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Hydrological Assessment and Irrigation Water Optimization Based on Cropping Patterns in the Way Bungur Irrigation Area, Indonesia

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Abstract

Efficient water management is essential for sustaining agricultural productivity, particularly in regions supported by technical irrigation systems such as the Way Bungur Irrigation Area in Pringsewu Regency, Indonesia. Although water availability in this region is generally adequate, its utilization remains inefficient due to cropping schedules that are not aligned with seasonal hydrological conditions, especially during the dry season. This study evaluates irrigation water requirements based on crop types and the official Cropping Pattern Plan (SK RTT), and compares them with water availability estimated using the F.J. Mock hydrological model. Input data include rainfall records, climatological parameters, river discharge, and field measurements. Crop water requirements were calculated using the FAO Penman–Monteith method, while water availability was assessed through dependable flow analysis. Results indicate that water availability in the Way Bungur watershed generally exceeds irrigation demand across three cropping seasons. However, temporal mismatches between planting schedules and water surplus or deficit periods lead to suboptimal water use. These findings highlight the importance of integrating annual water balance analysis into cropping pattern planning to enhance allocation efficiency, reduce risk, and promote sustainable agricultural development.

Keywords: cropping pattern planning; hydrological modeling; irrigation water requirements; water balance analysis; way bungur watershed

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INTRODUCTION

In tropical regions, sustainable irrigation management is critical to ensuring food security amid increasing climate variability. Indonesia, with its extensive agricultural landscapes, faces similar challenges, particularly in areas dependent on technical irrigation systems (Creata et al., 2025;

Sutrisno & Hamdani, 2019). One such region is the Way Bungur Irrigation Area in Pringsewu Regency, Lampung Province, which plays a strategic role in local food production.

The irrigation scheme in Way Bungur relies primarily on water sourced from the Way Sekampung watershed. Each year, the local government issues a Cropping Pattern Plan Decree (Surat Keputusan Rencana Tata Tanam, SK RTT), which serves as the official guideline for irrigation scheduling and water allocation (Ariyanto, 2022). Although assessments suggest that water availability in the region is generally sufficient to support three cropping seasons, inefficiencies persist due to misalignments between planting schedules and actual hydrological conditions particularly during the dry season (Dainty et al., 2016). During these periods, the Way Sekampung River often fails to meet the scheduled irrigation demand, leading to water shortages, delayed planting, and reduced agricultural productivity.

Previous studies have examined water availability using hydrological models such as the F.J. Mock method or focused on single-season assessments (Anika et al., 2021; Putri et al., 2023). However, few have integrated official cropping plans with detailed irrigation water requirement estimations and multi-season hydrological simulations. This study aims to fill that gap by combining SK RTT data, crop water demand calculations using the FAO-56 Penman–Monteith method (Baskoro & Suprapto, 2024), and water availability simulations based on the F.J. Mock model (Qarinur et al., 2022) calibrated with local climatic data from the Way Sekampung watershed.

By applying this integrated approach, the study seeks to evaluate the adequacy of irrigation water supply across planting seasons and identify potential deficits. The findings are expected to inform adaptive irrigation planning and provide a replicable framework for optimizing water resource management in tropical agricultural systems. Furthermore, this research contributes to the broader discourse on climate-resilient agriculture by demonstrating how localized hydrological modeling can support decision-making in irrigation governance.

METHOD

This study employed a descriptive quantitative approach and was conducted in the Way Bungur Irrigation Area, administratively located in Gading Rejo District, Pringsewu Regency, Lampung Province, Indonesia with a coordinates 05°25′29.53″ S and 104°54′19.93″ E as shown in **Figure 1**. The data utilized in this study comprised both primary and secondary sources. Primary data were obtained through field surveys, particularly by measuring instantaneous discharge. Secondary data included rainfall records, climatological data, watershed maps, irrigation area maps, and the Cropping Pattern Plan (SK RTT) of Pringsewu Regency for the 2024–2025 planting year.

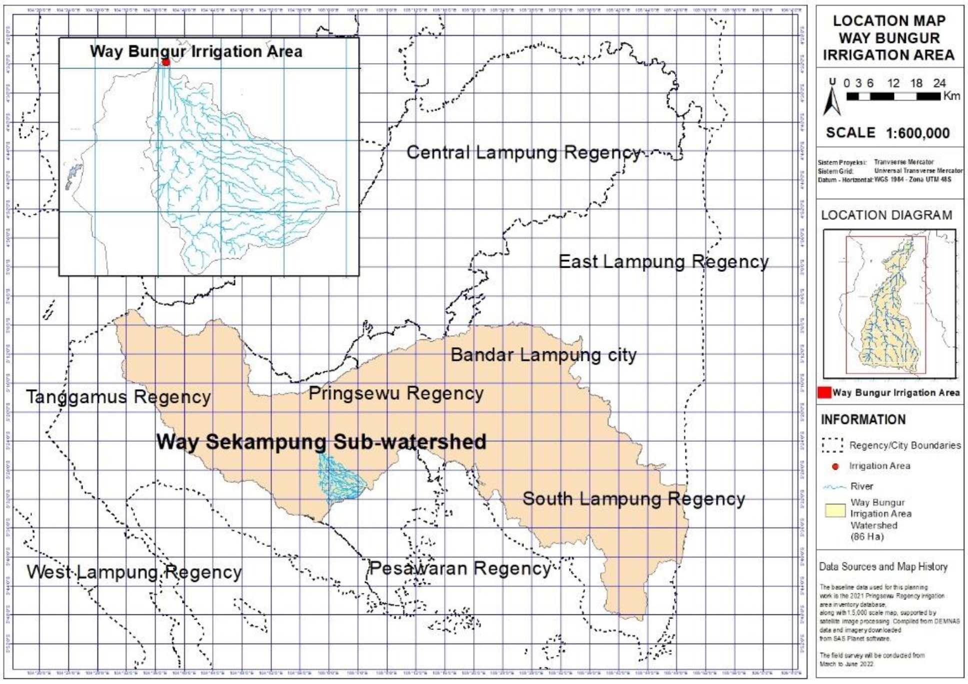

Figure 1. Way Bungur Irrigation Area

Climatological Data

The Climatology as the study of climate, provides essential information to support human activities and to facilitate planning in various sectors (Imran, 2013). In this study, climatological data were obtained from the Meteorology, Climatology, and Geophysics Agency (BMKG) at the Branti, Gunung Megang, Reno Basuki, and Cisaat Natar stations. The dataset comprised rainfall, wind speed (u), sunshine duration (n/N), air temperature (T), and relative humidity (RH) recorded over a 12 year period (Susilowati et al., 2019).

Rainfall Data

Daily rainfall data (1996–2017) were obtained from the Mesuji Sekampung River Basin Authority and processed using the Thiessen polygon method. Four stations within the Way Bungur watershed (PH-011, PH-009, PH-016, and R040) were used. Effective rainfall was assumed to be 70% of mean mid-month rainfall, as not all precipitation contributes to crop water use (Fitriansyah et al., 2020). For rice and secondary crops, effective rainfall can be estimated using expressions involving Re, R80, and R50 (Sidabutar et al., 2022), as shown in equation (1) for rice crops and (2) For secondary crops (Palawija) :

$$Re = 0.7\ x\ (\frac{R_{80}}{15}) \qquad (1)$$

$$Re = 0.7\ x\ (\frac{R_{50}}{15}) \qquad (2)$$

Evapotranspiration Analysis

Evapotranspiration, representing water loss through evaporation and transpiration, is driven primarily by solar radiation and influences discharge, reservoir storage, irrigation potential, and crop water demand (Nuryanto et al., 2013). It also affects atmospheric humidity, where saturation leads to condensation and rainfall (Fibriana et al., 2018).

Dependable Flow Analysis Using the F.J. Mock Method

Irrigation water requirements are typically assessed at the 80% probability level, meaning discharge may fall below dependable flow 20% of the time (Destiany et al., 2019). In this study, dependable flow was estimated using the F.J. Mock method, with the 80% probability discharge calculated via the Weibull distribution (Sidabutar et al., 2022), as shown in equation (3):

$$P = \frac{m}{(n+1)} \qquad (3)$$

Explanation:
P : The probability of occurrence of a set of values expected during the observation period (%)
m : the rank of the data
n : the total number of data

Irrigation Water Requirement Analysis

Irrigation water requirement is defined as the combined contribution of rainfall, groundwater, and irrigation to meet evapotranspiration demand, losses, and crop needs (Sari, 2019). In this study, requirements for rice and secondary crops were determined as follows (Fitriansyah et al., 2025):

1. Net Field Water Requirement (NFR): Calculated as ETc + percolation + water layer replacement – Re.
2. Irrigation Requirement (IR): Derived by adjusting NFR for irrigation efficiency, which accounts for canal seepage, leakage, and evaporation losses. For secondary crops, IR is computed as ETc – Re, adjusted by efficiency.
3. Diversion Requirement (DR): Expressed in discharge (l/s/ha) using a conversion factor of 8.64.Diversion Requirement (DR): Expressed in discharge (l/s/ha) using a conversion factor of 8.64.

Water Balance

Water balance analysis evaluates deficits or surpluses, thereby optimizing water resource use and anticipating risks under varying conditions (Dewi et al., 2021; Wintyaswan et al., 2022), as shown in equation (4):

$$WB = Q_{dep} - DR \qquad (4)$$

where:
WB : water balance (m^3/s)
Qdep : dependable discharge (m^3/s)
DR : net water requirement at the intake (m^3/s)

RESULTS AND DISCUSSION

Rainfall Pattern and Seasonal Implications

Rainfall data from four representative stations within the Way Bungur catchment PH.009 Kuto Dalem, PH.011 Way Guring Suka Agung–Bulok, PH.016 Pajar Esuk II, and R.040 Pematang Nebak were analyzed for the period 1996–2017 using mid-month records and the Thiessen Polygon method. Coefficients for each station are presented in **Table 1**. The analysis reveals a distinct seasonal pattern: high rainfall from January to March (120–145 mm/month), a pronounced decline from April to September (reaching a low of ~30 mm/month), and a recovery from October to December. This pattern has direct implications for watershed management and agricultural planning. During the rainy season, water storage and flood control are essential, while in the dry season, efficient irrigation becomes critical. Accordingly, rice cultivation is best scheduled during the wet season, whereas drought-tolerant or secondary crops are more suitable during the dry season.

Table 1. Calculation of Area and Thiessen Coefficients

No	Rainfall Station	Area Size (Km^2)	Thiessen Coefficient
1	PH.009 Kuto Dalem	184,313	0,9123
2	PH.011 Way Guring Suka Agung -Bulok	114,922	0,1199
3	PH.016 Pajar Esuk II	331,196	0,3455
4	R. 040 Pematang Nebak	328,185	0,3424
	Total	958,617	1

Effective Rainfall (R80) and Irrigation Dependence

The R80 analysis, which estimates effective rainfall at an 80% reliability level, shows a similar annual trend. From January to March, R80 values range between 65–80 mm/month, declining sharply to 10–25 mm/month from April to August, and rising again to 25–50 mm/month from September to December. Compared to crop water requirements, R80 values remain substantially lower, especially during the dry season. This indicates that rainfall alone is insufficient to meet irrigation demands, reinforcing the critical role of supplemental irrigation. These findings support the need for dynamic water allocation strategies that respond to seasonal deficits.

Climatological Conditions and Crop Suitability

Climatological data from BMKG (1976–1998) provide further insight into the agro-climatic suitability of the region: *humidity*: Relative humidity consistently exceeds 70%, which helps reduce evapotranspiration losses but may increase pest and disease risks during the wet season; *temperature*: Average air temperature remains stable between 25–27 °C, supporting physiological processes for rice and secondary crops; *wind speed*: Low to moderate wind speeds pose minimal mechanical risk but can accelerate evapotranspiration during dry periods; and *solar radiation*: Adequate for photosynthesis, though reduced during the rainy season due to cloud cover.

Overall, these conditions make the Way Bungur watershed highly suitable for food production. However, climatic variability particularly reduced rainfall and increased evapotranspiration during the dry season poses challenges for water management and crop scheduling.

Evapotranspiration Calculation

Evapotranspiration was calculated using the Modified Penman method, selected for its accuracy in tropical climates. Parameters included air temperature, humidity, solar radiation, and wind speed. Results show that during the rainy season, rainfall consistently exceeds evapotranspiration, resulting in a water surplus. Conversely, in the dry season, evapotranspiration surpasses rainfall, creating a water deficit. This seasonal fluctuation directly influences cropping decisions. Water-intensive crops like rice are best cultivated during surplus periods, while secondary or drought-tolerant crops are recommended during deficit periods. These findings underscore the importance of water-saving practices, reservoir development, and efficient irrigation systems to maintain year-round agricultural productivity.

Calculation of Reliable Discharge

Reliable discharge was calculated using the F.J. Mock method, which incorporates rainfall data, climatological parameters, and watershed characteristics. The instantaneous discharge measurement of the Way Bungur River on May 24, 2022, yielded an average value of 0.6662 m^3/s, representing field conditions during the dry season. By contrast, the reliable discharge calculated using the F.J. Mock method provides an overview of annual discharge variations derived from long-term rainfall and climate records. The discrepancy between measured and calculated values for the same month is reasonable, as field measurements capture only instantaneous conditions, whereas model calculations reflect monthly averages. This demonstrates that measurement data are valuable for validating actual field conditions, while calculated results are more suitable for long-term planning. Such planning is particularly important for optimizing water management and determining appropriate cropping patterns in the Way Bungur watershed, as shown in **Figure 2**.

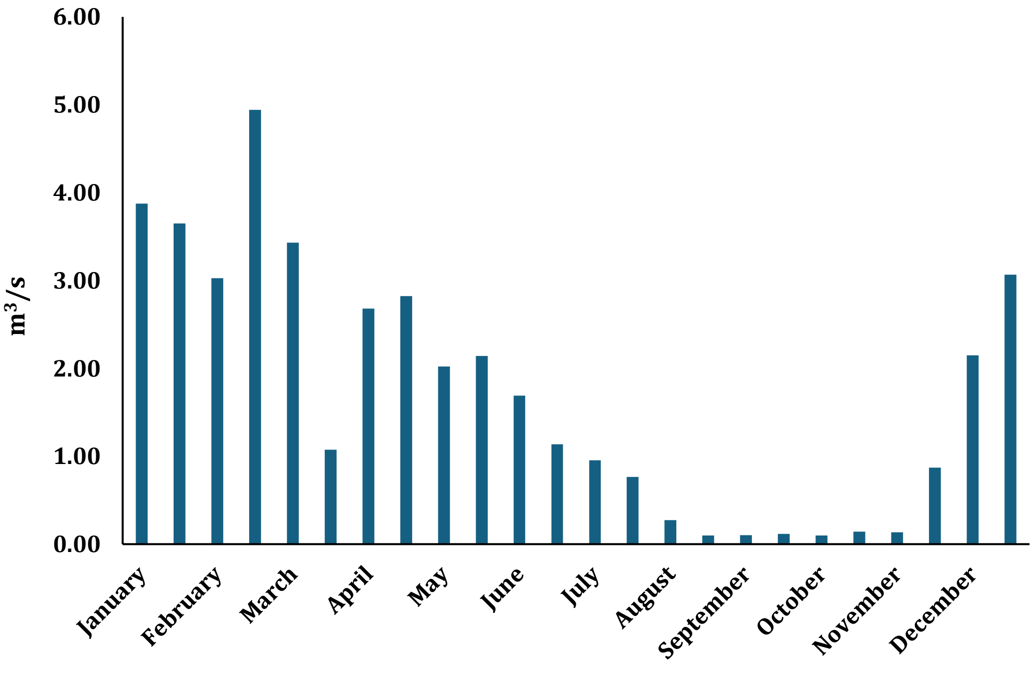

Figure 2. Reliable Discharge

Calculation of Water Requirements

Water requirements during land preparation were estimated using the Van De Goor and Zijlstra (1968) method, while irrigation requirements were determined based on water discharge per hectare, adjusted for irrigation efficiency. The results indicate that water availability in the Way Bungur watershed consistently exceeds irrigation demand across the three cropping seasons. In the first rice season (December 15–April 14), the water requirement of 0.167 m^3/s is met by an available supply of 3.180 m^3/s, supporting 83 ha of rice. In the second season (April 15–August 14), the requirement of 0.55 m^3/s is fulfilled by 12.90 m^3/s, covering 54 ha of rice and 14 ha of secondary crops. In the third season (August 15–December 14), the requirement of 0.040 m^3/s is satisfied by 3.846 m^3/s, supporting 5 ha of secondary crops. The planting dates and cultivated areas follow the 2024 Pringsewu Regency Official Planting Plan ensuring that the analysis reflects both the hydrological conditions of the Way Bungur watershed and the officially designated cropping pattern. This relationship between water availability and crop water demand is illustrated in **Figure 3**.

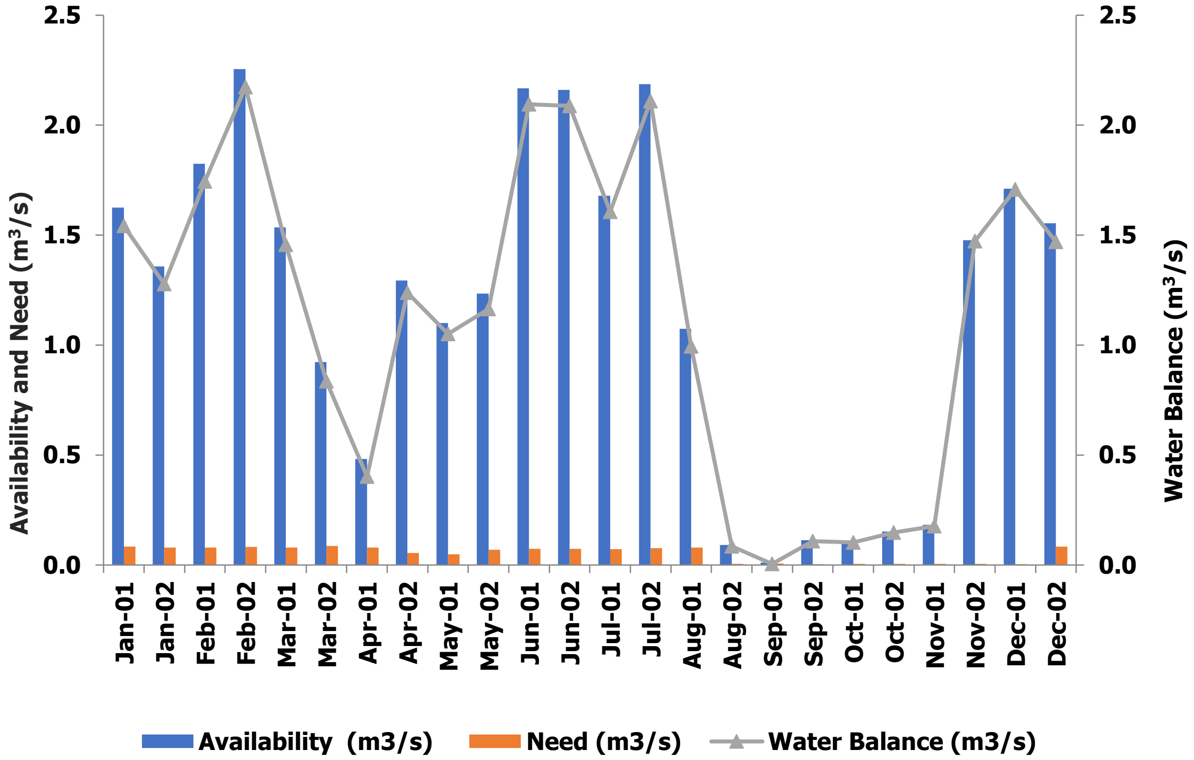

Figure 3. Water Balance in Way Bungur

The integrated analysis of rainfall, climatology, evapotranspiration, and discharge confirms that while water resources are abundant, their seasonal distribution requires careful management. The study highlights the need for adaptive irrigation planning, informed by hydrological modeling and reliable climate data.

CONCLUSION

This study presents a comprehensive hydrological assessment of the Way Bungur Irrigation Area by integrating rainfall analysis, climatological evaluation, evapotranspiration modeling, and irrigation water demand estimation based on the 2024 Pringsewu Regency Official Cropping Pattern Plan (SK RTT). The findings reveal that the Way Bungur watershed exhibits a distinct seasonal rainfall pattern, with water surpluses during the rainy season and deficits during the dry season. Effective rainfall (R80) remains consistently lower than crop water requirements, underscoring the critical role of supplemental irrigation in sustaining agricultural productivity. Evapotranspiration and reliable discharge calculations indicate that water availability in the watershed consistently exceeds crop demand across all three cropping seasons. Specifically, the theoretical water requirements for 83 ha of rice in Season I, 54 ha of rice and 14 ha of secondary crops in Season II, and 5 ha of secondary crops in Season III can be met by the available supply. However, water utilization has not been fully optimized due to misalignments between the prescribed planting schedules and the actual timing of water availability. This temporal mismatch reduces irrigation efficiency and increases the risk of water stress during critical growth periods. The novelty of this study lies in its integration of officially mandated cropping plans with dynamic hydrological modeling and field-based validation to evaluate irrigation adequacy across multiple planting seasons. By applying the FAO-56 Penman–Monteith method and calibrating the F.J. Mock model with localized climate data, the research offers a replicable framework for adaptive irrigation planning in tropical agricultural systems. To enhance irrigation efficiency and ensure sustainable agricultural productivity, it is essential to align cropping schedules with the annual water balance. This approach supports more responsive water allocation, reduces seasonal risks, and strengthens resilience against climate variability. Future research should incorporate socio-economic factors, farmer decision-making behavior, and real-time hydrological monitoring to further refine irrigation governance and support long-term food security in tropical regions.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest concerning the publication of this article. The authors also confirm that the data and the article are free of plagiarism.

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