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Research paper

Optimization of water usage at irrigation area of pakis-malang regency-Indonesia by using linear programming

Lily Montarcih Limantara [1] *, Mohammad Bisri [1], Risq Fajrianto [1]

[1] *Department of Water Resources, Faculty of Engineering University of Brawijaya – Indonesia*
**Corresponding author E-mail: lilymont2001@gmail.com*

Abstract

Irrigation area of Pakis-Malang Regency-East Java Province of Indonesia has water deficit mainly in dry season. This study intended to analyze the optimization of water usage by using linear programming. The optimization is regarding to the existing condition cropping pattern and the other four alternatives of the new ones. Method of water balance was used for comparing irrigation water requirement in every cropping pattern and water availibility. Result showed that the 51% of dependable discharge represented the available discharge in irrigation area of Pakis during the 10 last years (from 2006 until 2015). For this condition discharge, the suitable cropping pattern is the existing one with the cropping intensity in one year is as 252.756% and the benefit of agricultural yields is Rp. 45,734,799,598.

Keywords: *Irrigation; Water Balance; Optimization; Benefit of Agricultural Yield.*

1. Introduction

The land and water resources are becoming very limited due to the rapid change of population [1, 2]. Therefore, the crop optimization has received the extensive attention in the recent years. However, the mathematical models have been developed to determine the maximum benefit subjected to the some constraints due to the optimal use of the available resources. Land and water are the key factors for sustainable agricultural development of a nation [3] like Indonesia which is as an agricultural country. Water is as a main demand for agriculture, so water availability for agriculture has to be always available. However, the water availability is sometimes surplus or deficit for any agricultural area. To know the water availability, there is needed the water balance analysis. The rest of surplus water availability can be used for maximizing the productivity of agricultural yield so it produces the maximum benefit. One of the analysis methods that can be used is the optimization technique [4]. To optimize is identic with to maximize something with the limited resources. Optimization in water resources is cllassified into two categories [5] such as before or after the water structure is built. Generally, optimization model is a process of the best alternative selection among a number of the available solution alternatives [6], [7].

The various techniques for optimization have been developed for developing the most efficient use of the available resources [8]. Kuo et al. [9] focused especially on the developing irrigation and planning model using a customized genetic algorithm to simulate on-farm irrigation system, and to optimize the allocation of the irrigated area to alternative crops for maximum the net benefit. Benli and Kodal [10] compared a nonlinear optimization model to a linear one and found that the former can give the higher farm income values than the linear one under the deficit irrigation conditions. Boustani et al. [11] used the multi-objective programming approach to develop the optimal cropping pattern in the Jahrom region, Iran under water the deficit condition. However, the various modelling approaches have been applied to optimize the cropping pattern worldwide including the linear and nonlinear optimization models [12 - 15]; deterministic linear programming and chance-constrained linear programming models [16], the interactive fuzzy multi-objective optimization approach [17], the goal program approach [18], the multi-objective fractious. Among these different models, linear programming has been found to be one of the best and simple techniques for optimizing an irrigated area where various crops are competing for a limited quantity of land and water resources [1].

Optimization in this study is to optimize the usage of water availability for irrigation so that the distribution of water usage is more effective and efficient. In addition, it can produce the maximum benefit of agricultural product yield. Fig. 1 presented the water balance for existing condition of cropping pattern in the irrigation area of Pakis in 2014/2015.

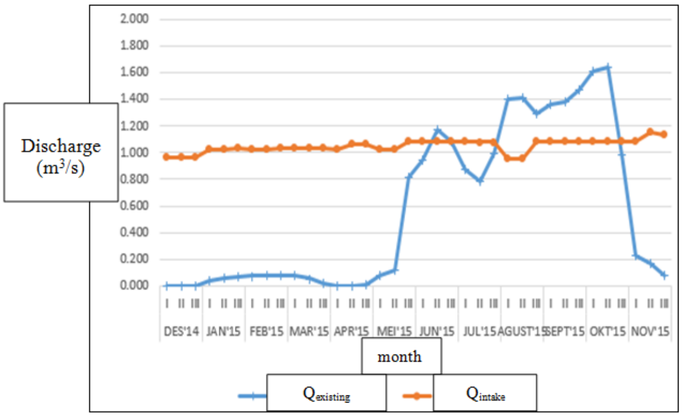

Fig. 1: Water Balance of Existing Condition Cropping Pattern in 2014/2015.

The water balance as above showed that in 2015 the water availability was still deficit if it was compared to the irrigation water requirement on the second period of June; first, second, and third period of August; first, second, and third period of September; first and second period of October.

Based on the existing condition, it is needed to determine the suitable cropping pattern so the water usage is not more than water availability by optimizing the water usage distribution due to the some alternatives of cropping patterns. Linear programming is used for solving the problem. Therefore, this study intended to optimize the surplus water usage in the irrigatian area of Pakis in order to get the water balance and the maximum benefit of agricultural yield.

2. Material and method

The study location is on the irrigation area of Pakis where is located in the two districts such as the Pakis and Jabung District-Malang Regency-East Java of Indonesia. The area of paddy field is 721 ha. Map of location is as in the Fig. 2.

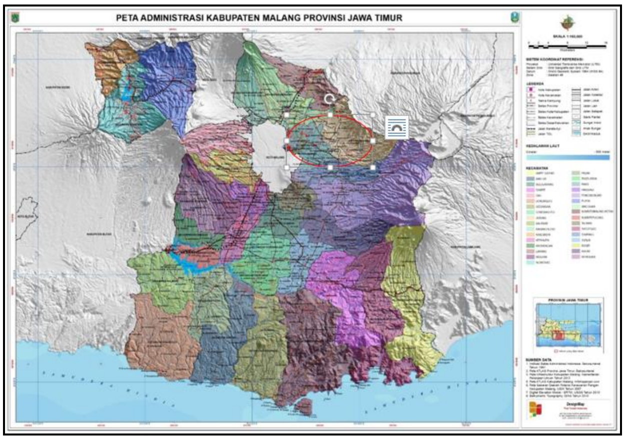

Fig. 2: Map of the Study Location Source: Petatematikindo.Files.Wordpress.Co.

Fig. 2 presents the administrative map of Malang Regency where the location study of Pakis District is there. However, Fig. 3 presents the irrigation scheme of Pakis irrigation area

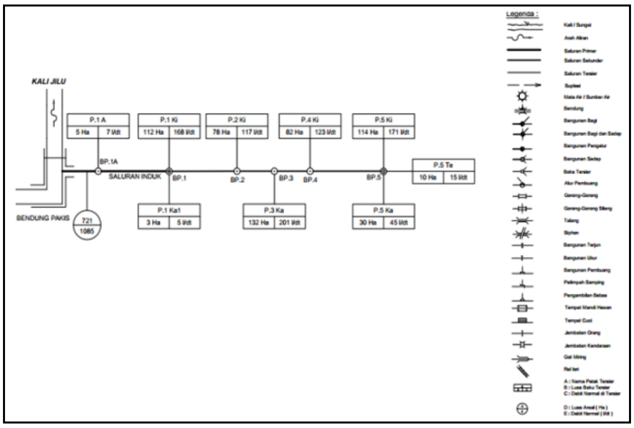

Fig. 3: Irrigation Scheme of Pakis Irrigation Area Source: Water Resources Department of Malang Regency.

Systematically, the steps of study analysis are as follow: 1)To analyze the dependable discharge of 97% (dry seasonal discharge); 80%; 75% (low seasonal discharge); 50% (normal seasonal discharge); and 26% (sufficient seasonal discharge); 2) To analyze the potential evapotranspiration; 3) To analyze the area rainfall; 4) To evaluate the rainfall data by using the consistency test; 5) To calculate the design rainfall of 80% (R_{80}); 6) To analyze the irrigation water requirement; 7) To formulate the mathematical model; 8) To analyze the water balance; 9) To analyze the optimization of water usage due to the some alternatives of cropping patterns by using Linear programming; and 10) To make the result recapitulation about the optimal irrigation area and maximum benefit of irrigation production (yield).

The mathematical model which is used for solving the optimization of irrigation area by using the Linear Progamming is as follow [5]:

Objective function

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

Constraint:

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

And

$$x_n \geq 0 \tag{3}$$

For m = 1, 2, 3,…, m

For n = 1, 2, 3,…, n

Where:

Z = objective function/ maximum benefit of agricultural yield (Rp)

x_n = objective variable of irrigation/ area of irrigation (ha)

a_{mn} = constant/ volume of irrigation water requirement (m^3/ha)

b_m = volume of water availability (m^3)

c_n = profit/ net benefit of paddy field irrigation (Rp/ha)

m = number of constraint

n = number of decision variable

System analysis by using the mathematical model provides a suitable methodology to analyse the various aspect of water resources system planning [16]. The Linear programming would give some advantages for analysing the water resources system planning as follow [20], [21]: (1) The constraints and the objective function which are used in this program are as the linear function; (2) This program is quite simple because there are many solvers can be used to solve this problem; (3) If it can be built the optimization procedure (the objective function with any kinds of constraints), it can approach the real problem. The step by step to carry out the Linear programming is as follow [22], [23]: (1) To build the optimization models; (2) To determine the resources which would be optimized (for this case study are area and cropping pattern of irrigation); (3) To calculate the quantities of input or output for every kind of activity unit; (4) To build the mathematical modelling.

3. Results and discussion

3.1. Analysis of dependable discharge

Analysis of dependable discharge used the probability of 97% (dry seasonal discharge), 80%, 75% (low seasonal discharge), 51% (normal seasonal discharge), and 26% (sufficient seasonal discharge) [24]. The maximum value of 97% dependable discharge was occurred on January (= 1.027 m^3/s) and the minimum was on December (= 0.096 m^3/s). The maximum value of 80% dependable discharge was occurred on January (= 1.134 m^3/s) and the minimum was on August (= 0.441 m^3/s). The maximum value of 75% dependable discharge was occurred on January (= 1.139 m^3/s) and the minimum was on October (= 0.803 m^3/s). The maximum value of 51% dependable discharge was occurred on January (= 1.192 m^3/s) and the minimum was on August (= 0.935 m^3/s). The maximum value of 26% dependable discharge was occurred on January (= 2.373 m^3/s) and the minimum was on October and November (= 1.091 m^3/s). Then, the dependable discharge (m^3/s) of 97%, 80%, 75%, 51%, and 26% were converted into volume

(m^3) for analysis of water balance and it was presented as in the Table 1.

Table 1: Volume of Dependable Discharge with the Probability of 97%, 80%, 75%, 51%, and 26%

Cropping pattern	Volume of 97% (m^3)	Volume of 80% (m^3)	Volume of 75% (m^3)	Volume of 51% (m^3)	Volume of 26% (m^3)
I	662,342.400	1.050,883.200	1,093,478.400	1,155,600.000	1,371427.200
II	445,651.200	1,053,129.600	1,086,912.000	1,133,136.000	1,454,889.600
III	348,624.000	800,841.600	944,352.000	1,058,745.000	1,214,179.200

3.2. Analysis of irrigation water requirement

Irrigation water requirement was analysed based on the determination of cropping pattern. The method of water balance was used in this study as follow [25]:

$$NFR_{padi} = Cu + Pd + NR + P - Reff \quad (4)$$

$$NFR_{palawija} = Cu + P - Reff \quad (5)$$

Where:
NFR = net water requirement in paddy field (mm/day)
Cu = wáter requirement for crop (mm/day)
Pd = wáter requirement for land preparation (mm/day)
P = percolation (mm/day)
Reff = effective rainfall (mm/day)
There were 5 alternatives of cropping pattern which were analysed in this study: 1) Cropping pattern-existing: paddy, corn, cane – paddy, corn, cane – paddy, corn, cane (planting start on the second period of December); 2) Cropping pattern-alternative-1: paddy, cane – paddy, cane – paddy, corn, cane (planting start on the second period of December); 3) Cropping pattern-alternative-2: paddy, corn, cane – paddy, corn, cane – corn, cane (planting start on the second period of October); 4) Cropping pattern-alternative-3: paddy, corn, cane – paddy, corn, cane – paddy, corn, cane (planting start on the second period of October); and 5) Cropping pattern-alternative-4: paddy, soy, cane – paddy, soy, cane – paddy, soy, cane (planting start on the second period of December). Table 2 presented the irrigation water requirement for the whole alternatives of cropping pattern.

Table 2: Irrigation Water Requirement

Alt cropping pattern	Cropping pattern	Volume of irrigation water requirement (m^3/ha)			
		paddy	Corn	Soy	cane
Existing	I	0.000	619.395	-	0.000
	II	1,031.605	837.776	-	869.721
	III	1,490.567	1,105.133	-	1,119.745
Alt-1	I	0.000	0.000	-	0.000
	II	1,031.605	0.000	-	869.721
	III	1,490.567	1,105.133	-	1,119.745
Alt-2	I	374.438	732.095	-	148.554
	II	20.576	663.632	-	167.538
	III	0.000	1.056.581	-	796.048
Alt-3	I	374.438	732.095	-	243.554
	II	252.603	663.632	-	167.538
	III	1,895.005	1,056.581	-	1,426.979
Alt-4	I	0.000	-	543.339	0.000
	II	1,031.605	-	762.056	869.721
	III	1,490.567	-	1,003.204	1,119.745

3.3. Mathematical model of optimization

There are three variables for formulating the problems in optimization by using Linear programming as follow: 1) Decision variable. The decision variable in this case is the determination pattern of area for every kind of crop in the irrigation area; 2) Objective variable. The objective variable in this case is to maximize the benefit for solving the imbalanced water irrigation; and 3) Constraint variable. The constraint in this case is the area irrigation which can be planted for every cropping pattern in the Pakis irrigation area. In addition, the constraint is the limitation of water potency in this irrigation area.

3.3.1. Objective function

$$\text{Max } Z = A.X_{1a} + B.X_{1b} + C.X_{1c} + A.X_{2a} + B.X_{2b} + C.X_{2c} + A.X_{3a} + B.X_{3b} + C.X_{3c}$$

Where:
Z = objective function to maximize benefit (Rp)
A, B, C = production price of paddy (A), corn (B), and cane (C) (Rp/ha)
X_{1a}, X_{2a}, X_{3a} = area of paddy in every season (ha)
X_{1b}, X_{2b}, X_{3b} = area of second crop in every season (ha)
X_{1c}, X_{2c}, X_{3c} = area of cane in every season (ha)

3.3.2. Constraint

1) Total area of irrigation:

$$X_{1a} + X_{1b} + X_{1c} \leq Xt_1$$

$$X_{2a} + X_{2b} + X_{2c} \leq Xt_2$$

$$X_{3a} + X_{3b} + X_{3c} \leq Xt_3$$

Where:
Xt_n = total area of paddy field in the Pakis irrigation area for every cropping season-n

2) Dependable volume of the water availability:

$$V_{p1}.X_{1a} + V_{j1}.X_{1b} + V_{t1}.X_{1c} \leq Vs_1$$

$$V_{p2}.X_{2a} + V_{j2}.X_{2b} + V_{t2}.X_{2c} \leq Vs_2$$

$$V_{p3}.X_{3a} + V_{j3}.X_{3b} + V_{t3}.X_{3c} \leq Vs_3$$

Where:
$V_{p1,2,3}$ = water requirement of paddy in every season (m^3/ha)
$V_{j1,2,3}$ = water requirement of second crop in every season (m^3/ha)
$V_{t1,2,3}$ = water requirement of cane in every season (m^3/ha)
$Vs_{1,2,3}$= dependable volume of water availability on the cropping season I, II, and III (m^3)

3) Area of cane:
$X_{1c} \leq Xte_1$
$X_{2c} \leq Xte_2$
$X_{3c} \leq Xte_3$
Subject to $X_{1c} = X_{2c} = X_{3c}$
Where:
Xte_n = the maximum area of cane for every season is 15 ha

3.4. Recapitulation of optimum value

3.4.1. Water balance

The result of water balance was obtained by comparing the dependable discharge and the irrigation water requirement. The dependable discharge of 97% (dry seasonal discharge), 80%, 75% (low seasonal discharge), 51% (normal seasonal discharge), and 26% (sufficient seasonal discharge were compared with irrigation water requirement of cropping pattern-existing, cropping pattern alternative-1, 2, 3, and 4.

3.4.2. Cropping intensity

The value of cropping intensity was presented as the percentage of every cropping pattern during one year as in the Table 3 below.

Table 3: Cropping Intensity of Every Cropping Pattern

Probability of dependable discharge	Cropping intensity (%)				
	Existing	Alt-1	Alt-2	Alt-3	Alt-4
97% (dry)	128.079	128.079	153.082	92.059	128.079
80%	246.171	206.073	241.989	234.150	226.900
75% (low)	216.316	206.089	281.148	277.796	246.423
51% (normal)	252.256	217.851	284.831	281.481	253.465
26% (sufficient)	263.069	230.290	296.761	284.733	263.106

The value of optimum cropping intensity due to the dependable discharge of 97% is as 153.082% for cropping pattern alternative-2. The value of optimum cropping intensity due to the dependable discharge of 80% is 246.171% for cropping pattern-existing. The value of optimum cropping pattern intensity due to the dependable discharge of 75% is 281.148% for cropping pattern alternative-2. The value of optimum cropping pattern intensity due to the dependable discharge of 51% is as 284.831% for cropping pattern alternative-2. The value of optimum cropping pattern intensity due to the dependable discharge of 26% is as 296.761% for cropping pattern alternative-2

3.4.3. Benefit of agricultural product (yield)

The benefit of agricultural product (yield) during one year is presented as in Table 4.

Table 4: Benefit of Agricultural Product (Yield) During One Year

Prob. Of dependable discharge	Benefit of agricultural product (Rp)				
	Existing	Alt-1	Alt-2	Alt-3	Alt-4
97% (dry)	25,535,757,709	25,535,757,079	25,931,711,739	11,775,137,354	25,535,757,079
80%	40,881,650,129	37,963,309,448	36.043.105.278	36,487,699,294	37,963,309,448
75% (low)	43,808,432,474	40,880,735,011	39,814,423,828	41,826,875,335	41,720,967,975
51% (normal)	45,734,799,598	43,194,431,323	40,909,808,215	43,800,215,552	43,936,348,857
26%(sufficient)	47,937,450,350	45,551,840,356	42,849,298,862	46,883,191,978	46,191,692,423

The optimum benefit of agricultural product due to the dependable discharge of 97% is Rp. 25,931,711,739,- for cropping pattern alternative-2. The optimum benefit of agricultural product due to the dependable discharge of 80% is Rp. 40,881,650,129,- for cropping pattern-existing. The optimum benefit of agricultural product due to the dependable discharge of 75% is Rp. 43,808,432,474,- for cropping pattern-existing. The optimum benefit of agricultural product due to the dependable discharge of 51% is Rp. 45,734,799,598,- for cropping pattern-existing. The optimum benefit of agricultural product due to the dependable discharge of 26% is Rp. 47,937,450,353,- for cropping pattern-existing

4. Conclusion

Based on the analysis as above, it is concluded as follow: Water balance of the existing condition (cropping period of 2014/2015) in Pakis irrigation area indicates that there is still happened water deficit due to the water requirement of Pakis irrigation area. Analysis by using dependable discharge of 97% (dry), 80%, 75% (low), 51% (normal), and 26% (sufficient) which is compared with irrigation water requirement in every cropping pattern-existing, alternative-1, 2, 3, and 4 shows that the water availability has not still been able to fulfill irrigation water demand for cropping pattern-existing, alternative-1, 2, and 3.

Irrigation water requirement of cropping pattern-existing is in the range of 0.000 m^3/s until 1.641 m^3/s; however, for alternative-1: 0.000 m^3/s until 1.641 m^3/s; for alternative-2: 0.000 m^3/s until 1.782 m^3/s; for alternative-3; 0.000 m^3/s until 1.782 m^3/s; and for alternative-4; 0.000 m^3/s until 1.628 m^3/s Result of the dependable discharge analysis indicates that the dependable discharge of 51% represents the available discharges during the last 10 years (from 2006 until 2015). For the normal seasonal discharge (51%), the selected cropping pattern is the existing one (paddy, corn, cane – paddy, corn, cane – paddy, corn, cane) with the cropping intensity during one year is 252.756% and the benefit is Rp. 45,734,799,598.

Analysis for the other condition of the dependable discharge is as follow: a) for dependable discharge of 97% (dry): the selected cropping pattern is alternative-2 (paddy, corn, cane – paddy, corn, cane – corn, cane) with the cropping intensity during one year is 153.082% and the benefit is Rp. 25,931,771,739,-; b) for dependable discharge of 80%, the selected cropping pattern is the existing one (paddy, corn, cane – paddy, corn, cane – paddy, corn, cane) with the cropping pattern during one year is 246,171% and the benefit is Rp. 40,881,650,129,-; c) for dependable discharge of 75% (low), the selected cropping pattern is the existing one (paddy, corn, cane – paddy, corn, cane – paddy, corn, cane) with the cropping intensity during one year is 246.316% and the benefit is Rp. 43,808,432,474,-; and d) for dependable discharge of 26% (sufficient), the selected cropping pattern is the existing one (paddy, corn, cane – paddy, corn, cane – paddy, corn, cane) with the cropping intensity during one year is 263,069% and the benefit is Rp. 47,937,450,353,-.

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