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Analysis of Irrigation Water Demand and Availability in the Bukit Biru Irrigation Area

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Abstract: The increasing pressure on irrigation systems due to seasonal water fluctuations necessitates a detailed assessment of water availability and crop water demand, particularly in agricultural regions with fluctuating hydrological patterns. This study investigates the compatibility between Q80% dependable discharge and decadal crop water requirements in the Bukit Biru Irrigation Area, East Kalimantan, Indonesia. A quantitative approach was employed by analyzing ten-year hydrological data and computing crop water demand based on FAO Penman-Monteith equations, using parameters such as evapotranspiration (ET_0), crop coefficients (Kc), irrigation efficiency, and irrigated area. Data were presented in 24 dekades (half-monthly intervals) to identify periods of water surplus and deficit throughout the year. Results showed that from January to May, water availability exceeded crop requirements with a peak discharge of 1.02 L/s during the second dekade of January, while the lowest water availability occurred in December at 0.10 L/s. In contrast, crop water needs peaked at 0.74 L/s in the second dekade of November. Approximately 50% of the year experienced water deficits, with the most critical shortages occurring from August to December. These findings highlight the urgent need for adaptive irrigation planning, including cropping calendar adjustments and development of storage infrastructure such as farm reservoirs or embungs. Furthermore, the study recommends integrating hydrological evaluation with construction management strategies to support efficient water distribution systems and sustainable irrigation infrastructure. This research provides an essential basis for future studies in hydraulic modeling, irrigation efficiency analysis, and participatory water governance in smallholder farming systems.

Keywords: Crop Water Requirement; Irrigation Water Management; Q80 Dependable Discharge

1. Introduction

Water resources play a vital role in supporting sustainable irrigation systems, particularly in agrarian regions that rely heavily on surface water availability (Asdak, 2014; Rachman et al., 2020). Efficient and well-managed irrigation can enhance agricultural productivity and ensure both local and national food security (FAO, 2017; Suripin, 2004). One commonly used approach in irrigation water management is the calculation of dependable flow based on reliability probability, such as Q80%, which represents the discharge available 80% of the time during the observed period (Sutrisno, 2020; Hidayat & Saputra, 2019). This method helps ensure that irrigation planning considers minimum flow conditions that are realistic and drought-resilient (Nasution et al., 2021; Kodrat, 2018). An imbalance between available and required water often leads to inefficiencies in irrigation systems and crop failure, especially during the dry season or periods of reduced rainfall intensity (Irianto & Sugiarto, 2020; Rahmawati et al., 2022). Kumar et al. (2021) found that integrating dependable discharge in irrigation planning can improve water distribution efficiency by up to 23%, while Nguyen et al. (2022) reported that data-driven irrigation scheduling significantly reduces water loss in rice fields in Vietnam.

The Bukit Biru Irrigation Area, located in East Kalimantan, Indonesia, is one of the technical irrigation zones with high agricultural potential. However, it is increasingly affected by fluctuating river discharge caused by climate variability and irregular rainfall patterns (BPS Kutai Kartanegara, 2023; Pusat Litbang SDA, 2021). The mismatch between dependable discharge and crop water requirements indicates the need for comprehensive evaluation of water distribution schedules and cropping patterns (Yuliani et al., 2019). Additionally, irrigation systems in tropical regions such as Indonesia generally experience irregular flow, making efficient management highly relevant (Toreti et al., 2019; Hussain & Bhattarai, 2020). A global study by van Loon et al. (2021) highlights that mismatches between water supply and agricultural demand are among the leading causes of declining irrigation efficiency, particularly in gravity-fed systems. Therefore, this study focuses on evaluating the alignment between Q80% water availability and crop water demand throughout the year to develop adaptive planting strategies and provide recommendations for irrigation infrastructure improvement based on construction management principles (Nhamo et al., 2020).

2. Materials and Methods

2.1. Research Location

This research was conducted in the Bukit Biru Irrigation Area (DI Bukit Biru), located in Tenggarong Subdistrict, Kutai Kartanegara Regency, East Kalimantan Province, Indonesia. DI Bukit Biru is one of the technical irrigation areas managed by the local government and serves as a strategic rice cultivation center. The irrigation system in this area utilizes surface channels, with the main water supply sourced from a small seasonal river. The selection of this location was based on its importance in supporting regional food security and the presence of a water supply-demand gap that requires management through a construction-based approach.

2.2. Types and Sources of Data

The research used quantitative data with the following components:

1. River Discharge Data: Average daily river discharge data over the past 10 years, used for dependable flow (Q80%) analysis.
2. Crop Water Requirement Data: Based on crop types (rice and secondary crops), crop coefficients (Kc), and climatological data such as evapotranspiration (ETo) obtained from the Meteorological Agency (BMKG).
3. Hydrological and Irrigation Data: Technical information provided by the local irrigation authority (Department of Public Works and Water Resources, Kutai Kartanegara)
4. Geospatial Data: Includes irrigated area extent, irrigation channel network systems, and topographical conditions.

2.3. Analytical Methods

This study employed a descriptive quantitative approach through the following stages:

1. Dependable Flow (Q80%) Calculation

   The dependable discharge was calculated using a probability distribution method (e.g., log-normal or Gumbel), based on daily discharge data. The Weibull formula was used to determine the ranking order:

$$\boldsymbol{P = \frac{m}{n+1}}, \tag{1}$$

   Information :
   P = Probability
   m = Data rank
   n = Number of data points

   After determining the Q80% value, the discharge was converted into water volume (in liters/second or cubic meters/second) to compare with irrigation water requirements.

2. Net Crop Water Requirement Calculation

Crop water needs were calculated using the FAO Penman-Monteith formula for

$$\boldsymbol{ET_c = K_c \times ET_o}, \tag{2}$$

$$\boldsymbol{NFR = \frac{ET_c \cdot A}{864 \cdot Ef}}, \tag{3}$$

Information :
$\boldsymbol{ET_c}$ = Crop evapotranspiration (mm/day)
$\boldsymbol{K_c}$ = Crop coefficient
$\boldsymbol{ET_o}$ = Reference evapotranspiration (mm/day)
$\boldsymbol{A}$ = Irrigated area (ha)
$\boldsymbol{Ef}$ = Irrigation efficiency

3. Water Balance Analysis

The Q80% discharge values were compared with crop water requirements per dekad (10-day period) to calculate the difference (surplus or deficit):

$$\boldsymbol{\Delta Q = Q_t - Q_k} \tag{4}$$

If
$\boldsymbol{\Delta Q < 0}$, then a water deficit occurs and managerial or structural intervention is required.
$\boldsymbol{Q_t}$ = Available discharge
$\boldsymbol{Q_k}$ = Crop water requirement

3. Results

To illustrate the relationship between irrigation water availability and crop water requirements throughout the year, the data were presented in tabular and graphical formats for each monthly dekad. The table displays the dependable flow (Q80%) and crop water requirement (in liters per second) for each two-week period, while the figure provides a comparative visualization of seasonal fluctuations. This presentation is intended to facilitate the identification of surplus and deficit periods, which serve as the basis for evaluating the irrigation system management in the Bukit Biru Irrigation Area.

	Jan I	Jan II	Feb I	Feb II	Mar I	Mar II	Apr I	Apr II	May I	May II	Jun I	Jun II	Jul I	Jul II	Aug I	Aug II	Sep I	Sep II	Oct I	Oct II	Nov I	Nov II	Dec I	Dec II
Water Availability (Q80%)	0,96	1,02	0,72	0,43	0,45	0,69	0,67	0,67	0,94	1,01	0,85	0,85	0,59	0,63	0,41	0,44	0,30	0,30	0,19	0,20	0,15	0,15	0,10	0,11
Crop Water Requirement	0,52	0,00	0,00	0,65	0,69	0,70	0,64	0,64	0,58	0,54	0,00	0,00	0,00	0,00	0,01	0,04	0,03	0,00	0,68	0,69	0,73	0,74	0,70	0,68

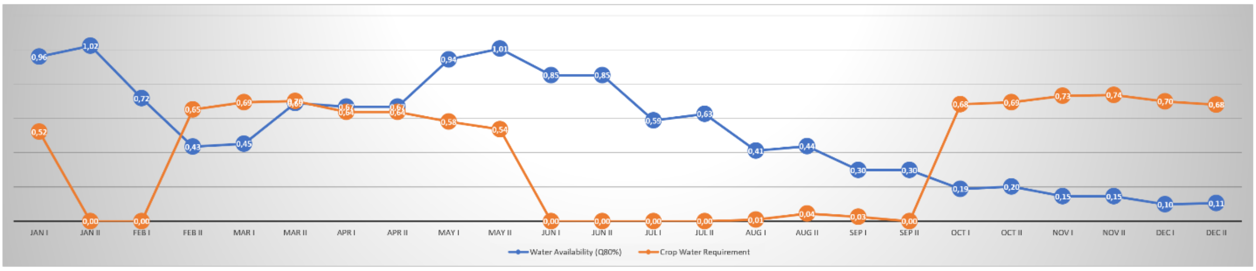

Figure 1. Comparison of Irrigation Water Availability (Q80%) and Crop Water Requirement per Dekade in Bukit Biru.

The Figure Illustrates Seasonal Fluctuations and Highlights Periods of Surplus and Deficit Conditions Throughout the Year.

Based on the analysis of the table and graph, it is evident that both Q80% water availability and irrigation water demand vary significantly throughout the year. Water surplus periods (Q80% > crop water requirement) predominantly occurred in the early months, particularly from January to May. In the second dekad of January, the available discharge reached 1.02 L/s, while the crop water requirement was only 0.00 L/s, indicating a potential for water storage or conservation (Asdak, 2014; Hidayat & Saputra, 2019). Similarly, in the first and second dekads of May, the water availability remained high—above 0.90 L/s—while crop water demand tended to decrease. This pattern suggests favorable conditions for the main cropping season if planting is scheduled appropriately.

However, a substantial water deficit was observed from August to December. During this period, water requirements gradually increased—peaking at 0.74 L/s in the second dekad of November—while available discharge continued to decline, reaching its lowest point of 0.10–0.11 L/s in the first and second dekads of December. These months are considered critical and pose a high risk of crop failure if not managed with proper irrigation strategies or crop pattern adjustments (Nasution et al., 2021; Kodrat, 2018). The most severe deficits were recorded from October to December, which corresponds to the regional dry season.

An analysis of the difference between Q80% and crop water requirement revealed that 12 out of 24 dekads (50% of the year) experienced water deficits, indicating that during half of the year, irrigation supply was insufficient to meet crop needs. This finding underscores the urgent need for integrated irrigation management systems, including the use of water storage facilities such as embungs and the development of efficient irrigation channel networks as part of a sustainable construction management approach (Sutrisno, 2020; FAO, 2017).

4. Discussion

The calculation results emphasize the importance of crop planting schedules based on water availability data. Farmers in the Bukit Biru Irrigation Area should be encouraged to utilize the water surplus period (January–May) for cultivating water-intensive crops such as rice. During the water deficit period (August–December), it is advisable to shift toward more drought-tolerant crops such as secondary crops or legumes (Yuliani et al., 2019; Rahmawati et al., 2022). This strategy can reduce the risk of crop failure and enhance the efficiency of irrigation water use.

From a construction management perspective, the graphical data presented serves as a foundation for planning additional infrastructure, such as farm ponds (embung) and small upstream reservoirs. These structures are intended to collect and store excess water during the surplus period for use during times of deficit (Suripin, 2004; Pusat Litbang SDA, 2021). Moreover, the implementation of automated flow control systems can improve the precision of water distribution in accordance with actual field demand. Rehabilitation and construction of damaged tertiary channels should be prioritized and scheduled in alignment with the cropping calendar to optimize performance.

Strategically, the integration of hydrological analysis and construction management approaches will support the development of sustainable irrigation systems. Utilizing data on water availability and demand is not only critical for technical efficiency, but also serves as a valuable decision-making tool in irrigation infrastructure projects—whether for rehabilitation, capacity enhancement, or the adoption of efficient water distribution technologies (Irianto & Sugiarto, 2020; Rachman et al., 2020). Therefore, a multidisciplinary approach that combines hydrological engineering and construction planning is essential for effective agricultural water resource management.

5. Conclusions

The analysis revealed that irrigation water availability (Q80%) in the Bukit Biru Irrigation Area fluctuates significantly throughout the year, with the highest value of 1.02 L/s recorded in the second dekad of January and the lowest value of 0.10 L/s in the first dekad of December. Meanwhile, crop water requirements peaked at 0.74 L/s in the second dekad of November and dropped to as low as 0.00 L/s during several dekads in the early and middle parts of the year.

Out of the 24 dekadal periods analyzed, 12 dekads (50%) experienced a water deficit, where crop water demand exceeded available supply. The most critical deficit occurred between August and December, with a maximum negative difference of –0.63 L/s in the second dekad of November. In contrast, water surplus periods were observed from January to May, with the maximum surplus of +1.02 L/s occurring in January II, when no crop water demand was present. This mismatch between water availability and demand underscores the urgent need for efficiency-based irrigation systems and adaptive infrastructure planning.

To ensure the sustainability of irrigation systems, comprehensive management strategies must be developed. These include adjusting planting schedules, constructing water storage infrastructure such as farm ponds (embung), and implementing responsive flow regulation technologies. Construction management approaches should prioritize the reinforcement of tertiary networks and routine maintenance based on irrigation performance data.

Future research is recommended to evaluate the technical efficiency of existing water distribution networks through hydraulic simulation methods (e.g., HEC-RAS 2D) and to conduct economic analyses of new irrigation infrastructure investments. Moreover, the scope of study can be extended to institutional and social aspects, including farmer participation in water management, irrigation tariff models, and the adoption of water-saving irrigation technologies at the farm level. These insights have both theoretical and practical implications for sustainable agricultural water governance.

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