WATER ALLOCATION OPTIMIZATION FOR COMBINED USERS OF ENERGY GENERATION AND IRRIGATION DEMAND AT THE UPSTREAM BRANTAS RIVER REACH USING MIXED INTEGER LINEAR PROGRAMMING METHOD

OPTIMISATION DE L'ALLOCATION DES EAU POUR LES UTILISATEURS COMBINEES DE PRODUCTION D'ÉNERGIE ET IRRIGATION LA DEMANDE AU AMONT BRANTAS RIVER REACH EN UTILISANT LA MÉTHODE MIXTE DE PROGRAMMATION ENTIER LINEAR

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ABSTRACT

Brantas River is a major river in East Java, Indonesia, having approximately 12.000 km^2 basin area and 320 km length. The river became the main water sources in the area through 4 large cascade dams at the upstream, which are Sengguruh Dam, Karangkates Dam, Wlingi Dam, and Lodoyo Dam. Mixed Integer Linear Programming (MILP) method has been inroduced for optimization modelling. The data to be used in the model is ten-day-period (decade) of discharge data from December 2011 to November 2012 to be converted to seasonal data. The aim of the optimization is to maximize the profit of the farm (irrigation) in Lodagong Irrigation Area to gain the energy production in Sengguruh Dam, Karangkates/Sutami Dam, Wlingi Dam, and Lodoyo Dam (hydro power plant). From the optimization modeling based on water allocation obtained that maximum benefits from both irrigation area and energy generation is IDR 903.92 billion; which is the best value comparing with optimization modeling based on the maximizing irrigation benefitsof IDR 883.58 billion and based on maximizing energy benefits which is IDR 841.03 billion.

RÉSUMÉ

Brantas River est une rivière importante dans l'Est de Java, en Indonésie, ayant environ 12.000 km2 la superficie du bassin et 320 km de longueur. Le fleuve est devenu les principales sources d'eau de la région à travers 4 grands barrages en cascade à l'amont, qui sont Sengguruh Dam, Karangkates Dam, Wlingi Dam, et Lodoyo Dam. Méthode de programmation linéaire en nombres entiers mixte (PPIM) a été inroduced pour la modélisation de l'optimisation. Les données qui seront utilisées dans le modèle est de dix jours-période (dix ans) des données sur les sorties de Décembre 2011 to Novembre 2012 pour être converti en données saisonnières. Le but de l'optimisation est de maximiser le profit de la ferme (irrigation) dans Lodagong zone d'irrigation de gagner la production d'énergie dans Sengguruh Dam, Karangkates / Sutami Dam, Wlingi Dam, et Lodoyo Dam (hydro Power Plant). De la modélisation d'optimisation basée sur l'allocation de l'eau obtenus que le maximum d'avantages à la fois de la zone de l'irrigation et la production d'énergie est IDR 903.92 milliard; ce qui est la meilleure valeur en comparant avec la modélisation d'optimisation basée sur les avantages de l'irrigation de maximiser IDR 883.58 milliard et basée sur la maximisation des avantages de l'énergie qui est IDR 841.03 milliard.

Keywords:dam ; reservoir ; farming ; hydro power ; optimization

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1. Introduction

1.1 Background

As a major river in East Java Indonesia, Brantas River become an timportant water source in the basin area of 12.000 km^2 with 320 km length originated at Sumber Brantas Villaga to Surabaya, the capital city of East Java Province. Several large dams have been constructed in purpose of water conservation and flood control. The river supplies irrigation as well as municipal, industrial and domestic water, including water power generator produce electricity energy.

1.2 Objectives

The objective of this research is to optimize the use of available water in river in order to gain the maximum benefit that obtained from power generators and irrigation water supply in the upper reach of Brantas River. Trade off solution may be obtained by using integer linear programming approach.

2. Methodology

2.1. Research Location

This research is located in the upstream reach of Brantas River, in the southern part of the district of Malang, East Java, Indonesia. Map and river scheme are shown in Figure 1.

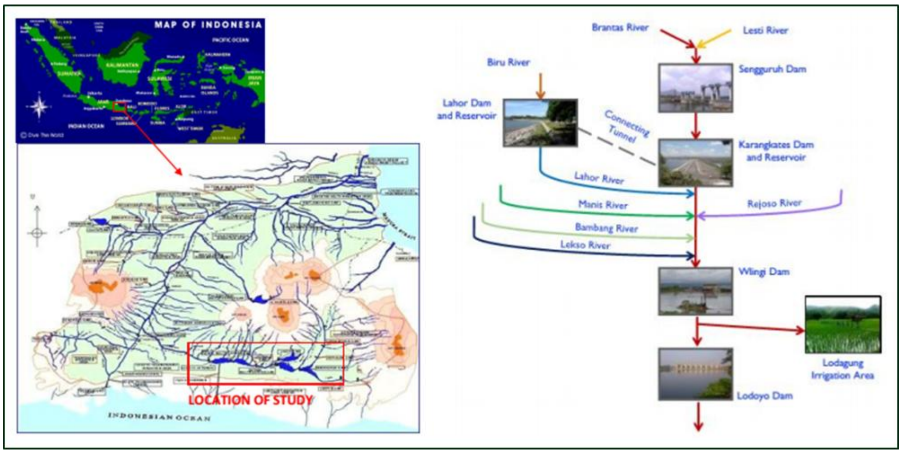

Figure 1. Location of Study and River Scheme

2.2. Research Objects

As research objects, 4 large dams named Sengguruh, Karangkates, Wlingi and Lodoyo, are currently installed power generatos consequently 2x14,5 MW, 3x35 MW, 2x27 MW and 1x4.5 MW. One reservoir belongs to Karangkates Dam, actually a pair of Karangkates and Lahor Reservoirs connected by tunnel, with the total capacity of 175 million cubic meter. This reservoir is purposed to conserve water for irrigation as well as municipal and industry supplies combined withflood control. See Table 1 for the name, location and function of Dams.The data to be used in the model is ten-day-period (decade) of discharge data from December 2011 to November 2012 to be converted to seasonal data.

Table 1 Name, Location and Function of Dam

No.	Name of Dam	Location	Function
1.	Sengguruh	Village of Sengguruh, Kepanjen, 24 km south of Malang.	Elevtricity power generator 2x14.5 MW, control sediment entering Karangkates.
2.	Karangkates-Lahor	Village of Karangkates, Sumber-pucung, Malang. Lahor is 1.5 km north of Karangkates.	Flood control, irrigation, municipal and industry water supply, electricity power generator 3x35 MW.
3.	Wlingi	Village of Jegu, Kutojayan, Blitar.	Glood Control, sediment control, flood control and electricity power generator 2x27 MW
4.	Lodoyo	7 km downstream of Wlingi Dam.	Electricity power generator 1x4.5 MW and sediment control from Wlingi Dam.

2.3 Formulation

The use of Linear Programming formula, the objective equation aims to maximize both electricity energy and farm production benefits as Equation 1. The benefit (Z) is the summation of unit power benefit (number of turbines operated and irrigation for cropping patern area)

Max Revenue $Z = \Sigma\, bt_i.T_{ik} + \Sigma\, ba_j.A_{jk}$, i = 1 (Sengguruh), 2 (Karangkates), 3 (Wlingi), 4 (Lodoyo) (Eq.1)
j = 1 (Rice crop), 2 (Corn crop)
k = 1 (Rainy season), 2 (1st Dry season), 3 (2nd Dry season)

Subject to:

Power generator:	$p_{ik}.T_{ik}$	$\leq P_{ik}$	, i = 1 to 4, k = 1 to 3
Farm area:	$\Sigma\, qa_{jk}.A_{jk}$	$\leq A_{total}$	, j = 1 to 2, k = 1 to 3
Water balance:	$qt_1.T_{1k}$	$\leq Q_{1k}$	, k = 1 to 3
	$qt_2.T_{2k} - V_k + V_{k+1} + S_k$	$= Q_{2k}$	, k = 1 to 3
	$qt_3.T_{3k} + \Sigma\, qa_{jk} - S_k$	$\leq Q_{3k}$	, j = 1 to 2, k = 1 to 3
	$qt_4.T_{4k} + \Sigma\, qa_{jk} - S_k$	$\leq Q_{4k}$	, j = 1 to 2, k = 1 to 3
Reservoir at Karangkates:	V_1	$= V_{initial}$	
	V_k	$\leq V_{capacity}$	, k = 2 to 3
Non negativity	T_{ik}	≥ 0 and Integer	
	A_{jk}, V_k, S_k	≥ 0 and Real	

Where:

- T_{ik} : Number of turbine at i-Dam and k-Season
- A_{jk} : Area of irrigation for j-Crop and k-Season (Ha)
- V_k : Volume of water at Karangkates reservoir in k-Season (m^3), except V_1 = initial volume at first season
- S_k : Spill out discharge at Karangkates reservoir in k-Season (m^3)
- bt_i : Unit benefit of turbine at i-Dam (Rupiah/Turbine)
- ba_j : Unit benefit of j-Crop (Rupiah/Ha)
- p_{ik} : Unit power production (Megawatt)
- qt_i : Unit discharge for turbine operation (m^3/season/turbine)
- qa_{jk} : Unit discharge for irrigation (m^3/season/Ha)

Then the Mixed Irrigation Linear Programming (MILP) will be:

Objective 1 Maximizing Both Irrigation and Energy:

$$\text{Max } Z = (377.0496\, T_{S1} + 377.0496\, T_{S2} + 377.0496\, T_{S3} + 377.0496\, T_{K1} + 377.0496\, T_{K2} + 377.0496\, T_{K3} + 377.0496\, T_{W1} + 377.0496\, T_{W2} + 377.0496\, T_{W3} + 377.0496\, T_{L1} + 377.0496\, T_{L2} + 377.0496\, T_{L3} + 19.65\, A_{R1} + 19.65\, A_{R2} + 19.65\, A_{R3} + 8.868\, A_{C1} + 8.868\, A_{C2} + 8.868\, A_{C3}) \times 10^6$$

Subject to Constraints:

$$
\begin{aligned}
14.5\, TS_1 &\leq 29 \\
14.5\, TS_2 &\leq 29 \\
14.5\, TS_3 &\leq 29 \\
35\, T_{K1} &\leq 105 \\
35\, T_{K2} &\leq 105 \\
35\, T_{K3} &\leq 105 \\
27\, T_{W1} &\leq 54 \\
27\, T_{W2} &\leq 54 \\
27\, T_{W3} &\leq 54 \\
4.5\, T_{L1} &\leq 4.5 \\
4.5\, T_{L2} &\leq 4.5 \\
4.5\, T_{L3} &\leq 4.5 \\
A_{R1} + A_{C1} &\leq 12499 \\
A_{R2} + A_{C2} &\leq 12499 \\
A_{R3} + A_{C3} &\leq 12499 \\
54328.32\, T_{S1} &\leq 643.6031 \times 10^6 \\
54328.32\, T_{S2} &\leq 670.5556 \times 10^6 \\
54328.32\, T_{S3} &\leq 286.5378 \times 10^6 \\
14826.24\, T_{K1} - V_1 + V_2 + S_1 &= 962.7508 \times 10^6 \\
14826.24\, T_{K2} - V_2 + V_3 + S_2 &= 1002.721 \times 10^6 \\
14826.24\, T_{K3} - V_3 + S_3 &= 458.187 \times 10^6 \\
52565.76\, T_{W1} + 123109\, A_{R1} + 76364\, A_{C1} - S_1 &\leq 1384.319 \times 10^6 \\
52565.76\, T_{W2} + 123109\, A_{R2} + 76364\, A_{C2} - S_2 &\leq 1385.102 \times 10^6 \\
52565.76\, T_{W3} + 123109\, A_{R3} + 76364\, A_{C3} - S_3 &\leq 588.4799 \times 10^6 \\
111974.4\, T_{L1} + 123109\, A_{R1} + 76364\, A_{C1} - S_1 &\leq 1851.886 \times 10^6 \\
111974.4\, T_{L2} + 123109\, A_{R2} + 76364\, A_{C2} - S_2 &\leq 1893.865 \times 10^6 \\
111974.4\, T_{L3} + 123109\, A_{R3} + 76364\, A_{C3} - S_3 &\leq 697.0769 \times 10^6 \\
V_1 &= 175 \times 10^6 \\
V_2 &\leq 175 \times 10^6 \\
V_3 &\leq 175 \times 10^6 \\
T_{S1}, T_{S2}, T_{S3}, T_{K1}, T_{K2}, T_{K3}, T_{W1}, T_{W2}, T_{W3}, T_{L1}, T_{L2}, T_{L3} &\geq 0 \text{ and Integer} \\
A_{R1}, A_{R2}, A_{R3}, A_{C1}, A_{C2}, A_{C3}, V1, V2, V3, S1, S2, S3 &\geq 0 \text{ and Real}
\end{aligned}
$$

By using the same constraints, the programs also execute for 2 other objectives, that are

Objective 2 Maximizing Irrigation:
$$\text{Max } Z = (19.65\, A_{R1} + 19.65\, A_{R2} + 19.65\, A_{R3} + 8.868\, A_{C1} + 8.868\, A_{C2} + 8.868\, A_{C3}) \times 10^6$$

Objective 3 Maximizing Energy:
$$\text{Max } Z = (377.0496\, T_{S1} + 377.0496\, T_{S2} + 377.0496\, T_{S3} + 377.0496\, T_{K1} + 377.0496\, T_{K2} + 377.0496\, T_{K3} + 377.0496\, T_{W1} + 377.0496\, T_{W2} + 377.0496\, T_{W3} + 377.0496\, T_{L1} + 377.0496\, T_{L2} + 377.0496\, T_{L3}) \times 10^6$$

3. Result

The calculation of mixed integer linear programming using QM for Windows (POMQMv3). Assumptions for boundaries are: the total area at Lodagung Irrigation Scheme is 12,499 Ha, maximum of reservoir volume at Karangkates Dam is 175,000,000 m^3 and maximum number of turbines or power generators that was shown in Table 1, Result of calculation for each three seasons, that are rainy, 1^{st}dry and 2^{nd} dry seasons are shown in Table 2.Therefore by comparing results from each strategies we can find trade-off benefit of crop and energy production which can be shown in Table 3 and Figure 2.

Table 2. Results of Calculation for Each Season

Operational Alternatives		Unit	Maximize Irrigation at Season			Maximixe Both at Season			Maximize Energy at Season		
			Rainy	1^{st} Dry	2^{nd} Dry	Rainy	1^{st} Dry	2^{nd} Dry	Rainy	1^{st} Dry	2^{nd} Dry
Number of Turbines Operated at											
1	Sengguruh Dam	Unit	2	2	2	2	2	2	2	2	2
2	Karangkates Dam	Unit	3	3	3	3	3	3	3	3	3
3	Wlingi Dam	Unit	2	2	0	2	2	2	2	2	2
4	Lodoyo Dam	Unit	1	1	1	1	1	1	1	1	1
Irrigated Area at Lodagung Scheme											
1	Rice Plant	Ha	12499	12499	9922	12499	12499	9922	12499	12499	1696
2	Corn Crop	Ha	0	0	0	0	0	0	0	0	10530
Condition at Karangkates Reservoir											
1	Volume of Reservoir	Million m^3	175	0	175	175	0	175	175	0	0
2	Spillway Reslease Discharge	Million m^3	1138	828	633	1138	828	633	1138	1002	458

Table 3. Trade Off Benefit between Irrigation and Energy (in Rupiah)

Alternative Strategy	Maximize Irrigation	Maximize Both	Maximize Energy
Energy Benefit	197.385.465.600	217.746.144.000	217.746.144.000
Irrigation Benefit	686.197.650.000	686.178.000.000	623.281.590.000
Total Benefit	**883.583.115.600**	**903.924.144.000**	**841.027.734.000**

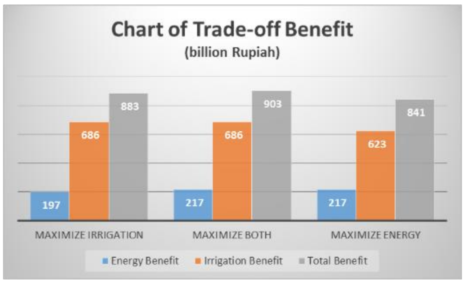

Figure 2. Trade-off Benefit

4. Conclusion

The optimizations are done by calculating from three strategies that are maximizing irrigation benefits, maximizing energy benefits, and maximizing both irrigation and energy benefits.

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