Irrigation Network Optimization Using Linear Programming in Wates Irrigation Area, Kediri Regency

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***Abstract*.**

Indonesia, as an agrarian country, has a high dependence on the agricultural sector, where the irrigation system plays a crucial role in increasing agricultural productivity. One of the main challenges in irrigation systems is the optimal efficiency of water distribution. This study aims to analyze the condition of the existing irrigation network in the Wates Irrigation Area (Daerah Irigasi/D.I.), Kediri Regency, and to develop an agricultural land optimization strategy based on the availability of irrigation water and a suitable cropping pattern. To enhance the effectiveness of water distribution and allocation in the Wates Irrigation Area, optimization of the existing irrigation network is necessary, considering seasons and water availability. A comparison between the water discharge requirements and the available network capacity is essential. The methodology of this research includes the evaluation of the irrigation network condition, analysis of crop water requirements, and the application of an optimization method using linear programming. The data used comprises climatological data, rainfall, and cropping patterns during the 2014-2024 period. The results indicate that the optimization of irrigation water distribution can increase the efficiency of resource utilization, reduce water wastage, and improve agricultural yields. It is expected that the implementation of this optimization will result in an optimal irrigation network compared to the existing one, thereby increasing farmer welfare and ensuring sustainable food availability. The research findings also provide recommendations for local government and relevant agencies in planning and managing more efficient and optimal irrigation networks in the future. The evaluation in the Wates Irrigation Area identifies that the hydraulic performance of the majority of existing irrigation channels is inadequate due to insufficient capacity and flow velocity exceeding the safe limit, thus requiring a total redesign of the channel dimensions to meet the planned discharge. Concurrently with this infrastructure improvement, agricultural land optimization utilizing a linear programming model with the objective function of maximizing profit and constraints of water availability and land area, tested several alternative cropping patterns; although irrigation water requirements vary (lowest at 914,761 m3/ha in Alternative I), the analysis shows that Alternative I, which begins planting in October I, yields the most significant MK I planting area (876 Ha) and is the most effective cropping pattern as it generates a maximum profit of Rp. 50,465,748,346.

Keywords: *Cropping Pattern; Irrigation Network; Linear Programming; Optimization and Boundary Irrigation Area.*

I. INTRODUCTION

Indonesia is known as an agrarian country with the majority of its population dependent on the agricultural sector as its main livelihood. This sector plays a vital role in providing food for a population that continues to grow every year. Indonesia's geographical advantages, such as favorable natural conditions, rich biodiversity, and a tropical climate that allows sunlight to be available all year round, provide opportunities for people to carry out agricultural activities in a sustainable manner (Soelaiman et al., 2018). These factors make Indonesia have great potential in meeting national food needs independently.In meeting food needs, irrigation systems have a fundamental role in distributing water to agricultural land. Irrigation is an effort to provide and flow water to support national food security and improve the welfare of the community, especially farmers. However, the rapid development of the industrial sector and the expansion of settlements have led to a decrease in the area of agricultural land, which has an impact on reducing food production amid increasing demand every year (Sutrisno, 2020).One of the strategies to optimize irrigated land to increase agricultural productivity is through optimization, which is a method that aims to obtain the maximum or minimum value of a function under certain conditions. If the problem faced is related to the search for maximum value, then the approach used is maximization (Suprodjo & Purwanti, 1982). In the context of decision-making, optimization plays a role in determining the best solution that suits the needs of the analyzed system.

One of the techniques that is often used in optimization is linear programming, which is a mathematical method used in operational research to solve various optimization problems (Nasedi & Anwar, 1985 in Tamizi, 2005).The Wates Irrigation Area is located in Wates District, Kediri Regency, East Java Province, with an area of approximately 970.9 hectares. This region produces rice and corn as the main commodities in the agricultural sector. The main source of water for the irrigation system in this area comes from the Wukusari River Intake. However, based on information from local farmers, there are several obstacles in water distribution, such as misuse by community members who deliberately deflect or cut tertiary channels, so that rice fields that should receive water supply have a deficit, which risks causing crop failure (Wijayanti et al., 2021). In addition, water supply is often delayed due to suboptimal conditions of secondary channels. Some of the main problems include damage to channel infrastructure, lack of pairs at certain points, sedimentation that causes siltation, and narrowing of channel dimensions due to the growth of wild plants, which ultimately reduces the efficiency of irrigation systems and agricultural land productivity (Prasetyo & Handayani, 2019).The research "Analysis of Optimization of Planting Patterns of Irrigation Networks in Cidurian Tangerang Irrigation Areas Using Linear Programs" by Ira Damayanti and Budi Santosa in 2022 used a linear program method with the help of Lingo software to evaluate several alternative planting patterns.

Based on the results of the optimization analysis of planting patterns using a linear program, it was obtained that in Alternative 1, the optimal area of land that can be planted for peanut plants in Planting Season (MT) 2 is 971 Ha, cucumbers are 1,362 Ha, and MT 3 rice is 658 Ha, with a maximum profit of Rp 60,762,100,000. In Alternative 2, the optimum land area that can be planted is only in MT 3 for rice plants covering an area of 2,993 hectares, with a maximum profit of Rp 68,390,050,000. Meanwhile, Alternative 3 has the same optimal land area as Alternative 2, which is 2,993 Ha for MT 3 rice plants, with a profit of Rp 68,390,050,000. The maximum profit is found in Alternatives 2 and 3, with an 83% increase in profit compared to the existing conditions. Another study conducted by Nassir and Hambali in 2016 on the optimization of planting patterns in the irrigation network of Rias Village using a linear program method with limited water availability, was analyzed to maximize the profits of agricultural products by determining the optimal land area. The optimization results showed that the best planting pattern was rice-chili peppers with a rice area of 500 ha in the first planting season, chili peppers 1,383 ha in the second planting season, and chili peppers 785 ha in the third planting season. This pattern provides a maximum profit of IDR 646,172,803,646 per year. Meanwhile, Frahmana in 2018 conducted a study that examined the optimization of agricultural land use in the Majalaya Secondary Channel irrigation network, Walhar Dam, Karawang Regency, using a linear program method.

The optimization results show that the optimal land area for the first planting season is 95 Ha for rice, 205 Ha for palawija, and 190 Ha for sugarcane with a maximum profit of Rp 9,065,285,350. In the second planting season, the optimal land area is 120 Ha for rice and 170 Ha for palawija with a profit of Rp 3,090,050,750. Meanwhile, in the third planting season, the optimal land area for rice is 165 Ha and for palawija 95 Ha with a profit of Rp 4,055,360,900. Overall, this optimization increased farmer profits by 14.43% compared to the previous system.Therefore, to increase the effectiveness of water distribution and allocation in the Wates Irrigation Area, it is necessary to optimize the existing irrigation network by considering the season and water availability. It is very important to compare the water discharge needs with the available network capacity. If the capacity of the irrigation network is inadequate, then channel replanning must be carried out immediately to support the optimization process. One method that can be applied is the use of the Linear Solver Excel program, which allows for more efficient calculation and allocation of resources (Yulianto et al., 2022). With the implementation of this optimization, it is hoped that it will not only increase agricultural yields but also improve the welfare of farmers in Kediri Regency, especially in Wates District.

II. METHODS

The study area is located in Wates District, Kediri Regency, East Java Province, which is one of the 26 sub-districts in the region. Astronomically, Wates District is located at the coordinates of 7°55′0.588" South Latitude and 112°7′48.486" East Longitude. This area is dominated by a flat topography with several undulating parts and is located at the foot of Mount Kelud, so it has geomorphological and hydrological characteristics that support agricultural activities. Wates District consists of 18 villages with a population of around 93,000 people in 2024 and has an area of 72.51 km², making it the district with the second highest population density in Kediri Regency after Pare District. The location of the Wates Irrigation Area (DI) planning as well as the topographic conditions and existing irrigation network are shown in the location map and contour map presented in this study.This study uses secondary data as the main basis in the process of analysis and planning of irrigation networks. Secondary data is data obtained indirectly through related agencies, official documents, maps, archives, and relevant publications. The data used includes data on the existing condition of the irrigation network obtained through field surveys and irrigation network maps, daily rainfall data for a ten-year period sourced from the Kediri Regency Irrigation Public Works Office, and climatological data obtained from the Kediri Regency Meteorology, Climatology, and Geophysics Agency (BMKG).

The climatological data includes air temperature, wind speed, air humidity, and the duration of solar irradiation. In addition, this study also uses the Indonesian Terrain Map (RBI) as the basis for planning irrigation networks and determining channel dimensions based on elevation differences, as well as local environmental condition data obtained through direct observation at the study site.The analysis of the irrigation network was carried out based on topographic maps and boundaries of irrigation areas with reference to the KP-01 Irrigation Planning Guidelines. This analysis aims to determine the layout, classification, and naming of irrigation canals and buildings in primary, secondary, and tertiary networks. The results of the irrigation network analysis are used as a basis for calculating irrigation water needs and as a reference in planning irrigation network optimization. The stages of irrigation network planning in this study are adjusted to the provisions described in the discussion of primary and tertiary irrigation networks. The calculation of irrigation water needs or Net Farm Requirement (NFR) is carried out based on planting patterns, rainfall analysis results, and climatological data.

The calculation process refers to the method of water demand in the rice fields that has been explained in the theoretical study. Rainfall analysis was carried out using an arithmetic average method by considering data from three rain stations, namely Sidomulyo Station, Kwarasan Station, and Corner Station. The results of the NFR calculation are used as a basis for determining the irrigation water needs in the planned network.The analysis of crop profits is carried out to determine the net income obtained by farmers in each planting season. Harvest profit is calculated as the difference between the total income and production costs incurred by farmers per hectare in one planting season. Income is obtained from crop production per hectare multiplied by the selling price of agricultural products, while production costs include seeds, fertilizers, labor, and other operational costs. This yield profit value is further used as a function of purpose in the optimization analysis to obtain maximum profit from the planned irrigation system.The research flow chart illustrates the stages of planning and optimization of the irrigation network carried out in this study, starting from data collection, hydrological analysis, calculation of irrigation water needs, analysis of irrigation networks, to analysis of crop profits. The flowchart is used to show the relationship between the stages of the analysis systematically and is presented in the form of a flowchart at the end of this chapter.

III. RESULT AND DISCUSSION

Evaluation of Existing Irrigation Channels

An evaluation of the physical condition of the irrigation network in the Wates Irrigation Area (DI Wates) was conducted, covering primary, secondary, and tertiary channels. This assessment aimed to determine the functional adequacy and operational performance of the channels in supporting optimal irrigation water delivery to agricultural land within the study area. The evaluation results serve as a basis for formulating recommendations for improvement and optimization of the irrigation network in subsequent sections.Field surveys and inventory of existing conditions indicate that the majority of the irrigation network in DI Wates consists of unlined earthen channels. Approximately 60% of the observed channel length remains in the form of natural soil channels, while the remaining sections have been lined with stone masonry. However, around 30% of the lined channels exhibit structural damage ranging from minor to moderate conditions. The dominance of unlined channels potentially leads to several operational issues, including water losses due to seepage, erosion of channel beds and side slopes, and sedimentation that reduces hydraulic capacity and flow conveyance. These conditions were observed in several channel segments that experienced siltation and cross-sectional deformation as a result of natural processes. Meanwhile, damage to masonry-lined channels commonly includes cracking, dislodged stones, and deterioration of channel beds.The observed degradation of irrigation infrastructure is influenced by multiple factors, including the aging of irrigation structures, insufficient routine maintenance, and flow discharges exceeding design capacity. These conditions negatively affect the efficiency of water distribution and increase the risk of inequitable irrigation supply to agricultural areas. Therefore, a comprehensive evaluation of irrigation channel performance in DI Wates is essential to support network optimization, reduce water losses, and ensure the long-term sustainability of the irrigation system.

1. Hydrological Analysis
2. Rainfall Data Processing

Rainfall data were utilized as the basis for determining dependable rainfall and effective rainfall. The dataset covers a ten-year period from 2014 to 2024 and was obtained from three rainfall stations: Sidomulyo, Kwarasan, and Pojok. The analysis employed the *basic year method*, whereby daily rainfall data were aggregated into monthly rainfall totals for each station from January to December over the observation period.Daily rainfall data for each month were summed and presented in tabular form for the three rainfall stations. These aggregated datasets formed the foundation for subsequent dependable and effective rainfall analyses.

Effective Rainfall

Effective rainfall is defined as the portion of total rainfall that is effectively available to meet crop water requirements during the growing period. In this study, effective rainfall was calculated separately for paddy rice and palawija crops using standard coefficients.An example calculation for the Sidomulyo Station during the first half of January is as follows: The effective rainfall values were calculated on a 15-day (semi-monthly) basis for all stations throughout the year. The results for Sidomulyo, Kwarasan, and Pojok stations are summarized in.

Average Effective Rainfall

To obtain representative effective rainfall values for the study area, the effective rainfall from the three stations was averaged using the arithmetic mean: Based on this approach, the average effective rainfall for paddy and palawija crops was determined for each period throughout the year. The results are presented in and serve as input parameters for irrigation water requirement analysis and network optimization

Discharge of Water Needs Each Season of Planting Each Plant

The value of the volume of irrigation water needs is determined quantitatively based on the results of calculations derived from the determination of the planned planting pattern. After the values of water need per period are determined, the next step is to add aggregate for each type of crop in each planting season. The total volume of water from this sum is then determined as the amount of total irrigation water needed for that period.The following is an example of the calculation of alternative irrigation water needs I in the rainy season for rice plants:

The rainy season begins in November the first period until February the second period. The value is taken from the results of the NFR calculation for each plant and then summed up.

Alternative PTT water needs I rainy season:

= 0.000 + 0.000 + 0.000 + 0.000 + 0.009 + 0.636 + 0.878 + 0.103

= 1,626 lt/s/ha

= 1.626 / 1000 = 0.002 m3/s/ha

= 0.002 x 24 x 24 x 60

= 140,499 m3/ha

So the results of the calculation of the rainy season for rice plants are 140,499 m^3/ha.

Flagship Volume

Dependable volume is defined as the amount of irrigation water availability obtained through *dependable discharge* calculations, which represent the level of reliable water availability at a given probability. In the context of this study, the mainstay volume has a crucial role and will functionally be used as the main constraint function or constraint *function*. This means that the total planned irrigation water requirement must be adjusted and must not exceed the maximum limit of this available and reliable volume of water.

Here is an example of the flagship volume calculation in November period I:

Known:

Q 80% mainstay = 0.341 m3/s

So the mainstay volumes for the month of November are:

Flagship V 80% = 0.341 x 24 x 60 x 60 = 29447.557

A summary of the mainstay volume calculation for the whole can be seen in the following table:

Table 1. Discharge of Irrigation Water Availability (m3/ha)

Moon	Period	Qandalan m3/s	Water Availability Volume (m^3)		
			MH	MK1	MK2
Nov	I	0.000	0.029		
	II	1.287	111201.532		
From	I	2.547	220090.013		
	II	2.281	197096.496		
Jan	I	2.166	187158.029		
	II	1.878	162275.735		
Stuart O'T	I	0.998	86236.108		
	II	1.835	158526.231		
Mar	I	1.211		104626.027	
	II	0.271		23373.611	
Apr	I	0.024		2057.894	
	II	0.189		16303.000	
May	I	0.002		151.826	
	II	0.000		17.862	
June	I	0.000		36.454	
	II	0.000		17.862	
Jul	I	0.000			8.752
	II	0.000			4.021
Stuttgart	I	0.000			2.101
	II	0.000			0.965
Sep	I	0.000			0.505
	II	0.320			27676.216
Oct	I	0.000			0.121
	II	0.598			51670.390
VOLUME (m3)			**964057.941**	**146566.675**	**27692.681**

Linear Program Optimization Modeling

Optimization is a systematic process in formulating real system problems in the form of mathematical models with the aim of obtaining the best or most effective solution according to the goals set by the decision maker. This process is carried out through the identification of decision variables, objective functions, and constraints that limit the system. In the context of irrigation water resource management, optimization is used as an analytical tool to determine the allocation of limited water discharge so that it can be used fairly and efficiently by all agricultural land served, so that agricultural production can be maximized.In this study, the optimization method used is Linear Programming, which is a mathematical modeling technique that aims to maximize or minimize a function of a goal by considering a number of linear constraints. The optimization model is focused on maximizing crop profits and planting areas of rice and palawija plants in each planting season through optimal planting patterns and irrigation water distribution.The mathematical model in optimization analysis consists of objective functions and constraint functions. The purpose function is formulated to maximize the total profit of agricultural products obtained from rice and palawija cultivation activities in three planting seasons, namely the rainy season, dry season I, and dry season II. Profits are calculated based on production income per hectare, with a rice crop profit coefficient of Rp26,055,000.00 per hectare per planting season and palawija crops of Rp11,412,000.00 per hectare per planting season.

The decision variable in this model is the area of land planted with rice and palawija in each plot and planting season.The function of constraints in the optimization model consists of two main types, namely water availability constraints and land area availability constraints. Water availability constraints limit the total irrigation water needs of rice and palawija plants so that they do not exceed the volume of irrigation water available in each planting season. Plant water needs are expressed in cubic meters per hectare and adjusted to the characteristics of each growing season. Meanwhile, the constraint of land availability limits the total area of rice and palawija planting in each plot so that it does not exceed the available standard rice field area. The total area of raw rice fields in the Wates Irrigation Area is set at 1,216 hectares.To analyze the effect of different planting schedules on optimization results, this study uses three alternative planting patterns. Alternative Planting Pattern I is an existing planting pattern with planting time starting in November period I. Alternative Planting Pattern II is a planting pattern with a planting schedule advanced for 15 days so that it starts in October period II. In contrast, the Alternative Planting Pattern III is a planting pattern with a planting schedule postponed by 15 days so that it starts in November period II. Each alternative was analyzed using the same optimization model structure, with differences in the value of water requirements and irrigation water availability according to the hydrological conditions of each alternative.By using the Linear Program approach, this optimization model is expected to be able to provide recommendations for the most optimal planting pattern and irrigation water allocation for each alternative, so that it can be the basis for decision-making in sustainable irrigation management and oriented towards increasing agricultural yields.

IV. CONCLUSION

1. Based on the results of the evaluation of the physical condition of the irrigation network in the Wates Irrigation Area (DI), it can be concluded that the performance of the irrigation network is still not optimal, characterized by the dominance of natural channels of ±60% and damage to around ±30% of the canals of the river rock pair. These conditions have the potential to cause water loss due to seepage, erosion, and sedimentation, thereby reducing the effectiveness and reliability of irrigation water distribution to agricultural land. The main factors that affect this condition include the age of the irrigation building, lack of routine maintenance, and flow discharge that exceeds the planned capacity, so the results of this evaluation are an important basis in the formulation of recommendations for the improvement and optimization of the irrigation network to improve the efficiency and sustainability of the irrigation system in DI Wates.
2. Planned irrigation water needs for Irrigation Areas (D.I.) The boundaries show significant variations influenced by differences in the determination of the initial planting period for each scheme. Quantitatively, Alternative I requires 914,761 m^3/ha, Alternative II requires 944,807 m^3/ha and Alternative III requires 943,175 m^3/ha. These differences in values reflect the impact of different planting patterns and land use schedules on each alternative, which directly affects the total volume of water that must be allocated per hectare.
3. Planting pattern optimization, it can be concluded that alternative planting patterns provide a more efficient distribution of land area compared to existing conditions. In the rainy season, the planting area is relatively fixed in all conditions, namely rice 935 ha and corn 281 ha, indicating sufficient water availability. The main change occurred in Dry Season I, where the area of rice planting increased from 687 ha (existing) to 800 ha in Alternatives I and II, and there was a corn allocation of 76 ha and 6 ha respectively, while in Alternative III rice decreased to 649 ha without corn planting. In the Second Dry Season, the rice planting

area was relatively small and stable in the range of 46-49 ha, and there was no corn planting in all alternatives due to water limitations. Overall, the optimization results show a more adaptive land use to water availability, especially in the First Dry Season, so that it is more optimal than the existing conditions and is suitable for recommending as a planting pattern in the Wates Irrigation Area.

4. The formulation of a linear program model for agricultural land optimization in the Wates Irrigation Region specifically targets a single-purpose function, namely maximizing profits. This means that all decision variables (such as planting area allocation and planting schedule) are directed to find combinations that will result in the highest financial value or harvest profit within the limits of available resource constraints.

5. The formulation of the agricultural land optimization program in the Wates Irrigation Area establishes the function of constraints based on two main resource limitations: water availability and land area. This means that the optimal solution to maximize harvest profits must be subject to hydrological constraints, i.e. the volume of allocated, irrigated water mainstays, as well as the physical constraints of the land, i.e. the total area of raw rice fields in the region. These two constraint functions play an important role in limiting decision variables and ensuring that optimization results are realistic and sustainable.

6. In the existing planting pattern, the initial planting began on November I with an area of MH 1216 ha, MK I 687 Ha and MK II 49 Ha which resulted in an income of Rp. 46,726,366,228. To increase the maximum profit in the planting pattern, there are four conclusions in this final project, so it can be concluded as follows:

a. Alternative I at the beginning of planting began on November I with an area of MH 1216 Ha, MK I 876 Ha and MK II 46 Ha so that it made a profit of Rp. 50,465,748,346.

b. Alternative II at the beginning of planting began in October II with an area of MH 1216 Ha, MK I 806 Ha and MK II 46 Ha so that it made a profit of Rp. 49,688,836,759.

c. Alternative III at the beginning of planting began in November II with an area of MH 1216 Ha, MK I 649 Ha and MK II 48 Ha so that it made a profit of Rp. 45,718,600,524.

So that an alternative planting pattern that is effective in terms of profit is the Alternative I planting pattern.

7. Based on the results of the evaluation of the dimensions of the existing channels in the Wates Irrigation Area, it can be concluded that all channel segments analyzed have not met the criteria for the planned discharge capacity, as shown by the Q value of the channel (0.325–2.531 m^3/s) which is categorized as "NOT OK" to the discharge needs. However, in terms of flow velocity, the existing velocity value is in the range of 0.776–1.406 m/s and still meets the technical requirements, because it is within the limits of Vmin = 0.2 m/s and Vmax = 2.0 m/s, and meets the criteria *of Froude* number (Fr < 1) which indicates subcritical and stable flow conditions. The results of the replanning of the channel dimensions showed that after the cross-sectional adjustment, the Q values of the plan and V of the plan were in accordance with the needs, so this evaluation confirmed that the main problem of the DI Wates irrigation network lies in the mismatch of the cross-sectional dimensions of the existing channel with the planned discharge, and became an important basis in the formulation of recommendations for improvement and optimization of the irrigation network at the next stage.

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