

Evaluation of the Effectiveness of Irrigation Water Distribution in Range Weir Irrigation Areas Using the Water Balance Method

M. Fahmi Husein¹, Awliya Tribhuawana^{2*}

Universitas Swadaya Gunung Jati, Indonesia

Email: muhammad.122130076@ugj.ac.id¹; tribhuwana69@gmail.com²

Keywords:	Abstract
Water Balance, irrigation water distribution, dependable discharge, irrigation water requirement, Rentang Irrigation Area	Irrigation systems play an essential role in supporting agricultural productivity and food security, particularly in areas where water availability is influenced by seasonal variability and infrastructure conditions. The Rentang Irrigation Area in West Java is one of the largest irrigation systems in Indonesia and contributes significantly to rice production; however, challenges related to uneven water distribution, water losses, and fluctuating water availability affect irrigation performance. This study aims to evaluate the effectiveness of irrigation water distribution in the Rentang Weir Irrigation Area using the Water Balance method. The research employed a quantitative evaluative approach by analyzing irrigation water availability and demand. Data collected included river discharge, rainfall, climatological parameters, cropping patterns, and irrigation network conditions. Water availability was determined using dependable discharge analysis, while irrigation water requirements were calculated based on the FAO-56 Penman–Monteith method and Indonesian Irrigation Planning Standard (KP-01). The results indicate that water availability varies significantly according to seasonal conditions, with water surpluses occurring during the rainy season and deficits appearing during the dry season. The effectiveness of water distribution is influenced by the balance between supply and demand, irrigation network conditions, and water losses caused by seepage, evaporation, leakage, and sedimentation. The Water Balance method provides an effective evaluation framework for assessing irrigation performance and supporting sustainable water resource management. This study recommends optimizing planting patterns and improving irrigation operation and maintenance to enhance water distribution efficiency in the Rentang Irrigation Area

INTRODUCTION

Water is a very important resource that determines the sustainability of the agricultural sector because most of the global freshwater demand is used for irrigation activities. The agricultural sector uses about 70 percent of the total global freshwater intake and is the largest consumer of water compared to other sectors (Food and Agriculture Organization, 2024). Recently, water management challenges have become increasingly complex due to climate change, which affects the availability of water for crops. He and Rosa (2023) estimate that in a global warming scenario of 1.5°C to 3°C, green water scarcity could threaten food production that supports about 1.23–1.45 billion of the world's population. On the other hand, population growth and suboptimal management of water resources are the reasons why half of the world's irrigated land faces limited blue water or unsustainable irrigation systems (Ingrao et al., 2023). This situation has encouraged efforts to improve the efficiency of water use through more efficient irrigation management and more accurate calculation of plant water needs (Ali, Hussain, & Zahid, 2025; Lakhier et al., 2024; Muharomah et al., 2025).

In Indonesia, the success of food production is still highly dependent on surface irrigation systems. However, most of the irrigation networks that operate today were built decades ago, to the point that the physical condition and efficiency of their water services have deteriorated (Ministry of Public Works, 2018). To improve the performance of the irrigation network, the government stipulated the Regulation of the Minister of Public Works and Public Housing Number 12/PRT/M/2015 concerning the evaluation of the system based on six aspects: physical infrastructure conditions, plant productivity, supporting facilities, personnel organization, documentation, and participation of the Water User Farmers Association (Water User Farmers Association). The application of guidelines in various irrigation areas shows that the level of network performance still varies from low-medium to good, so water distribution problems are still faced in most irrigation areas in Indonesia (Yekti et al., 2020).

One of the strategic irrigation areas in Indonesia is the Rangang Irrigation Area located on the North Coast of West Java. This irrigation area serves around 87,840 hectares in Majalengka, Cirebon, and Indramayu districts. The Rangeng Dam has a strategic role in controlling the flow of the Cimanuk River to the Sindupraja and Cipelang Irrigation Systems, and is therefore considered an important infrastructure for rice production in West Java (Cimanuk Cisanggarung River Area Center, 2025). The contribution of the DI Rangeng service area to rice production in West Java is more than 12–16 percent, therefore, the feasibility of the irrigation system has an important role in regional and national food security (Central Statistics Agency of West Java Province, 2024, quoted in the Cimanuk Cisanggarung River Area Center, 2025). However, the age of the network is quite old causing water loss in the channel to reach up to 15% so that the distribution of water, especially in downstream areas, is not completely uniform and timely.

Several studies have been conducted to assess irrigation systems with a variety of approaches. Hidayat et al. (2024) and Prameswari and Marselina (2025) focused their analysis on water availability using the F.J Mock and WEAP methods, Yekti et al. (2020) focused on evaluating the performance of the physical and institutional based network of the Irrigation System Performance Index. Other studies are also starting to use remote sensing, the Internet of Things, and machine learning for irrigation management. However, the application of these technologies faces many challenges, such as limitations of historical data, model complexity, and readiness of infrastructure and resources in the field, especially in large-scale irrigated areas (Review of remote sensing approaches, GIS, and machine learning for dry agricultural regions, 2025).

There is still a gap in the literature as most studies only consider water availability or irrigation network performance, but not both aspects simultaneously within a single evaluation framework. It is also the first study to investigate the efficiency of water distribution in the DI Range based on a reliable integrated analysis of flow, plant water requirements using the FAO-56 Penman–Monteith method, and conducting an analysis of water distribution efficiency in BPS-level irrigation systems, especially since the launch of the irrigation network modernization program in 2025. The results are expected to provide a more comprehensive insight into the relationship between water availability, irrigation demand, and water distribution efficiency in large-scale technical irrigation networks.

Based on the above description, a study to analyze the balance of irrigation water availability and needs using the Water Balance method, and to evaluate the effectiveness of

water distribution in the DI Range irrigation system was conducted, focusing on the operational conditions of the network.

METHOD

This research was conducted in the Rangang Dam irrigation area consisting of the Sindupraja and Cipelang Irrigation Systems with a service area of $\pm 87,840$ ha in Majalengka, Cirebon and Indramayu districts, West Java. The Rangeang Dam on the Cimanuk River was chosen as the location for collecting discharge data in the water availability analysis.

This study uses a quantitative approach followed by an analytical method and the type of research is evaluative to evaluate how effective the distribution of irrigation water is in actual conditions without treatment of the object. The analysis used baseline data (10 days) to observe in more detail changes in water availability and demand.

Data collection consists of primary data and secondary data. Primary data is observation of the condition of the irrigation network, and secondary data includes discharge, rainfall, climatology, planting patterns, and technical data of the irrigation network obtained from BBWS Cimanuk Cisanggarung, BPSDA, BMKG, and other related organizations.

The analysis was carried out by calculating reliable flows (irrigation water needs according to FAO-56 Penman–Monteith), then determining the water balance by comparing water supply and demand in each base period. The results of further analysis will be evaluated in accordance with the KP-01 Irrigation Planning Standard and the Regulation of the Minister of PUPR Number 12/PRT/M/2015 to evaluate the distribution of irrigation water up to the DIS Weir Range related to its effectiveness.

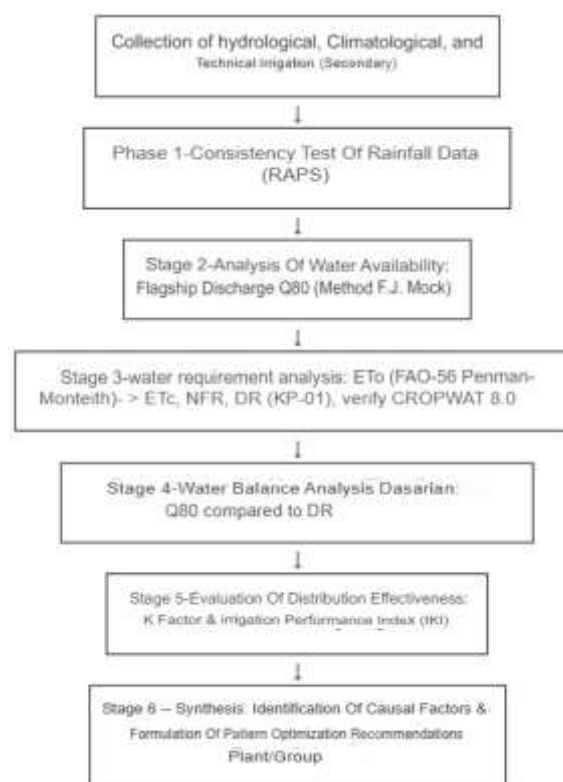


Figure 1 Research Stages

RESULTS AND DISCUSSION

The table here proves the distribution of rainfall during each period of one year. Rainfall varies between periods, with peak rainfall occurring in November in period II of 278.00 mm and the lowest in May in period I of 2.00 mm. In general, rainfall is greater at the beginning and end of the year (rainy season) and less in the middle of the year/month of May to August which represents the dry season. The variation in rainfall will affect the availability of irrigation water and is the main parameter in the study of water balance in DI Rantang.

Table 1. Total Water Requirement

Ket.	Jan		Feb		Mar		Apr	
Period of project	I	II	I	II	I	II	I	II
mm/day	222	222	143	182	237.1	239	135	68.89
Ket.	May		Jun		Jul		Agu	
Period of project	I	II	I	II	I	II	I	II
mm/day	2	206	128	128	230	227	156	102.5
Ket.	Sep		Oct		Nov		Of the	
Period of project	I	II	I	II	I	II	I	II
mm/day	150	107.7	110	122	249.1	278	92.8	47.67

Average Flagship Debit

The Mainstay Channel discharge used is the average discharge data for 2006-2025. The Average Mainstay Channel discharge data is presented in the form of the table below:

Table 2. Average Mainstay Channel Discharge

Ket.	Jan		Feb		Mar		Apr	
Period of project	I	II	I	II	I	II	I	II
Average	1708	2000	2450	2417	3217	227.6	3071	2360.5
Ket.	May		Jun		Jul		Agu	
Period of project	I	II	I	II	I	II	I	II
Average	1454	1123	477.5	332.9	276.8	250.9	157.7	204.84
Ket.	Sep		Oct		Nov		Of the	
Period of project	I	II	I	II	I	II	I	II
Average	268	396.5	446.4	577.6	956.8	1247	1584	2157.3

Water Balance

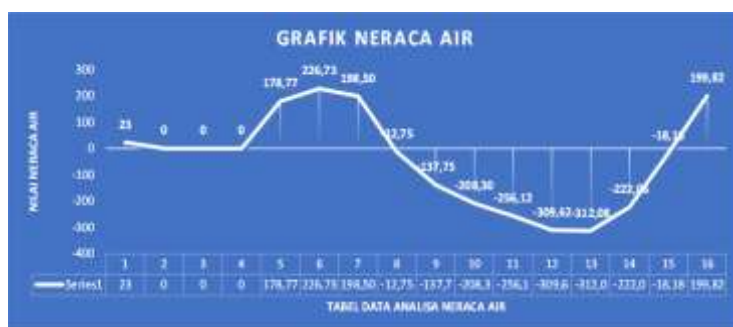


Figure 2. Water Balance

In terms of the base period, the water balance graph shows that water availability conditions are fluctuating. The water surplus occurred in periods 5-7 with a peak of 226.73 and the water deficit was in periods 9-15 with a base of -312.08 in period 13. The water balance was also overflowing at 16 with 199.82. This result indicates that the availability of water is affected by the season, thus it is necessary to regulate optimal water distribution especially during fixtures.

Water Balance Analysis using the FJ Method. Mock

Table 3. The water balance uses the FJ method. Mock

Remarks			WATER BALANCE					
			MONTHS					
No	Meteorological Data		January	February	March	April	May	June
1	Lunar Rainfall	mm	383.86	395.95	407.27	300.94	164.93	79.25
2	Daily Rainfall	days	13.71	15.43	14.81	12.27	8.63	4.00
3a	Temperature	°C	27.0	26.6	27.2	27.8	28.1	27.5
3b		°K	300.0	299.6	300.2	300.8	301.1	300.5
4	Duration of Sunlight	%	42.0	33.6	54.0	64.3	69.4	64.0
5	Air Humidity	%	86.6	88.4	86.8	84.2	80.8	81.6
6a	Wind speed	ml/day	168.90	168.90	142.23	257.80	142.23	115.56
6b		m/s	1.955	1.955	1.646	2.984	1.646	1.338

Table 4 The water balance uses the FJ method. Mock

Remarks		WATER BALANCE							YEAR
		MONTHS							
No	Meteorological Data	July	Aug	Sep	Oct	Nov	Of the		
1	Lunar Rainfall	mm	60.6961	24.6543	32.926	115.3	290.21	397.59	221.13

2	Daily Rainfall	days	7.014	2.46	2.2825	6.3775	11.596	14.044	9.3841
3a	Temperature	°C	27.32	27.76	28.58	29.08	28.04	27.64	27.722
3b		°K	300.32	300.76	301.58	302.08	301.04	300.64	300.72
4	Duration of Sunlight	%	78.02	79.58	79	69.66	50.66	45.68	
5	Air Humidity	%	76	74.2	71.6	73	81.4	83.2	80.65
6a	Wind speed	ml/day	177.792	320.026	275.58	222.24	213.35	168.9	197.79
6b		m/s	2.057778	3.704	3.1896	2.5722	2.4693	1.9549	2.2893

Data on Dam Structural Damage Range for the last 5 years from bbws cimanuk cisanggarung

Table 5 General Data (2024)

1	Name of Irrigation Area	DI Range
2	Area of Irrigation Area	87,803,00
3	Year of IKSI	2024
4	Name of the Branch/Observer Working Area	-
5	Total Area of Work Area for the Implementation of OP	-
6	Authority	Cimanuk-Cisanggarung River Area Center

Table 6 Asset Inventory Data (2024)

1	Area of Branch Work Area/Observer/UPTD	-
2	Field Terrain Type	-
3	Length of the main channel	129,26 Km
4	Secondary Channel Length	528,98 Km
5	Length of Supply Channel	0,00 Km
6	Drain Length	4,32 Km
7	Length of Flood Avoidance Channel	0,00 Km
8	Length of Carrying Channel	0,00 Km
9	Tertiary Channel Length	144,63 Km
10	Length of the Quarter Channel	0,00 Km
11	Tertiary Drain Length	2,10 Km
12	Number of Weir	1 Bh
13	Number of Pumps	0 Bh
14	Number of Mud Bags	2 Bh
15	Number of Regulatory Buildings (Share/Share/Tap)	776 Bh
16	Large Door Number (W>60 cm)	- Bh
17	Number of small doors (W<60 cm)	- Bh
18	Number of Large Handlebar Drat (L>2)	- Bh
19	Number of Small Handlebar Drats (L<2m)	- Bh
20	Number of Complementary Buildings	1.891 Bh
21	Number of Miscellaneous Buildings	940 Bh
22	Office	17 Bh

23	Housing	2 Bh
24	Warehouse	2 Bh
25	Maximum Plan Discharge Streamed	- M3/IT

Table 7 Irrigation Network Operational Conditions Index (2024)

NO	Description	Existing %	Max %	Min %	Optimum %
1	Physical Infrastructure	36,02	45	25	35
2	Planting Productivity	13,21	15	10	12,5
3	Supporting Facilities	4,13	10	5	7,5
4	Personnel Organization	12,20	15	7,5	10
5	Documentation	4,25	5	2,5	5
6	P3A	7,75	10	5	7,5
	QUANTITY	77,55	100	55	77,5

Recapitulation Table of Irrigation System Performance Assessment Results

Group 1 (DI more than 1000 ha)

1. The weight of the main network to the total performance is 80%
2. Tertiary network weight to total performance of 20
3. Group 2 (DI between 150 ha – 1000 ha)
4. The weight of the main network to the total performance is 60%
5. Tertiary network weight to total performance of 40%

Group 3 (DI less than 150 ha)

1. The weight of the main network to the total performance is 50%
2. Tertiary network weight to total performance of 50%

Table 8 Major Irrigation Systems (2024)

MAIN IRRIGATION SYSTEM			
No	Components	Index of Existing Conditions	Weight (80%)
1	Physical Infrastructure	36,02	28,82
2	Planting Productivity	13,21	10,56
3	Supporting Facilities	4,13	3,30
4	Personnel Organization	12,20	9,76
5	Documentation	4,25	3,40
6	P3A/Gp3A/Ip3a	7,75	6,20
		77,55	62,04

Table 9 Tertiary Irrigation Systems (2024)

IRRIGATION SYSTEM				
No	COMPONENTS	Index of Existing Conditions	Weight (20%)	TOTAL VALUE
1	PHYSICAL INFRASTRUCTURE	17,47	3,49	32,31
2	PLANTING PRODUCTIVITY	13,21	2,64	13,21
3	SUPPORTING FACILITIES	16,40	3,28	6,58
4	WATER DISTRIBUTION OFFICER	10,50	2,10	11,86
5	DOCUMENTATION	3,61	0,72	4,12
6	P3A	15,38	3,08	9,28
		76,56	15,31	77,36

Factors Causing Water Loss

Evaporative loss in an irrigation system is a factor that reduces the efficiency of air distribution through open channels from dams to the cropland. Based on the general nature of the irrigation network and the results of the water balance analysis, it can be concluded that water is lost due to: ..

Seepage Loss (Brake besan) Seepage occurs as a result of water seeping into the bottom and walls of irrigation canals, especially in earthen channels or channels that have not been walled. The amount of water loss due to seepage depends on the type of soil, the depth of the groundwater level and the condition of the channel.

Loss due to Percolation Percolation is the movement of water towards the lower layer of the surface of the spring water in the rice field. Instead of being reduced below are a number of additional reasons why plant growth naturally or increase groundwater needs, Evaporation Evaporation is the evaporation of water from the surface of irrigation canals and root rice fields under the influence of solar radiation, air temperature, humidity, wind. In times of drought, evaporation tends to be greater.

Leaks in Irrigation Buildings Many damaged buildings, tapping buildings, sluices, and canals can cause water discharge leakage, some of the water is lost before reaching the rice fields.

Channel Sedimentation Sediment deposits attached to the bottom of the channel will reduce the flow capacity and distribute water to the rice fields sub-optimally. Sedimentation can also trigger runoff water channels and even loss in some channels.

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CONCLUSION

This study shows that the availability of water in the Weir Research Range of the Water Users Association follows seasonal conditions while irrigation water needs are influenced by evapotranspiration, effective rainfall, planting patterns, and the area of irrigation area. The results of the air balance analysis (water balance) noted that the air surplus occurred in several periods, while there is the potential for a deficit in the dry season due to the decrease in mainstay discharge. The effectiveness of air distribution is a consequence of the interaction between air availability and demand, the condition of irrigation canals and air loss in the canals, while the canal system and the soil system are variables that cannot be easily changed. As a result, improving the efficiency of air distribution can refer to the regulation of planting patterns that are adjusted to the availability of water, i.e. a group air flow system in the event of a water shortage followed by an increase in the operation and maintenance of the irrigation network – A comprehensive pastoral management system can significantly improve the full capacity of irrigation water and result in better and effective management of the te-rong. Water Balance Irrigation Method states that the Water Balance Method can be used as an evaluation benchmark in supporting more efficient and sustainable agriculture in the Range Dam DI.

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