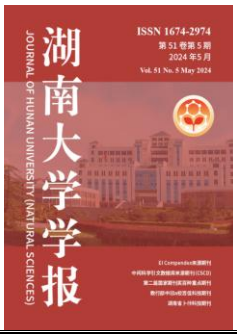

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Optimization Model for Irrigation Based on Seasonal Transition

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Abstract: Generally, irrigation optimization is carried out under existing conditions; however, this research aims to develop a pre- and post-season-transition irrigation optimization model. The methodology involves analyzing the seasonal transition conducted in previous research to identify the variables influencing model construction. This analysis is used to develop an optimization model before and after the seasonal transition. However, rainfall exhibits a dynamic nature and varies between different seasons. The importance of studying changes in climate patterns, such as fluctuations in precipitation levels and shifts in rainfall patterns, is crucial in understanding the impacts of climate change. The observation of rainfall characteristic changes in that season has a direct impact on the schedule of cropping patterns and water availability in irrigation areas, one of which is the irrigation area of Kedungsoko, Nganjuk, East Java Province, Indonesia. Climate change impacts the irrigation area, which spans approximately 788 hectares. This is indicated by the change in the optimization value. The analysis indicates that, based on data from 2001 to 2009 (pre-climate change), the benefits were approximately Rp 13,338,354,260, Rp 10,102,546,222, and Rp 5,159,418,693 for cropping seasons I, II, and III, respectively, resulting in a total benefit of about Rp 28,600,319,176. However, post-climate change (data after 2009), the benefits decreased to approximately Rp 12,893,821,171, Rp 10,213,765,338, and Rp 5,307,946,837 for the respective cropping seasons, with a total benefit of about Rp 28,415,533,345. The optimization results before and after climate change show a difference of approximately Rp 184,785,831, with smaller difference after climate change.

Keywords: irrigation optimization, seasonal transition, Kedungsoko.

基于季节转换的灌溉优化模型

摘要：一般来说，灌溉优化是在现有条件下进行的；但本研究旨在开发一个季节转换前和季节转换后的灌溉优化模型。该方法包括分析先前研究中进行的季节转换，以确定影响模型构建的变量。该分析用于开发季节转换前后的优化模型。然而，降雨表现出动态特性，在不同季节之间有所不同。研究气候模式的变化（例如降水量波动和降雨模式转变）对于理解气候变化的影响至关重要。观察该季节的降雨特征变化对灌溉区的种植模式和水资源供应有直接影响，其中之一是印度尼西亚东爪哇省恩甘朱克的凯东索科灌溉区。气候变化影响了大约788公顷的灌溉面积。优化值的变化表明了这一点。分析表明，根据2001年至2009年（气候变化前）的数据，第一、第二和第三种植季的收益分别约为13,338,354,260卢比、10,102,546,222卢比和5,159,418,693卢比，总收益约为28,600,319,176卢比。然而，气候变化后（2

009年之后的数据），各种植季的收益分别降至约12,893,821,171卢比、10,213,765,338卢比和5,307,946,837卢比，总收益约为28,415,533,345卢比。气候变化前后的优化结果相差约184,785,831印尼盾，气候变化后差异较小。

关键词：灌溉优化、季节转换、凯东索科。

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1. Introduction

Climate change is characterized by statistically significant changes in average temperatures, variability, and persistence over extended periods, typically spanning a decade or longer. Climate change is the result of internal and external processes and anthropogenic changes that persist in the atmospheric composition and land use. This definition serves as a key indicator for identifying climate change, whether it has occurred or if there has only been climate variability [1].

Climate change is inevitable. The best course of action is to adapt to the changing climate, much like we adapt to seasonal transitions. An effective way to address the uncertainties brought about by climate change is to determine cropping patterns and schedules based on the conditions of each season [2, 3].

Water resource management is not an easy job, especially when the problem is nationwide. It becomes increasingly difficult when events and climate are unpredictable or if a region is unstable [4, 5]. When making regional or national decisions, it is crucial to consider various technical and non-technical factors to reach a definitive conclusion [6, 7]. The primary objective of water resource management is to address the complex formula of demand and supply for water resources in a specific area. This involves considering various dimensions such as time, space, politics, economy, environment, and other relevant aspects [8, 9].

In recent years, numerous rivers in Indonesia have undergone significant development. The scarcity of surface water resources, particularly during the dry season, has underscored the importance of optimizing the operation and capacity of reservoir systems for multiple purposes [10]. However, it is imperative to monitor surface water resources to assess their quantity, determine water availability, ensure compliance with consumption norms (e.g., for irrigation), and analyze the discharge of substances from the catchment area [11]. To efficiently and effectively distribute and allocate water demand, it is imperative to create a system model for optimization. Optimization analysis provides more information about the distribution and allocation of water for each objective function [12].

The Kedungsoko irrigation area (DI Kedungsoko) in Nganjuk Regency spans approximately 788 hectares and is at risk due to seasonal transitions. The potential failure of harvests resulting from these transitions poses a threat to the stability of food supplies, which could have a domino effect on the economic and social systems. There are numerous strategies for maximizing agricultural yield. One of the most precise methods currently employed is intensification, which involves optimizing the existing agricultural system.

For the past four decades, irrigation optimization has been a primary focus of research in the agricultural industry. Despite this prolonged interest, a comprehensive and systematic optimization procedure for maximizing agricultural yields has yet to be developed. Current analyses in the field of agriculture typically rely on mathematical programming techniques such as linear and dynamic programming. However, these methods are often limited in their applicability to agricultural systems with multiple blocks and crop types, particularly when water resources are scarce [13, 14]. In light of the numerous past issues that have arisen, it is imperative to conduct an analysis on how climate change impacts the optimization of DI Kedungsoko.

2. Materials and Methods

2.1. Study Location

The research was conducted in Nganjuk Regency, specifically focusing on the irrigation area of Kedungsoko located in Malangsari Village, Sukomoro district. The area spans approximately 788 hectares. Fig. 2 shows the irrigation network scheme map of Kedungsoko.

Fig. 1 Research location (Own study)

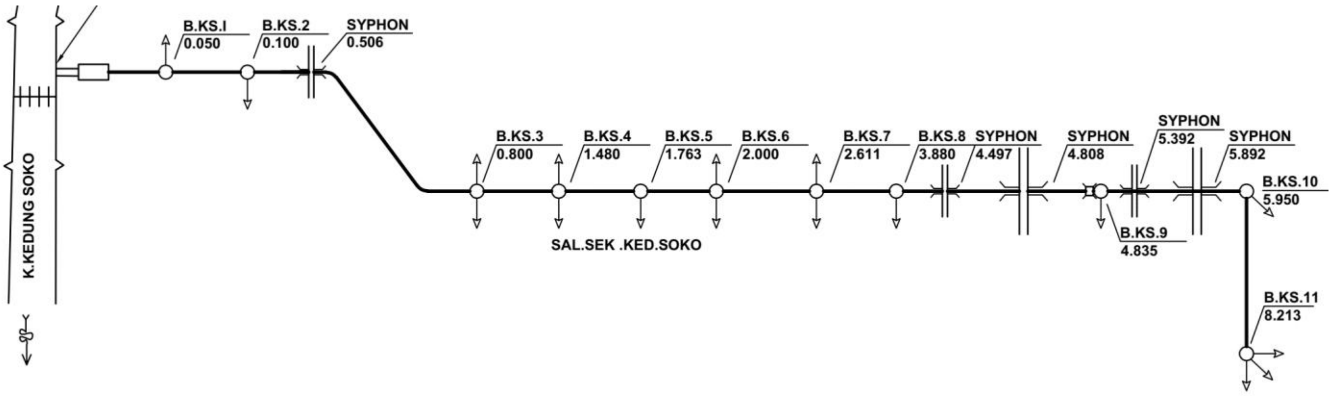

Fig. 2 Irrigation network scheme map of Kedungsoko (Own study)

2.2. Linear Programing

Linear programing is a method for solving an optimization model with a certain problem in which all the relationships between variables are linear [15]. This program serves two primary purposes: the objective function and constraints. The aim of linear programing is to reach the optimum value (maximum or minimum) from the objective function with all decision changes or non-negative variable values in the constraints.

Linear programming is an effective method for solving linear problems where the objective function and constraints are linear. All functions involved are represented in algebraic form. Linear programming is a mathematical method used to allocate limited resources to achieve a specific objective, such as maximizing or minimizing costs. Linear programming is commonly utilized in the economy, industry, military, and social fields. However, linear programing is related to the explanation of a case in the real world as a mathematical model that consists of a linear objective function with some linear constraints [15]. This study utilizes the linear programming method due to its simplicity in formulation and solving stages. Linear programming is chosen for its numerous advantages: the ability to solve systems with a large number of variables and constraints, simplicity and accuracy in application, widely available program packages, simplicity of mathematical functions, and the production of satisfactory results [15].

However, a limitation of this program is its inability to analyze the intricate irrigation system and its challenges with stochastic, time, and non-linear functions. The optimization process using linear programming starts with identifying decision variables to determine the optimal value, followed by defining the objective function. Constraints are then identified and expressed as equations or inequalities. Once the modeling is finished, an analysis or iteration is conducted to achieve the optimal condition.

A decision variable is determined to provide the optimal value for a specific target. On the other hand, an objective function is a mathematical function that needs to be either maximized or minimized to achieve a desired outcome [15]. The mathematical model of linear programing is as follows [15]:

$$\text{Max } Z = \sum_{n=1}^{n} c_n x_n \tag{1}$$

where:

Z - objective function (maximum benefit of agricultural yield) (Rp)

c_n - net benefit of rice field yield (Rp/ha)

x_n - irrigation area (ha)

A constraint is a mathematical function that limits the values of variables to optimize the objective function. It serves as a boundary that must be satisfied to achieve the desired outcome.

Discharge volume constraint:

$$\sum_{n=1}^{n} a_{mn} x_n \le b_m \tag{2}$$

and $x_n \ge 0$

for m = 1 ,2, 3,…,m

for n = 1, 2, 3,…,n

where:

x_n - variable (irrigation area) (ha)

a_{mn} - constant (volume of irrigation water requirement) ($m^3.ha^{-1}$)

b_m - volume of water availability (m^3)

c_n - net benefit of the irrigated area/rice field ($Rp.ha^{-1}$)

m - constraint number

n - number of decision variables

Area constraint:

$$X_1 + X_2 + X_3 \text{ ....} \le X_m \tag{3}$$

where:

X_1 - area of the rice field (ha)

X_2 - area of the second crop field (ha)

X_3 - area of cropping season III (ha)

X_m - available area (ha)

3. Results and Discussion

3.1. Area Constraint Variable

The first constraint is determined by the area variable in each tertiary block based on the scheme map of DI Kedungsoko. The results are presented in Table 1.

Table 1 Tertiary block area in DI Kedungsoko (Own study)

No	Distribution Building	Name of Tertiary Block	Area (ha)
1	BK S.1a	KS.2 Ka	3
2	BK S.1	KS.1 Ki	2
3	BK S.2	KS.2 Ka	3
4	BK S.3	KS.3 Kr	4
		KS.3 Ka	83
5	BK S.4	KS.4 Kr	10
		KS.4 Ka	25
6	BK S.5	KS.5 Ka	55
7	BK S.6	KS.6 Kr	7
		KS.6 Ka	3
8	BK.S 7	KS.7 Kr	8
		KS.7 Ka	126
9	BK S.8	KS.8 Ka	104
10	BK S.9	KS.9 Ka	140
11	BK S.10	KS.10 Ki	25
		KS.10 Ki	25
		KS.10 Ki	25
		KS.9 Ka	140
	Total		788

The table above illustrates the breakdown of area distribution within each tertiary block, with a total area of approximately 788 hectares in DI Kedungsoko.

3.2. Determination of the Climate Change Period

The baseline for climate change was established by analyzing annual rainfall data collected from the Banaran and Patihan rainfall stations within the Kedungsoko watershed. The analysis utilized rainfall data spanning from 2001 to 2019, encompassing 19 years.

Analysis of rainfall data from the stations reveals a shift in the timing of the rainy season. Prior to 2010, the rainy season typically began in the last 10 days of November. However, starting in 2010, the onset of the rainy season occurred earlier, in late October [16]. Therefore, for optimizing strategies post-season change, data from 2010 to 2019 will be utilized for analysis.

3.3. Irrigation Water Requirements

Irrigation water is the water sourced from a river or reservoir and distributed through an irrigation network system to regulate the water levels in agricultural areas. The irrigation water requirements can be analyzed using the following steps:

1. Analyzing potential evapotranspiration
2. Analyzing the consumptive use of crops.

Land preparation is essential to ensure that the soil is adequately moist for the nursery process, which should be conducted concurrently with the land preparation. This process typically takes place 20-30 days prior to planting paddy. The water requirement during this period is approximately ± 5 mm per day, with an inundation level of around 300 mm.

3. Determining irrigation efficiency

Irrigation efficiency is the ratio between the outflow from the intake gate and the discharge arriving at the tertiary gate. It can also be described as the amount of water lost in the irrigation channel due to factors such as evaporation, leakage, and seepage in the primary, secondary, and tertiary channels. The overall efficiency value of the channel is typically assumed to be 80%.

4. Analyzing water intake requirements

Irrigation water intake requirement is the clean water needed in the irrigated rice area, which is multiplied by the efficiency of the irrigation channel. The water intake requirements vary depending on the month and each crop season. This analysis serves as the foundation for determining the allocation of water from the available discharge at the intake. The irrigation water intake requirements can be found in Table 2.

Table 2 Maximum irrigation water requirements before and after climate change (Own study)

No.	**Cropping pattern of DI Kedungkoso**	**Cropping period**	**Maximum irrigation water requirement (l/s/ha)**	
			Paddy	**Second crop**
1	Before climate change	I	2.52	0.57
		II	2.56	0.63
		III	1.12	1.01
2	After climate change	I	2.43	0.32
		II	2.26	0.60
		III	0.00	0.94

3.4. Optimization Using Linear Programing

Optimization involves solving a model design that is based on constraint functions or mathematical functions that impose limitations [15]. This research focuses on three key elements:

a. *Objective function:* The goal is to maximize the benefit by calculating the sum of the prices of paddy and second crop per hectare, multiplied by the irrigation area for each cropping season (periods 1 to 3).

b. *Decision variable:* the irrigation area per cropping season.

c. *Constraints:* the total irrigation area and the availability of water discharge (Q_{80})

The optimization results for water balance before climate change are presented in Table 3, utilizing the solver function in Excel.

Table 3 Optimization results for water balance before climate change (Own study)

Month		Q dependable 80% (m^3/s)	Q irrigation water requirement (m^3/s) Before	surplus (+) deficit (-)	condition
Nov	III	0.403	0.218	0.184	fulfilled
Dec	I	0.707	0.575	0.132	fulfilled
	II	0.918	0.918	0.000	fulfilled
	III	0.992	0.272	0.720	fulfilled
Jan	I	0.651	0.606	0.044	fulfilled
	II	0.688	0.688	0.000	fulfilled
	III	0.677	0.529	0.148	fulfilled
Feb	I	0.722	0.435	0.287	fulfilled
	II	0.749	0.450	0.299	fulfilled
	III	0.750	0.625	0.125	fulfilled
Mar	I	0.729	0.329	0.401	fulfilled
	II	0.723	0.000	0.723	fulfilled
	III	0.722	0.007	0.714	fulfilled
Apr	I	0.746	0.105	0.640	fulfilled
	II	0.623	0.431	0.192	fulfilled
	III	0.549	0.371	0.178	fulfilled
May	I	0.553	0.423	0.130	fulfilled
	II	0.553	0.496	0.057	fulfilled
	III	0.554	0.551	0.003	fulfilled
Jun	I	0.553	0.550	0.003	fulfilled
	II	0.539	0.480	0.058	fulfilled
	III	0.502	0.332	0.171	fulfilled
Jul	I	0.375	0.375	0.000	fulfilled
	II	0.226	0.165	0.061	fulfilled
	III	0.180	0.000	0.180	fulfilled
Aug	I	0.151	0.005	0.146	fulfilled
	II	0.151	0.016	0.135	fulfilled
	III	0.151	0.028	0.123	fulfilled
Sep	I	0.129	0.042	0.086	fulfilled
	II	0.070	0.050	0.020	fulfilled
	III	0.070	0.060	0.010	fulfilled
Oct	I	0.070	0.070	0.000	fulfilled
	II	0.259	0.057	0.202	fulfilled
	III	0.124	0.059	0.065	fulfilled
Nov	I	0.189	0.189	0.000	fulfilled
	II	0.350	0.061	0.289	fulfilled
Total of fulfilled period (cropping season)					36
Fulfilled percentage in a year (%)					100

Based on Table 3, the water availability in the dry season can fulfill the irrigation water requirement for the whole month before climate change. The validation of the irrigation optimization is presented in Fig. 3. The entire irrigation water requirement curve for all periods lies below the inflow curve (Q_{80}). There are multiple points where the two curves intersect, indicating that the results are optimal and valid.

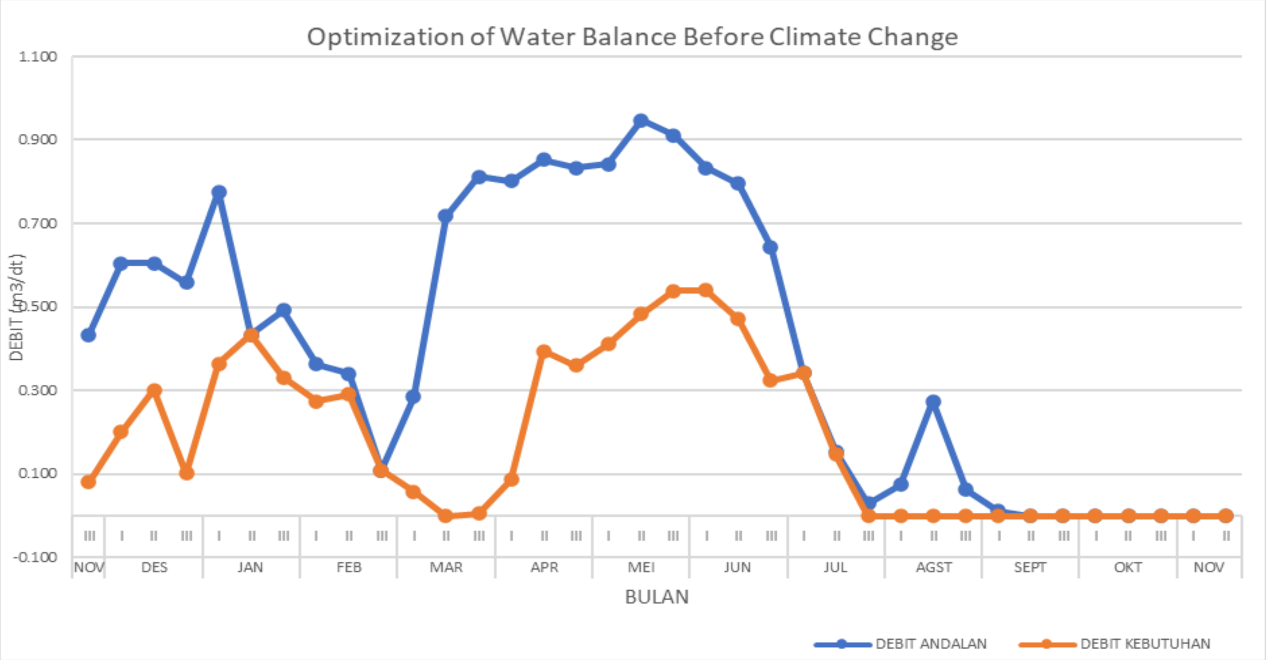

Fig. 3 Water balance curve before climate change (Own study)

The curves in Fig. 3 indicate no overlap line. All available water discharges have been optimally allocated. The optimization of water balance after climate change is presented in Table 4.

Table 4 Optimization results for water balance after climate change (Own study)

Month		Q dependable 80% (m^3/s)	Q irrigation water requirement (m^3/s) after climate change	surplus (+) deficit (-)	condition
Nov	III	0.403	0.095	0.307	fulfilled
Dec	I	0.707	0.313	0.394	fulfilled
	II	0.918	0.487	0.431	fulfilled
	III	0.992	0.338	0.654	fulfilled
Jan	I	0.651	0.225	0.426	fulfilled
	II	0.688	0.315	0.373	fulfilled
	III	0.677	0.343	0.334	fulfilled
Feb	I	0.722	0.287	0.435	fulfilled
	II	0.749	0.378	0.372	fulfilled
	III	0.750	0.750	0.000	fulfilled
Mar	I	0.729	0.179	0.551	fulfilled
	II	0.723	0.043	0.680	fulfilled
	III	0.722	0.026	0.696	fulfilled
Apr	I	0.746	0.118	0.627	fulfilled
	II	0.623	0.219	0.404	fulfilled
	III	0.549	0.270	0.279	fulfilled
May	I	0.553	0.421	0.132	fulfilled
	II	0.553	0.493	0.060	fulfilled
	III	0.554	0.546	0.009	fulfilled
Jun	I	0.553	0.522	0.030	fulfilled
	II	0.539	0.457	0.082	fulfilled
	III	0.502	0.316	0.186	fulfilled
Jul	I	0.375	0.375	0.000	fulfilled
	II	0.226	0.167	0.058	fulfilled
	III	0.180	0.000	0.180	fulfilled
Aug	I	0.151	0.005	0.146	fulfilled
	II	0.151	0.016	0.135	fulfilled
	III	0.151	0.028	0.123	fulfilled
Sep	I	0.129	0.042	0.087	fulfilled
	II	0.070	0.050	0.020	fulfilled
	III	0.070	0.060	0.010	fulfilled
Oct	I	0.070	0.070	0.000	fulfilled
	II	0.259	0.057	0.202	fulfilled
	III	0.124	0.058	0.066	fulfilled
Nov	I	0.189	0.189	0.000	fulfilled
	II	0.350	0.051	0.299	fulfilled
Total of fulfilled period					36
Fulfilled percentage in a year (%)					100

Table 4 illustrates that water availability during the dry season can meet the monthly irrigation water requirements following climate change. The validation of the irrigation optimization is presented in Fig. 4. The entire irrigation water requirement curve throughout the entire period falls below the inflow curve (Q_{80}). There are multiple points where the two curves intersect, indicating that the results are indeed optimal and valid.

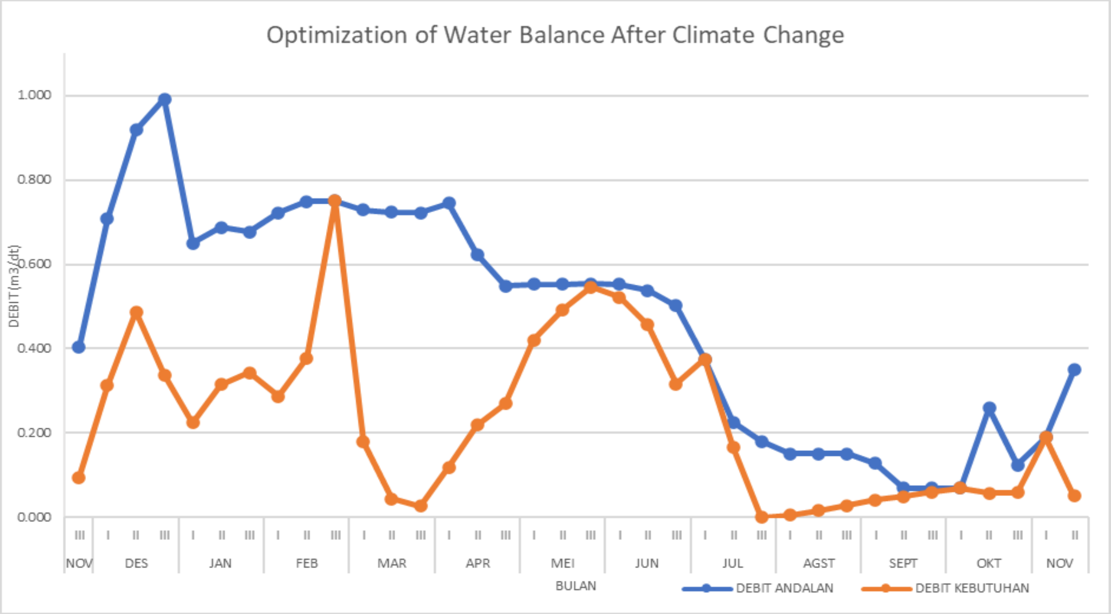

Fig. 4 Water balance curve after climate change (Own study)

The curves in Fig. 4 indicate no overlap line. All available water discharges have been optimally allocated. The optimization results are presented in Tables 5 and 6, respectively, before and after climate change.

Table 5 Benefits of optimized results before climate change (Own study)

No.	**Cropping season**	**Crop area (ha)**		**Net benefit (Rp/ha)**		**Total benefit (Rp)**
		Paddy	**Second crop**	**Paddy**	**Second crop**	
1	I	56.073	619.569	27,000,000	11,000,000	8,329,238,943
2	II	73.630	714.370			9,846,086,641
3	III	0.000	0.000			0.00
				Total benefit in a year		18,175,325,583

Table 6 Benefits of optimized results after climate change (Own study)

No.	**Cropping season**	**Crop area (ha)**		**Net benefit (Rp/ha)**		**Total benefit (Rp)**
		Paddy	**Second crop**	**Paddy**	**Second crop**	
1	I	264.114	523.886	27,000,000	11,000,000	12,893,821,171
2	II	96.610	691.390			10,213,765,338
3	III	166.238	74.503			5,307,946,837
				Total benefit in a year		28,415,533,345

Before climate change, during cropping season I, approximately 56.073 hectares were allocated for paddy cultivation and 619.569 hectares for the second crop, resulting in a total benefit of around Rp. 8,329,238,943. In cropping season II, about 73.630 hectares were designated for paddy cultivation and 714.370 hectares for the second crop, yielding a benefit of approximately Rp. 9,846,086,641. However, during cropping season III, no land was allocated for either paddy or the second crop, resulting in a total annual benefit of about Rp. 18,175,325,583.

In contrast, after climate change, the allocation of land shifted. During cropping season I, approximately 264.114 hectares were designated for paddy cultivation and 523.886 hectares for the second crop, resulting in a benefit of around Rp. 12,893,821,171. In cropping season II, about 96.610 hectares were allocated for paddy cultivation and 691.390 hectares for the second crop, yielding a benefit of approximately Rp. 10,213,765,338. Finally, in cropping season III, approximately 166.238 hectares were allocated for paddy cultivation and 74.503 hectares for the second crop, resulting in a benefit of about Rp. 5,307,946,837. Consequently, the total annual benefit amounts to approximately Rp. 28,415,533,345.

4. Conclusions

The research was carried out in Nganjuk Regency, specifically focusing on the irrigation area of Kedungsoko located in Malangsari Village, Sukomoro district. This area spans approximately 788 hectares. This research aimed to build an irrigation optimization model before and after seasonal transition. The analysis of seasonal transition was carried out in previous research. In the analysis of climate change, the determination was based on rainfall data from 2001 to 2019, spanning 19 years. Before climate change, optimization analysis utilized rainfall data from 2001 to 2009; post-climate change, the analysis shifted to rainfall data from 2010 to 2020. This transition marks the onset of a new seasonal pattern in 2010.

Based on the analysis conducted, the following conclusions can be drawn:

1) The identification of the climate change period was determined by analyzing the rainfall data in DI Kedungsoko, which revealed that climate change occurred in 2010.

2) The optimization of irrigation for the two conditions resulted in varying benefits before and after climate change. Before climate change, the benefits amounted to Rp. 18,175,325,583, whereas after climate change, the benefits increased to Rp. 28,415,533,345. This represents a significant increase in benefits of Rp. 10,240,207,762 or 56.34%.

3) The water balance analysis of the optimized cropping pattern in DI Kedungsoko indicates that water availability can meet the water requirements for each cropping season post-climate change. As a result, the water allocation operation pattern in DI Kedungsoko can be sustained.

References

[1] NAIT C., BISRI M., SOETOPO W., PRAYOGO T. B., KRISNAYANTI D., and LIMANTARA L. M. Climate change effects on Noel Puames River area rainfall in Kupang District. *Journal of Hunan University Natural Sciences*, 2022, 49(8): 187-192. https://doi.org/10.55463/issn.1674-2974.49.8.22

[2] MIATKOWSKI Z., & SMARZYNSKA K. Surface water resources of small agricultural watershed in the Kujawy Region, Central Poland. *Journal of Water and Land Development*, 2017, 33: 131-140. https://doi.org/10.1515/jwld- 2017-0028

[3] HIDAYAT F., RASYAD A., ZULKARNAIN, BUSTAMI A. L., and LIMANTARA L. M. Dependable discharge of Molek irrigation water requirement related to the participation perspective of irrigation management. *Journal of Southwest Jiaotong University*, 2022, 57(3): 300-310. https://doi.org/10.35741/issn.0258-2724.57.3.24

[4] JUWONO P. T., LIMANTARA L. M., and ROSIADI F. Optimization of irrigation cropping pattern by using linear programming: Case study on irrigation area of Parsanga, Madura Island, Indonesia. *Journal of Water and Land Development*, 2018, 39: 51–60. https://doi.org/10.2478/jwld-2018-0058

[5] JUWONO P. T., LIMANTARA L. M., and PUTRA A. R. Optimizing irrigation benefits in the water system using dynamic programming. *Journal of Southwest Jiaotong University*, 2021, 56(4): 890-901. https://doi.org/10.35741/issn.0258-2724.56.4.77

[6] JUWONO P. T., LIMANTARA L. M., SOETOPO W., and NOPEBRIAN A. Optimization of Irrigation Cropping Pattern (Case Study on Karang Anyar Irrigation Area, Malang Regency, Indonesia). *International Journal of GEOMATE*, 2018, 15(50): 197-204. https://doi.org/10.21660/2018.50.92322

[7] OSAMA S., ELKHOLY M., and KANSOH R. M. Optimization of the cropping pattern in Egypt. *Alexandria Engineering Journal*, 2017, 56(4): 557-566. https://doi.org/10.1016/j.aej.2017.04.015

[8] ASMELITA, LIMANTARA L. M., BISRI M., SOETOPO W., and FARNI I. Allocation of existing water irrigation in Panti Rao. *Journal of Southwest Jiaotong University*, 2022, 57(3): 355-362. https://doi.org/10.35741/issn.0258-2724.57.3.29

[9] BACHTIAR S., LIMANTARA L. M., SHOLICHIN M.,

and SOETOPO W. Water balance and potency of the Duriangkang-Muka Kuning reservoirs for supporting the raw water supply in Batam City, Indonesia. *Journal of Hunan University Natural Sciences*, 2022, 49(8): 55-59. https://doi.org/10.55463/issn.1674-2974.49.8.7

[10] BACHTIAR S., LIMANTARA L. M., SHOLICHIN M., and SOETOPO W. Assessment of water availability in the cascade reservoir of Duriangkang-Muka Kuning for supporting the integrated optimization. *Journal of Southwest Jiaotong University*, 2022, 57(2): 326-335. https://doi.org/10.35741/issn.0258-2724.57.3.26

[11] NAIT C., BISRI M., SOETOPO W., PRAYOGO T. B., KRISNAYANTI D., and LIMANTARA L. M. Simulation of Raknamo reservoir operation by using linear programming. *Journal of Southwest Jiaotong University*, 2022, 57(6): 544-553. https://doi.org/10.35741/issn.0258-2724.57.6.50

[12] GUSFIANA E., LIMANTARA L. M., SISINGGIH D., NURCAHYA E., and SAYEKTI R. M. Optimization model for reservoir water body surface area use in the floating photovoltaic power plant. *Journal of Southwest Jiaotong University*, 2022, 57(5): 1-6. https://doi.org/10.35741/issn.0258-2724.57.5.26

[13] WANG F., CHEN Y., LI Z., FANG G., LI Y., and XIA Z. Assessment of the irrigation water requirement and water supply risk in the Tarim River Basin, Northwest China. *Sustainability*, 2019, 11(18): 4941. https://doi.org/10.3390/su11184941

[14] SATYAGRAHA B., LIMANTARA L. M., BISRI M., and ANDAWAAYANTI U. Model of water economic value optimization based on the land use change. *Journal of Water and Land Development*, 2018, 36(I-III): 143-152. https://doi.org/10.2478/jwld-2018-0014

[15] LIMANTARA L. M., & SOETOPO W. *Water Management*. Penerbit Andi, Yogyakarta, 2020.

[16] PAMADYA O., JUWONO P. T., ANDAWAYANTI U., and ASMARANTO R. Detection of Climate Change in the Kedungsoko Irrigation Area – Nganjuk, Indonesia. *Journal of Hunan University Natural Sciences*, 2022, 49(4): 271-280. https://doi.org/10.55463/issn.1674-2974.49.7.2

参考文:

[1] NAIT C.、BISRI M.、SOETOPO W.、PRAYOGO T. B.、KRISNAYANTI D. 和 LIMANTARA L. M. 气候变化对古邦地区诺埃尔·普阿梅斯河地区降雨的影响。《湖南大学自然科学学报》，2022年， 49(8): 187-192。https://doi.org/10.55463/issn.1674-2974.49.8.22

[2] MIATKOWSKI Z. 和 SMARZYNSKA K. 波兰中部库亚维地区小型农业流域地表水资源。《水土发展杂志》，2017年， 33: 131-140。https://doi.org/10.1515/jwld- 2017-0028

[3] HIDAYAT F.、RASYAD A.、ZULKARNAIN、BUSTAMI A. L. 和 LIMANTARA L. M. 莫莱克灌溉需水量的可靠排放与灌溉管理的参与视角相关。西南交通大学学报，2022，57(3)：300-310。https://doi.org/10.35741/issn.0258-2724.57.3.24

[4] JUWONO P. T.、LIMANTARA L. M. 和 ROSIADI F. 利用线性规划优化灌溉种植模式：以印度尼西亚马都拉岛帕桑加灌溉区为例。水土开发杂志，2018，39：51-60。https://doi.org/10.2478/jwld-2018-0058

[5] JUWONO P. T.、LIMANTARA L. M. 和 PUTRA A. R. 使用动态规划优化水系统中的灌溉效益。西南交通大学学报，2021，56(4)：890-901。https://doi.org/10.35741/issn.0258-2724.56.4.77

[6] JUWONO P. T.、LIMANTARA L. M.、SOETOPO W. 和 NOPEBRIAN A. 灌溉种植模式优化（以印度尼西亚玛朗县卡朗安雅灌溉区为例）。几何形状国际期刊，2018，15(50)：197-204。https://doi.org/10.21660/2018.50.92322

[7] OSAMA S.、ELKHOLY M. 和 KANSOH R. M. 优化埃及的种植模式。亚历山大工程杂志，2017年，56(4): 557-566。https://doi.org/10.1016/j.aej.2017.04.015

[8] ASMELITA、LIMANTARA L. M.、BISRI M.、SOETOPO W. 和 FARNI I. 潘蒂拉奥现有灌溉水分配。西南交通大学学报，2022年，57(3): 355-362。https://doi.org/10.35741/issn.0258-2724.57.3.29

[9] BACHTIAR S.、LIMANTARA L. M.、SHOLICHIN M. 和 SOETOPO W. 印度尼西亚巴淡岛杜里昂康-穆卡库宁水库的水平衡和支持原水供应的效力。湖南大学自然科学学报，2022， 49(8): 55-59。https://doi.org/10.55463/issn.1674-2974.49.8.7

[10] BACHTIAR S.、LIMANTARA L. M.、SHOLICHIN M. 和 SOETOPO W. 评估杜里昂康-穆卡库宁梯级水库的水资源可用性以支持综合优化。西南交通大学学报，2022，57（2）：326-335。https://doi.org/10.35741/issn.0258-2724.57.3.26

[11] NAIT C.，BISRI M.，SOETOPO W.，PRAYOGO T. B.，KRISNAYANTI D.，LIMANTARA L. M. 利用线性规划模拟拉克纳莫水库运行。西南交通大学学报，2022，57（6）：544-553。https://doi.org/10.35741/issn.0258-2724.57.6.50

[12] GUSFIANA E.、LIMANTARA L. M.、SISINGGIH D.、NURCAHYA E. 和 SAYEKTI R. M. 浮动光伏电站水库水体表面面积利用优化模型。西南交通大学学报，2022， 57(5): 1-6。https://doi.org/10.35741/issn.0258-2724.57.5.26

[13]王锋、陈燕、李哲、方刚、李燕、夏哲。西北地区

塔里木河流域灌溉需水量及供水风险评估。可持续发展，2019，11(18)：4941。https://doi.org/10.3390/su11184941

[14] SATYAGRAHA B.、LIMANTARA L. M.、BISRI M. 和 ANDAWAAYANTI U. 基于土地利用变化的水经济价值优化模型。《水与土地发展杂志》，2018，36(I-III)：143-152。https://doi.org/10.2478/jwld-2018-0014

[15] LIMANTARA L. M. 和 SOETOPO W. 水管理。佩内比特·安迪，日惹，2020年。

[16] PAMADYA O.、JUWONO P. T.、ANDAWAYANTI U. 和 ASMARANTO R. 印度尼西亚恩甘朱克·凯东索科灌溉区气候变化检测。湖南大学自然科学学报，2022年， 49(4): 271-280。https://doi.org/10.55463/issn.1674-2974.49.7.2