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Irrigation Services Management Model as a Guideline for Optimizing Water Distribution in Rotational Group System

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Abstract: ***The function of irrigation as a buffer and support national food production increasingly faces various challenges. The need for food increases along with the increasing number of people who need food for their lives. Various problems can occur unexpectedly, especially when policies intersect with the interests of the community. The decline of water sources causes competition among users and even lead to vertical or horizontal conflicts therefore needed regulation for distribution of water irrigation which related to cropping patterns and water rotation. A comprehensive and integrated solution is needed through improving irrigation governance by involving technical aspects in the calculation of water optimization and non-technical aspects by involving farmer institutions. The purpose of this study is to obtain a relationship between the results of irrigation optimization and the results of institutional analysis as a guide in the implementation of water rotation. Meanwhile, the methodology used is descriptive research method in the area of irrigation. The results of this study will be obtained the guideline irrigation management system***

Keywords : ***irrigation system, water and institutional optimization, irrigation management system***

I. INTRODUCTION

Besides being known as an archipelago country, Indonesia is also once of the largest agricultural countries in the world because almost two-thirds of the population consumes rice as a main food [1]. However, water availability is extremely different between dry season and wet season therefore it's sometimes deficit or surplus for some agricultural area [2][3]. Irrigated rice production is the largest consumer of water in the agricultural sector, and its sustainability is threatened by increasing water shortages [4]. As a tropical country when the wet season water is extremely high but during the dry season it was lacks water.

According to BBWS SO (2018) data, agriculture being one of the largest water consumers, 60 % of the total agricultural is used water demand to irrigate the paddy field. Those statement was related to [5] mention that the plantation of paddy are special variety which have a unique character because paddy has a more sensitive nature to water especially during growth periods.

The function of irrigation as a buffer and supporting national food production is increasingly facing diverse challenges. The necessity for food always rises every year in line with the increasing number of people who need food for their survival. According to Arief [6], the average rice consumption in the population in Indonesia reached to 139 kg / year. This means that the available irrigation infrastructure must be able to produce rice production of 4 to 5 million tons per year [6]. Moreover for rice consumption in the world, Ndiiri *et.al* [7] state more than a third of the global population in the world believes that rice is the most important food crop in the world because it is a primary need. Therefore it is necessary to increase rice production every year in order to meet the food necessity of the population.

Belder *et al.*, [8], state flooding and maintaining the water level above the paddy field is characteristic of the conventional irrigation system. Then from research conducted by [4] mentioning irrigated rice production is the largest consumer of water in the agricultural sector, and its sustainability is threatened by increasing water shortages. The decreasing carrying capacity of the water source comes from the influence of climate change, the massive degradation of the upstream watershed and also a result of unsustainable water resources management.

According to Minister of Public Works Regulation No. 17 / PRT/ M / 2015 concerning the exploitation and maintenance of irrigation, mention that irrigation is an effort to provide, regulate and drain water to support agriculture. Therefore, the understanding of regulating irrigation water as follow: 1). Activities to divide water for primary and / or secondary networks. 2). Activities of distributing certain amounts of water from primary or secondary networks to tertiary ditches. 3).

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Activities utilizing tertiary plot water to irrigate agricultural land if necessary. Meanwhile for irrigation management based on community participatory consist of irrigation infrastructure, water availability, irrigation management, institutions and human resource.

The reformation of Irrigation regulation resulted managerial adjustments to water resources, especially for irrigation management. Various problems can occur unexpectedly especially when policies are considered to disturb community or when there are differences in interests between the community and the government. A comprehensive and integrated solution is needed through improving irrigation governance by involving technical aspects (including: calculation of water optimization) and non-technical aspects (reliable farmer institutions).

II. MATERIAL AND METHODS

A. Location of Study

The location of the study was conducted in the Sempor Irrigation System, Kebumen Regency, Central Java Province. The cropping patterns used by Padi, Padi, Palawija are divided into the first planting season, the second planting season and the third planting season. The Sempor Irrigation System obtains supplies from Sempor Resevoir through he weir which located in the downstream. The existing weir, Bojong, is located in the upstream area, then the following weirs: Rowokawuk Weir, Watubarut Weir and Sindut Weir. The Sempor Irrigation System serves 5,888 Ha, hence an irrigation area under the authority of central government (in accordance with Minister Regulation of Public Work No.14/PRT/2015 concerning Criteria and determination the status of irrigation area . The location map and Sempor Irrigation scheme are presented in Fig. 1 below

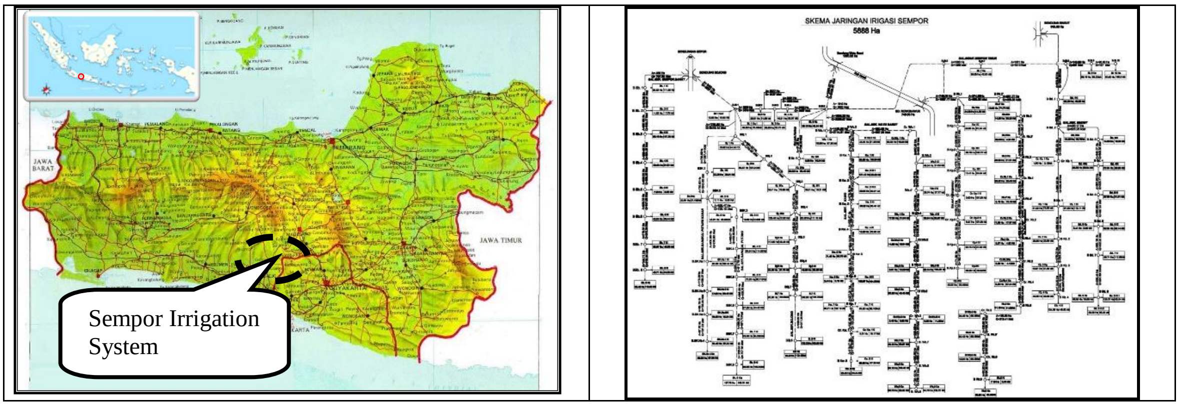

Fig. 1. The location map and scemes of Sempor Irrigation
Source: BBWS SO Office

B. The Method of Analysis

The method of analysis this study utilizes a linear programing with the purpose of getting the most optimum value between the water requirement and water availability. The principle of water supply and demand model is comparing two variables as the water is required for farming and the ability to provide water to stakeholders. The output of this method is to obtain a number from the calculation result of the ratio between the volume of water requirements for plants in an irrigation area and the volume of water that can be provided by an irrigation network.

C. Water Requirement or Demand

C.1. Water Demand for Paddy Field

The amount of water needed by the plant in a paddy field terrace is represented in this equation as follow:

$$NFR = ETc + P + WLR – Re \qquad (1)$$

Where:

NFR = water demand in the farm (mm/day),
ETc = water demand of plantation (mm/day)
\WLR = water layer replacement (mm/day)
P = percolation (mm/day)
R = rainfall

C.2. Crop Water Demand

Crop water demand is the amount of water needed to replace the loss of water as a result of evapotranspiration. Monteith, J. [9] developed the method of evaporation calculation. The amount of water plant demand (consumptive use) is counted based on this formula:

$$ETc = Kc.\ ETo \qquad (2)$$

Where:

ETc = plant evapotranspiration (mm/day)
ETo = plant reference evapotranspiration (mm/day)
]Kc = plant coefficient

C.3. Water Requirements for Land Preparation

Water for land preparation is the amount of water needed for preparation before the land is planted and carried out by flooding the fields until the land is saturated before transplantation and seedling period. According to definition in Design Criteria Number 01 (KP-01) [10], water requirements for land preparation including seedling are 250 mm, there are 200 mm is used for land saturated and at initial transplantation will be added 50 mm for rice plantation, for field crops it is recommended 50-100 mm. Water demand during land preparation is calculated by V.D Goor-Zijlstra formula, as follow:

$$IR = M.e^k / (e^k – 1) \qquad (3)$$

Where:

IR = irrigation water demand (mm/day)

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M = EO + P = (1.1 ETo + P) (mm/day), water demand to replace the loss of the result
k = MT/S
T = the duration of land preparation
S = the water demand for saturationis added by 50 mm

D. Water Availability

D.1. Dependable Flow (Q 80%)

Dependable flow is the amount of available discharge to occupy water needs by calculates the risk of failure which possible occurs. Dependable flow is calculated using a flow characteristic method with a dependable graph. From the graph, 80% of the discharge values are calculated for in each weir by considering the ability of the supply-discharge from the Sempor Channel. Therefore it can be known what the discharge capacity is supplied in each irrigation area. In determining the calculation of the dependable flow with an 80% probability, the Weibull Method is used, the equation can be seen as follow:

$$P = \frac{m}{n+1} . 100\% \quad (4)$$

Where:
P = probability
m = data sequence number
n = amount of data

D.2. Effective Rainfall

The height of rainfall (mm) is used to determine the time of starting the first planting and to estimate the irrigation water needs in the field and to calculate the amount of effective rainfall. Usually use the monthly rainfall data. Therefore, the effective rainfall constant / coefficient are calculated from the formula as below:
(1). The equation of daily effective rainfall for paddy plantation:

$$Padi = coefficient\ of\ effective\ rainfall\ .* \frac{R_{80}}{15} \quad (5)$$

(2). The equation of daily effective rainfall for palawija (soybean) :

$$Palawija = coefficient\ of\ effective\ rainfall * \frac{R_{50}}{15} \quad (6)$$

D.2. K-Factor

Water balance model on irrigation is comparing two variables between the water requirements needed to serve farming and the ability to provide water to stakeholders. The purpose of the model is to calculate the difference (delta) between the volume of water requirements for plantations in an irrigation area and the volume of water that can be provided by an existing irrigation network. It will be formulated into the K-Factor formula, which is a comparison between water requirements and water availability. The guidelines for determining parameters refer to definition of Design Criteria Number 01 (KP-01), 2013. Analysis of calculations using the data such as rainfall, climatology (wind velocity, temperature, air humidity), water discharge availability, reports on plant conditions, and crop production.

$$K = \frac{Qt}{Qb} \quad (7)$$

Where: Qt = available discharge and Qb = outflow discharge model\

D. Water Optimization

Optimization model is the preparation of a system that accordance with the real situation, which could be converted into a mathematical model by separating the main elements furthermore a solution in accordance with the goals or objectives of decision can be achieved [11]. The mathematical model used to describe a linear programming problem using the following equation [11]:
Objective Function:
Z = C1X1 + C2X2 + C3X3 + ... + CnXn (8)
Constraint Function:
1) a11X1 + a12X2 + a13X3 + ... + a1nXn <b1 (9)
2) a21X1 + a22X2 + a23X3 + ... + a2nXn <b2 (10)
m) am1X1 + am2X2 + am3X3 + ... + amnXn <bm (11)
and
X1 e ”0, X2 e” 0, ..., Xn e ”0 (12)

III. RESULTS AND DISCUSSION

A. Performance of Water User Farmers Association (P3A)

Based on the Decree of the Minister of Public Works No. 30 / PRT / 2015 concerning Guidelines for the Development and Management of Irrigation Systems states that to find out the condition and progress of an irrigation institution is known through its performance which is divided into 4 aspects of measurement variables as follows: (1) institutional aspects, as an indicator of measurement regarding the organizational procedures which carried out; (2) technical aspects of irrigation, indicators are calculated from the results of water distribution and delivery carried out by F; (3) technical aspects of agriculture, indicators are obtained from the results of planting and use of seedlings; (4) financing aspects, indicators are obtained from the use of the budget. The results of the calculation of these 4 aspects obtained the percentage of irrigation performance and conclusions by Farmers Association. If the value less from 50.00 means that it is not yet operational and if the value of more than 50.00 means it is already operational. Hence, if the results of the assessment are less than 50, it means the institution is categorized as Not Yet Develop (NYD), but if the results of the performance evaluation are more than 50, it means the institution is in the category of : Is Developing (ID), Developing (D), and Independent (I). Classification of institutional performance evaluation categories is shows as bellow.

Table- I. Categories of Irrigation Performance

Value (%)	Categories
< 50.00	Not Yet Develop
50.00 – 70.00	Is Developing
70.05 – 90.00	Develop
> 90.00	Independent

Source: Minister Regulation of Public Work No. 17 / PRT/ M / 2015

From the assessment results of institutional performance of farmers' associations from 78 institutions and 153 respondents which spread throughout overall irrigation area, it was found that 3.92% were included in the category of Independent (I), 16.34% including the category of Develop (D), by 54.90% including the Category of Is Developing (ID) and by 24.84% including in the category of Not Yet Develop (NYD) as shown in the Fig. 2

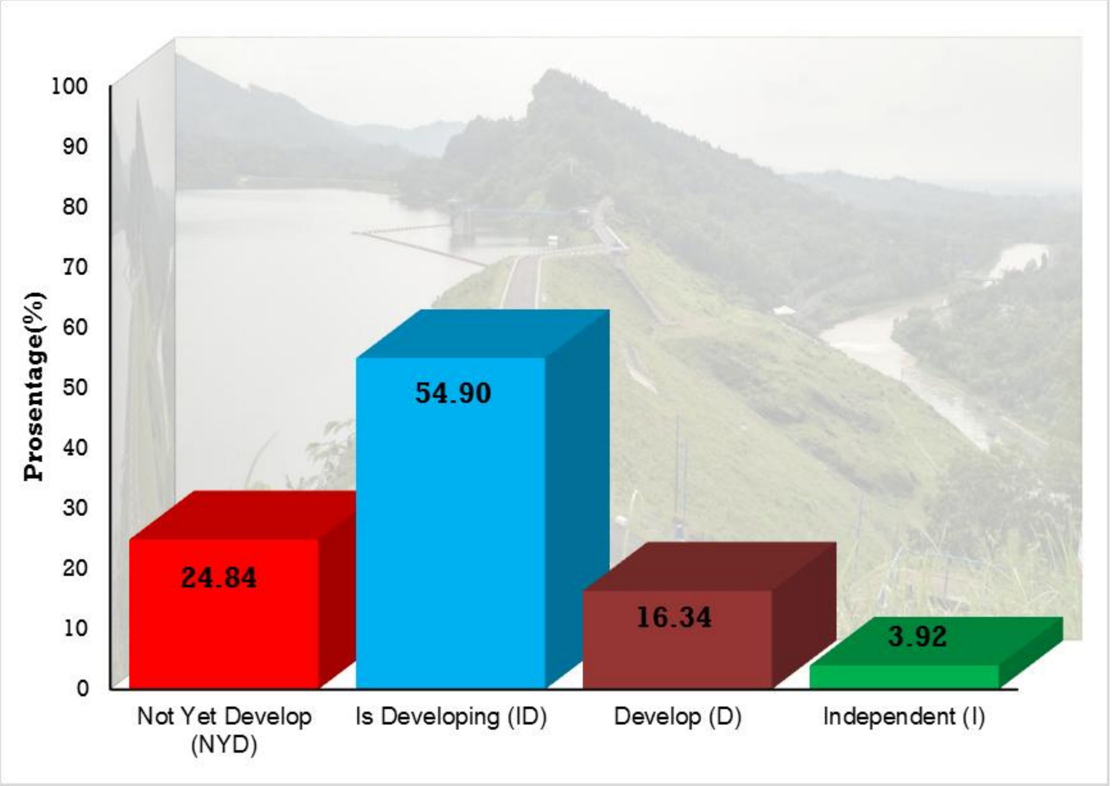

Fig. 2 The Category of Institution Performance
Source: Analysis Result, 2019

B. Performance Optimization of Water Supply Systems.

Providing water with a grouping (golongan) system is necessary to reduce the peak discharge when at the same time all areas need the water. This method is expected water can be distributed fairly, equitable and timely in the irrigation area and can be distributed in rotation system. Water supply for irrigated land from Sempor reservoirs is needed when the availability of water in dams in each irrigation area is shortage or when there is no water availability. Hence, there are two types of water shortage categories, namely: the condition when no water at all in the weir and water still available but not sufficient to fulfill the water demand of plantation according to the calculation of water requirements. Furthermore the pattern of water delivery in the paddy field area used the K-factor as a guideline for the pattern of water distribution, which is as follows

B.1. Water Optimization using Factor K = 1.0

Optimization by using K-factor = 1.0 (Fig. 7) obtained the results of 74% irrigation performance factor (table 4). This condition occurs due to the unavailable irrigation gate hence it cannot measure the discharge flow consequently in the downstream irrigation area such as Sindut Area does not irrigate. Moreover the performance of farmers association (P3A) is not functioning optimally; consequently the implementation of water delivery in irrigated land is not evenly distributed. Water rotation between irrigated lands cannot be done and the application of water distribution in each irrigation land is not running optimally therefore there is a decrease in irrigation performance. The following results of optimization calculations using factor- K = 1 as in the following Fig. 3 as bellow.

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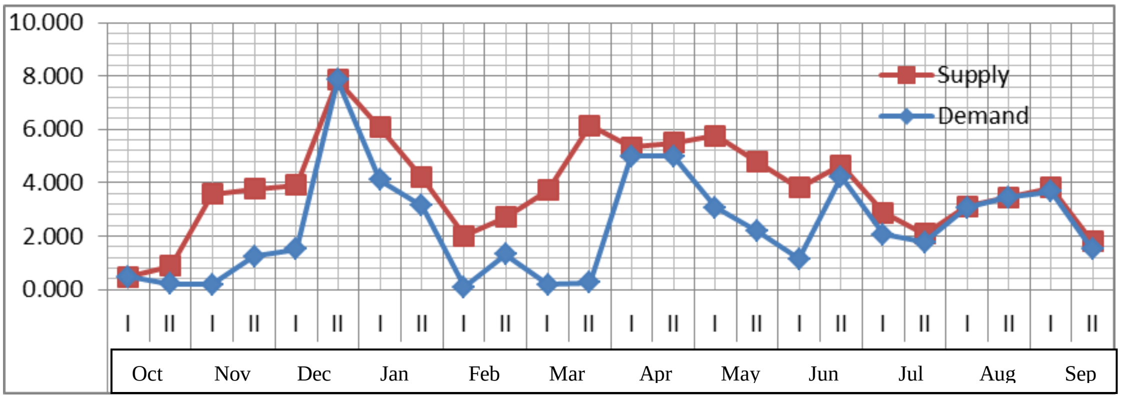

Fig. 3 Water Balance with the K-factor = 1.0
Source: Analysis Result, 2019

From Fig. 3 above, the optimization analysis results are obtained in the form of a graph between the water demand and water availability. In the third planting season (Third Cropping Pattern) the two lines of water supply and water demand adjacent each other, while in the first planting season and the second planting season there are a delta or differences between the two lines. From the graph above shows that water is still available and sufficient to irrigate during the first planting season and the second planting season. Therefore the overall irrigation performance was obtained by 74% with the classification of group planting area as in the following table below.

Table- II Irrigation Performance Factor with the K-factor = 1,0

Sub Irrigation Area	Total area	Golongan/Group System (distribution system of irrigation)			Irrigated Area	Irrigation Perfomance Factor	Volume of Water Requirement	Volume of Water Availability
	Ha	First group	Second group	Third group	Ha	%	m3	m3
Bojong Irr. Area	2,599	0	1,983	0	1,983	76	20,962,049	29,372,951
Watubarut Irr. Area	1,627	285	815	527	1,627	100	17,662,521	12,877,831
Sindut Irr. Area	916	0	0	0	0	0	0	0
Rowokawuk Irr. Area	746	0	746	0	746	100	7,887,817	6,030,415
Total	5,888				4356	74	46,512,387	48,281,197

Source: Analysis Result, 2019

B.2. Water Optimization using a Factor K = 0.70

Water balance calculation using a K-factor = 0.70 is performed if the available water has decreased therefore there is an imbalance between supply and demand. This condition requires an adjustment to the water supply pattern by changing operational at the irrigation gates. Reliability of operator for irrigation gate has not affected if the performance of farmer association (P3A) is not functioning optimally yet, consequently water supply in irrigate area cannot be done with a rotation system. Water distribution irrigate only based on the discharge of water released from the gates without regulation pattern. As a result, the method of providing water cannot be done by rotation among rice field hence irrigation performance is not optimally. The overall irrigation performance was obtained by 93% with the classification of group planting area as in the following Fig. 4 and Table- III as below.

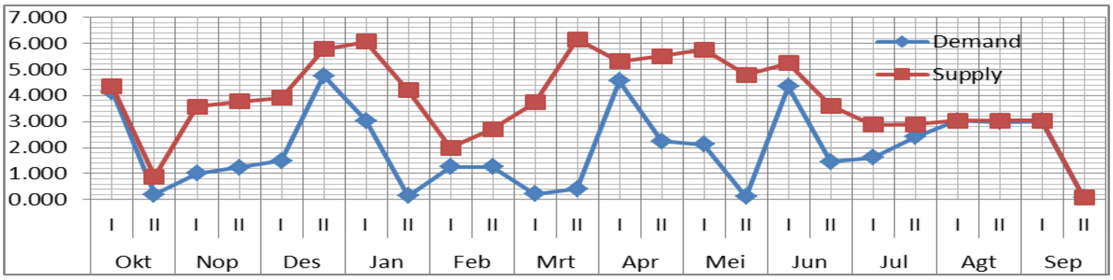

Fig. 4 Water Balance with the K-factor = 0.7
Source: Analysis Result, 2019

Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep

Table- III. Irrigation Performance Factor with the K-factor = 0.7

Sub Irrigation Area	Total area	Golongan/ Group System (distribution system of irrigation)			Irrigated Area	Irrigation Perfomance Factor	Volume of Water Requirement	Volume of Water Availibility
	Ha	First group	Second group	Third group	Ha	%	m3	m3
Bojong Irr. Area	2,599	2,599	0	0	2,599	100	26,028,389	28,483,926
Watubarut Irr. Area	1,627	1,627	0	0	1,627	100	16,294,032	12,837,103
Sindut Irr. Area	916	686	0	230	916	100	9,571,816	8,718,745
Rowokawuk Irr. Area	746	333	0	0	333	45	3,332,296	2,620,889
Total	5,888				5475	93	55,226,534	52,660,664

Source: Analysis Result, 2019

B.3. Water Optimization using a Factor K = 0.50.

The principle of water distribution using the K-Factor = 0.5 requires the following requirements: 1) the provision of irrigation water in each intake can be measured quite well, 2) the personnel who are able to operate the gate is available properly, 3) get supported from user namely farmer association (P3A) which have reliable and active performance. Then the calculation for water needs can be executed in accordance with the needs of plantation, therefore the provision of water in irrigated lands can be operate in rotation system. The benefit with K-factor = 0.5 is increasing the irrigation performance which will be obtained by 100%.

The pattern of water supply using K-factor = 0.5 was effectively used for a wide variety with group divisions system. The water distribution system can be done by: 1) vertical division of groups, 2) horizontal division of groups,3) distribution of groups in a scattered system.

B.3.1. Water supply pattern with a vertical system

Optimization calculations with the vertical system can be obtained to three groups in the water supply pattern, such as : one irrigation area in first group, one irrigation area in second group and two irrigation areas in third group. Regarding with the pattern can be obtained implementation of rotation system becomes easier to implemented and under supervision by farmer institutions (P3A) in the irrigation area. The irrigation performance was obtained by 100% as shows in Fig. 5 and Table- IV as below.

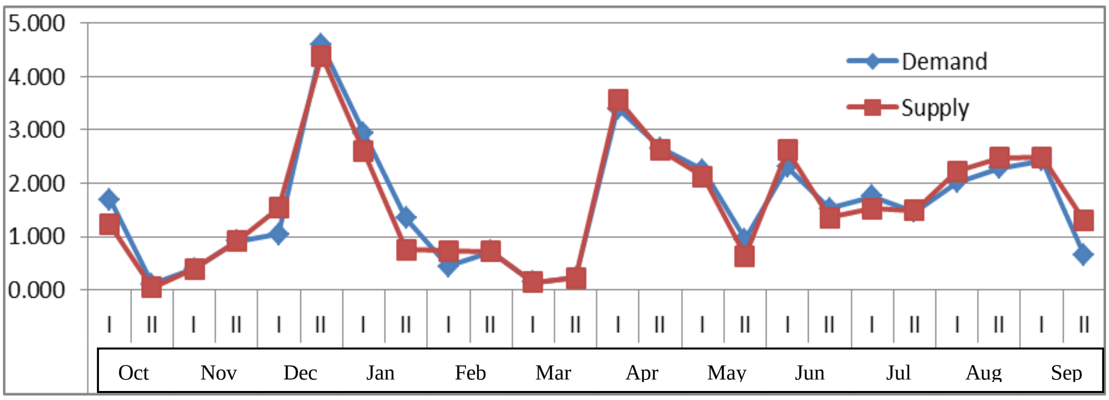

Fig. 5 Water balance use vertical system with the K-factor = 0.5
Source: Analysis Result, 2019

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Table- IV. Irrigation Performance Factor use vertical system with the K-factor = 0.5

Sub Irrigation Area	Total area	Golongan/Group System (distribution system of irrigation)			Irrigated Area	Irrigation Performances Factor	Volume of Water Requirement	Volume of Water Availability
	Ha	First group	Second group	Third group	Ha	%	m3	m3
Bojong Irr. Area	2,599	2,599	0	0	2,599	100	20,562,428	16,389,065
Watubarut Irr. Area	1,627	0	1,627	0	1,627	100	13,590,412	6,290,293
Sindut Irr. Area	916	0	0	916	916	100	8,500,785	5,965,434
Rowokawuk Irr. Area	746	0	0	746	746	100	6,923,128	3,444,551
Total	5,888				5888	100	49,576,753	32,089,344

Source: Analysis Result, 2019

B.3.2. Water supply pattern with a horizontal system

The results of the optimization calculation with the horizontal system can be obtained to three groups in the water supply pattern, consist of : two irrigation areas in second group, one irrigation area in third group and one irrigation area into two group rotation such as first group and second group. From the calculation results there is one irrigation area divided into two groups consequently participation and awareness from farmer association (P3A) are required in the supervision of rotation till all irrigation areas can be served. The irrigation performance was obtained by 100% as shows of Fig. 6 and Table- V as below.

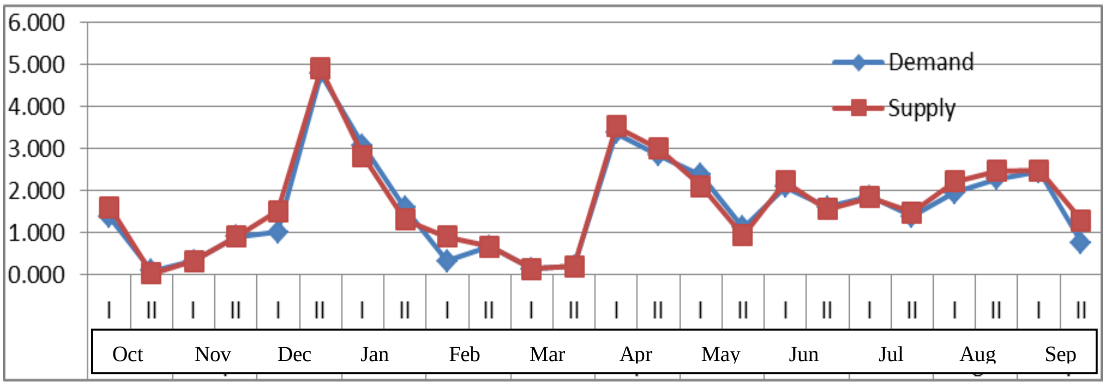

Fig. 6 : Water balance use horizontal system with the K-factor = 0.5
Source: Analysis Result, 2019

Table- V Irrigation Performance Factor use vertical system with the K-factor = 0.5

Sub Irrigation Area	Total area	Golongan/Group System (distribution system of irrigation)			Irrigated Area	Irrigation Performances Factor	Volume of Water Requirement	Volume of Water Availability
	Ha	First group	Second group	Third group	Ha	%	m3	m3
Bojong Irr. Area	2,599	870	870	859	2,599	100	22,122,111	20,279,272
Watubarut Irr. Area	1,627	540	540	547	1,627	100	13,859,290	7,287,315
Sindut Irr. Area	916	305	305	305	915	100	7,800,521	5,500,412
Rowokawuk Irr. Area	746	249	249	248	746	100	6,351,438	3,254,536
Total	5,888				5888	100	50,133,360	36,321,536

Source: Analysis Result, 2019

B.3.3. Water supply pattern with a scattered system

- The results of the optimization calculation with a scattered system obtained three groups in the pattern of water supply which can be divided evenly in each irrigation area.

This scattered system is very complicated and requires accuracy both for the calculation of water requirements based on the cropping pattern and the method of water provision. It is is absolutely necessary the role of the farmer association (P3A) in water rotation supervision. Moreover commitment from all parties, including regulators, operators and beneficiaries, is needed therefore no one is dominant among them. The use of this system is better in in justice among users because the distribution is fairly although for water operation is more difficult. The irrigation performance was obtained by 100% as shown on Fig. 7 and Table- VI as below

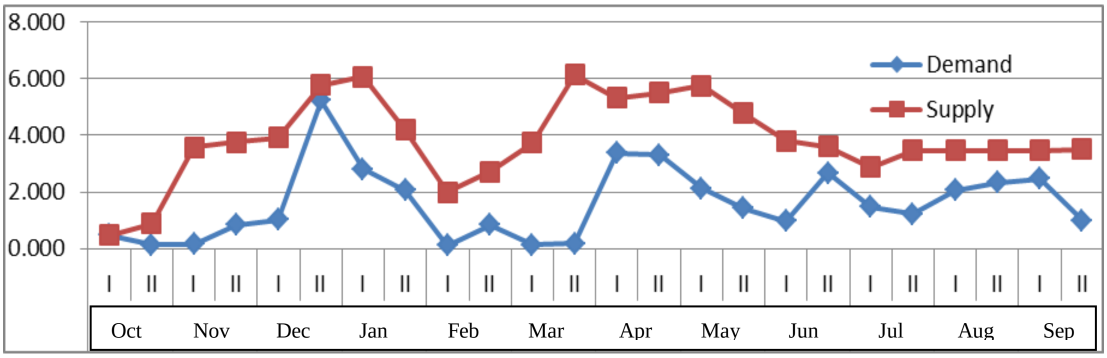

Fig. 7 Water balance use scattered system with the K-factor = 0.5
Source: Analysis Result, 2019

Table- VI. Irrigation Performance Factor use scattered system with the K-factor = 0.5

Sub Irrigation Area	Total area	Golongan/Group System (distribution system of irrigation)			Irrigated Area	Irrigation Perfomance Factor	Volume of Water Requirement	Volume of Water Availibility
	Ha	First group	Second group	Third group	Ha	%	m3	m3
Bojong Irr. Area	2,599	0	2,599	0	2,599	100	21,709,576	20,672,915
Watubarut Irr. Area	1,627	0	1,627	0	1,627	100	13,590,412	6,290,293
Sindut Irr. Area	916	0	0	916	916	100	8,500,785	5,965,434
Rowokawuk Irr. Area	746	606	140	0	746	100	5,963,929	2,939,766
Total	5,888				5888	100	49,764,702	35,868,408

Source: Analysis Result, 2019

B.3.4. Relation of Irrigation and Farmers Association Performance

In the irrigation management system, supply and demand factors become the main consideration because it can determine the achievement of a water service to its users. In order to obtain the main function of irrigation management in providing water supply to plants, irrigation channels / networks must be able to: 1), to take water from the source through weir (diverting), 2) to convey or drain water from the source to the irrigation area (conveying), 3). to distribute water to irrigated land (distributing), and 4). to regulate and measure the flow of existing water (regulating and measuring).

Therefore, the right policy to be applied in irrigation management uses the principle of provision management, namely management of services to users through participation. The principle of participatory irrigation is involved of other parties from planning, implementation of water distribution for maintenance to ensure the lifetime of irrigation and infrastructure facilities. Therefore, irrigation participatory is an irrigation which involves all stakeholders to increase community participation to be more concerned in irrigation management. In order to achieve optimal irrigation performance requires technical and non-technical approaches moreover not only determined by the results of water optimization calculations but also to institutional performance (P3A). From the figure 8 as bellow shows institutional performance will affected the irrigation performance if it's performance is more than or equal to 50% or at least included in the develop category. The Fig. 8 as below is the graph relationship between irrigation performance and institutions performance from farmers association (P3A).

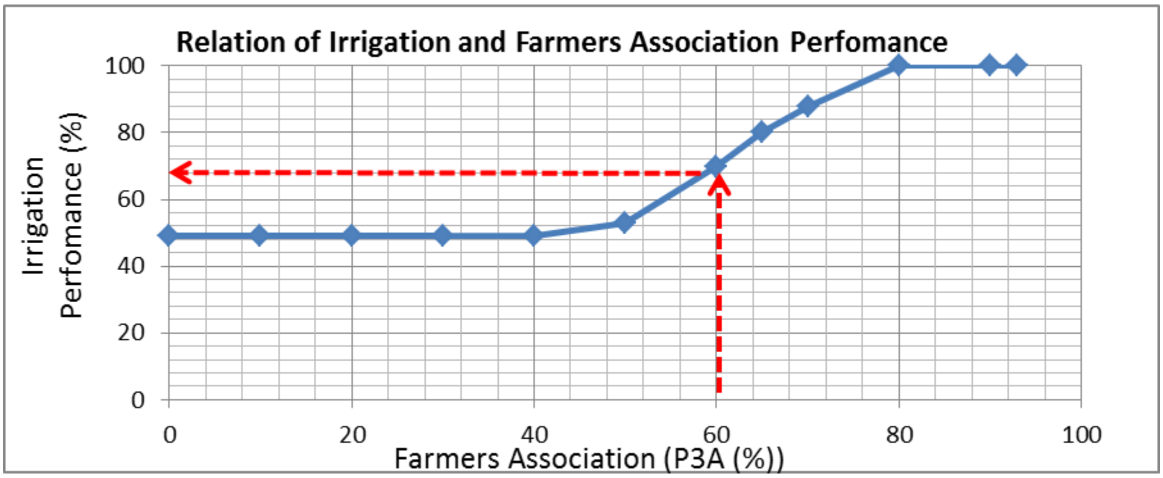

Fig. 8 Relation of Irrigation and Farmers Association Performance
Source: Analysis Result, 2019

IV. CONCLUSION

1. When there is an imbalance between water availability and water requirement, optimization calculations are needed to achieve the effectiveness of water supply therefore irrigation efficiency can be achieved.
2. Providing water with a grouping (golongan) system is necessary to reduce the peak discharge when at the same time all areas need the water. This method is expected hence water can be distributed fairly, equitable and timely in the irrigation area and can be distributed in rotation system.
3. Water distribution using K-factor = 0.5 with a vertical system, horizontal system or scattered systems can obtain irrigation performance optimally but requires participation and awareness from farmer associations (P3A) especially in the supervision of water distribution.
4. Reliable farmer associations are needed for able to divide water into rice fields in accordance with water requirements therefore all irrigation land can be irrigated optimally
5. Institutional performance will affected the irrigation performance if the performance is more than or equal to 50% or at least included in the developing category.

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