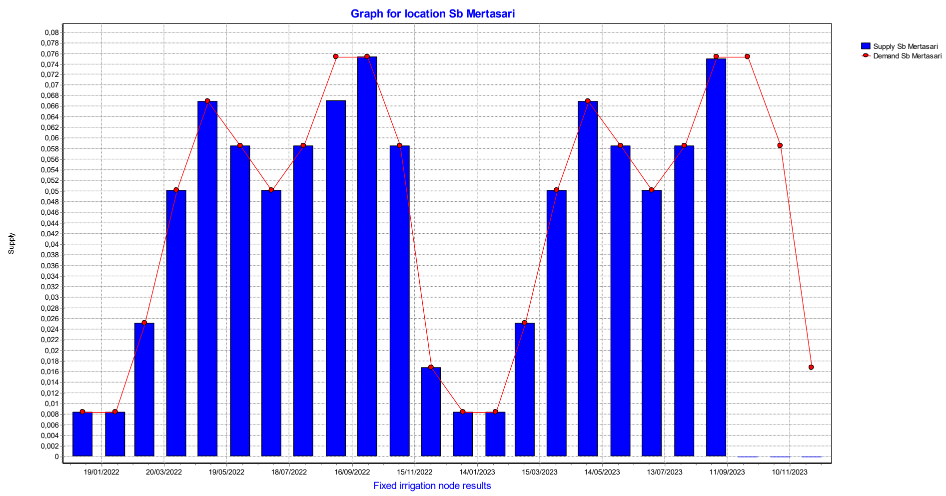

Figure 4. Graph of the relationship between supply and demand in Subak Mertasari (2022 – 2023)

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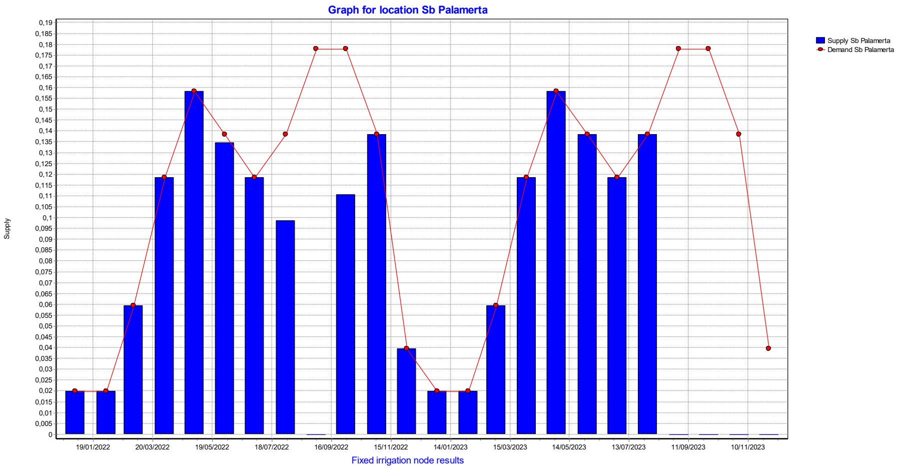

Figure 5. Graph of the relationship between supply and demand in Subak Palamerta (2022 – 2023)

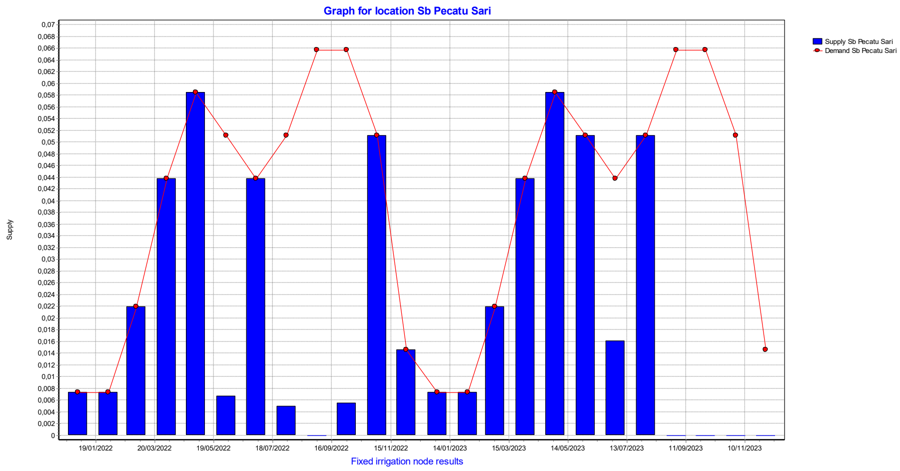

Figure 6. Graph of the relationship between supply and demand in Subak Pecatu Sari (2022 – 2023)

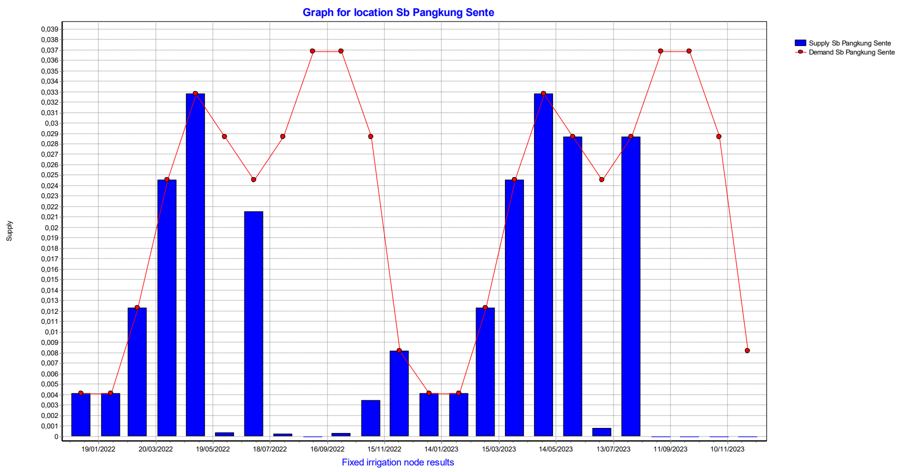

Figure 7. Graph of the relationship between supply and demand in Subak Pangkung Sente (2022 – 2023)

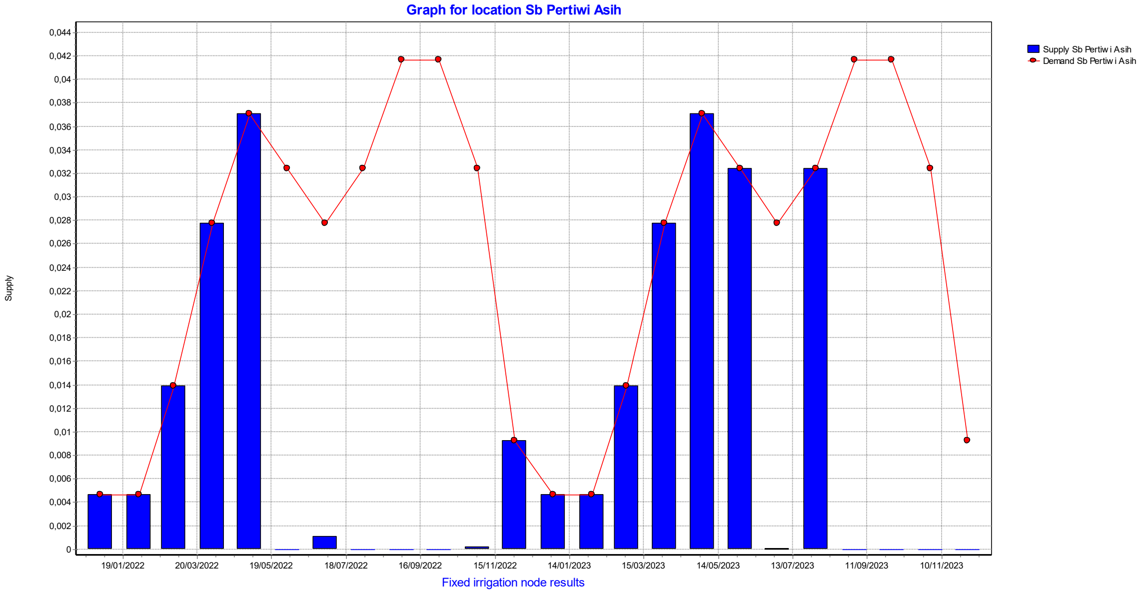

Figure 8. Graph of the relationship between supply and demand in Subak Pertiwi Asih (2022 – 2023)

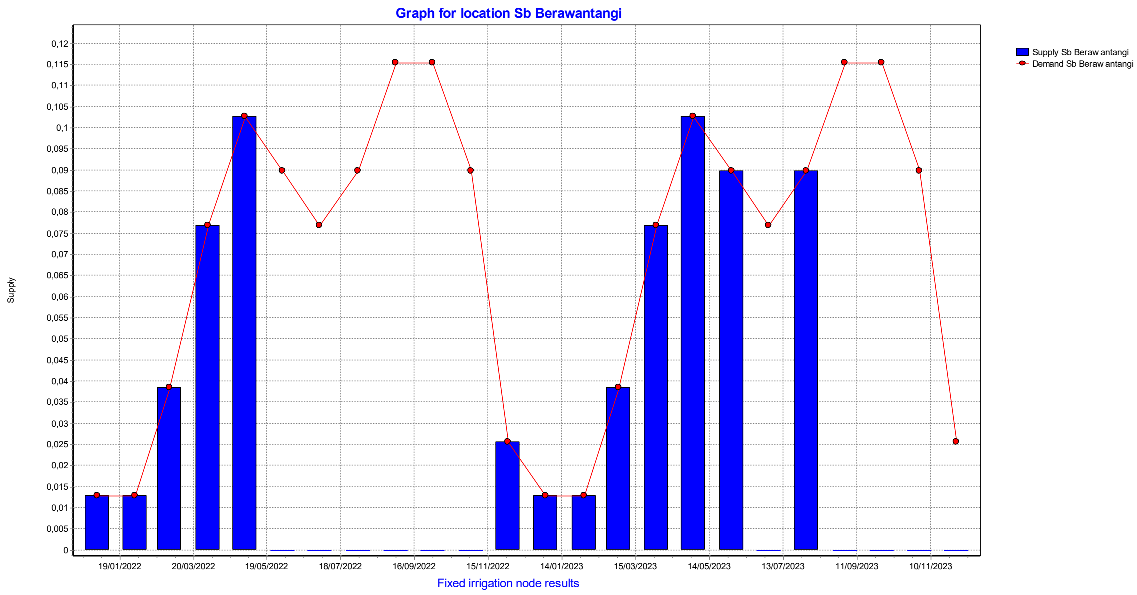

Figure 9. Graph of the relationship between supply and demand in Subak Berawantangi (2022 – 2023)

In the simulation results report of modeling in RIBASIM, data related to the annual average for irrigation water demands and water shortages per rice field/subak in units of million m^3 (Mcm) and m^3/s were obtained. The simulation results can be seen in detail in Table 5, Figure 10, and Figure 11.

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Table 5. Water allocation simulation results for Palasari Irrigation Area in RIBASIM

No.	Tertiary Plot	Yearly average			
		Demand (Mcm)	Shortage (Mcm)	Demand (m^3/s)	Shortage (m^3/s)
1	Subak Mertasari	1,456	0,210	0,046	0,007
2	Subak Palamerta	3,439	1,080	0,109	0,034
3	Subak Pecatu Sari	1,270	0,581	0,040	0,018
4	Subak Pangkung Sente	0,713	0,385	0,023	0,012
5	Subak Pertiwi Asih	0,806	0,474	0,026	0,015
6	Subak Berawantangi	2,231	1,318	0,071	0,042
	Total	9,915	4,049	0,314	0,128

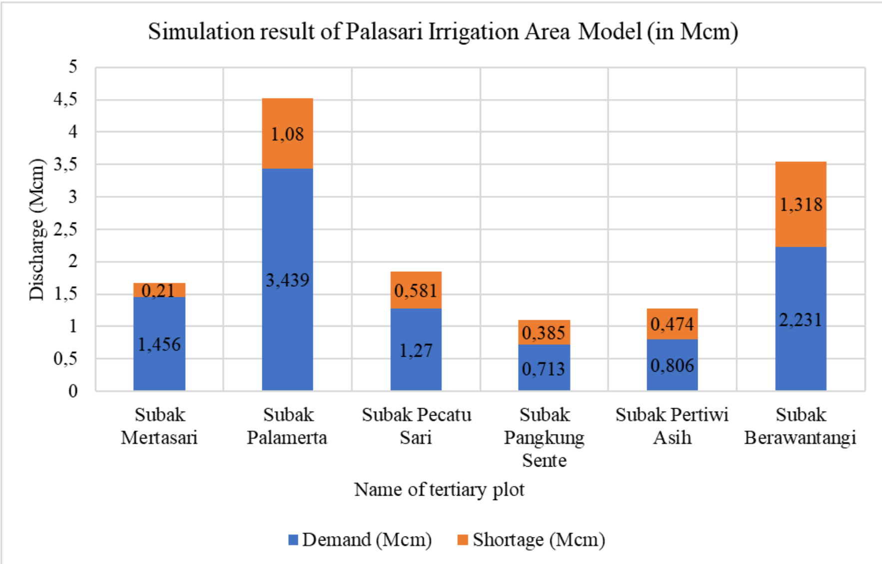

Figure 10. Simulation result of Palasari Irrigation Area model (in Mcm)

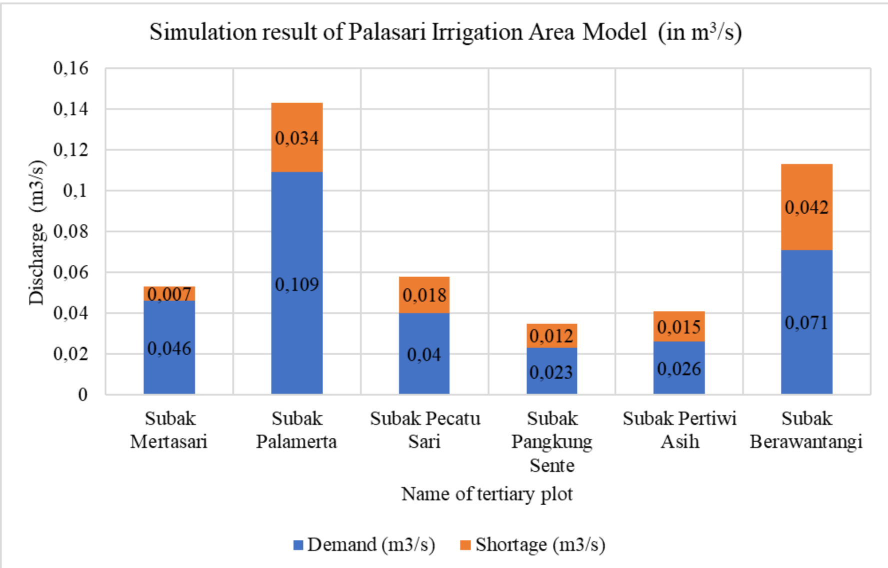

Figure 11. Simulation result of Palasari Irrigation Area model (in m^3/s)

Based on the analysis results of the simulation in RIBASIM above, it can be concluded that the existing irrigation inflow of Palasari Reservoir has not been able to fulfill the water demands in the Palasari Irrigation Area with a rice field area of 320 Ha. Meanwhile, with the yearly average irrigation water demands of the Palasari Irrigation Area simulated at 9.915 Mcm (0.314 m^3/s), there is still a water shortage of 4.049 Mcm (0.128 m^3/s) with a shortage percentage of 40.76%.

CONCLUSION

Based on the analysis results obtained in the research, several conclusions can be drawn to answer the problems that are the basis of this research. Palasari Reservoir is challenging problems related to the decrease in its water volume. When the rainfall intensity in the Jembrana area is very low, the condition of Palasari Reservoir is certain to face worrying drought. The Palasari Irrigation Area depends on the supply from Palasari Reservoir which is still insufficient. The lack of water sources that become inflow means that in the dry season the water volume of Palasari Reservoir often decreases. This condition is illustrated and described by the RIBASIM simulation model in this research which the water balance of Palasari Reservoir is stated to be deficit for supplying functional area of Palasari Irrigation Area. Since the yearly average irrigation water demands of the Palasari Irrigation Area simulated at 9.915 Mcm (0.314 m^3/s), there is still a water shortage of 4.049 Mcm (0.128 m^3/s) with a shortage percentage of 40.76%. Referring to the analysis result, it is important to plan a water management for Palasari Reservoir due to the lack of water supply in relatively high percentage. In order to form a management agency specifically for the Palasari Reservoir catchment area to be able to preserve forest, land and water conservation duties around the Palasari Reservoir so that the management of the Palasari Reservoir and its surrounding environment to support water supply can be carried out holistically and optimally. It is also recommended to the agency that has the authority to manage the Palasari Irrigation Area for the operation and maintenance duty of the irrigation network optimally so that all irrigation channels and structures that flow water to the rice fields can be utilized effectively and efficiently. In the science field, the recommendation is developing research related to optimizing irrigation water, especially in drought-prone areas, by utilizing references through previous research results or using applications/technology that can help facilitate research and implementation in the existing field. All the recommendations based on the research result is arranged to be expected in upgrading the water allocation management, especially for Palasari Reservoir and Palasari Irrigation Area. So that, from this water balance evaluation of Palasari Reservoir research can be an initial step for developed and advanced research for formulating decisions related to water allocation management specifically for irrigation demand and food estate.

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