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Optimizing the Citra Raya Conservation Lake as Raw Material for Clean Water Treatment in the Citra Raya Residential Area, Tangerang

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ABSTRACT: In Tangerang, Indonesia, the Citra Raya residential area relies on three Citra Raya Conservation Lakes as sources for clean water production. The area experiences flooding when the lakes overflow during the rainy season. Conversely, during the dry season, community access to clean water is disrupted due to a decrease in water discharge. This research was conducted to determine the water balance and to improve water management in the three lakes. The water demand study was carried out based on the number of active consumers in 2020, with projections made up to 2025. Flow characteristics and a basic planning month approach were used to analyze water availability. Water balance analysis was applied to compare the availability of reliable discharge with demand as a basis for optimization. Optimization was performed using linear programming. The optimization results indicate that the raw water availability in the conservation lakes is sufficient to meet the clean water demand of the Citra Raya area on a monthly basis. However, practical issues such as pipe leaks and legal violations create challenges. These problems necessitate further research.

KEYWORDS: Water balance, Water management, linear program, Solver.

I. INTRODUCTION

Decent clean water is a basic human need, so increasing the sustainability of its availability must be prioritized to achieve Sustainable Development Goal (SDG) 6: Clean Water and Sanitation [1]. Effective water resource management is crucial to meet the daily demand for clean water in the community [2-5]. Along with the rapid growth of urban populations, the demand for clean water has increased, along with a rise in domestic wastewater. Advances in water resource engineering technology have made it possible to use wastewater as raw material to be processed and reused [6-8], such as at the conservation lake in the Citra Raya area of Tangerang, Indonesia.

The Citra Raya Conservation Lake serves as a source of raw water to provide clean water for residents in the Citra Raya housing complex. The conservation lake system comprises three lakes: Chimanceuri Lake, Kusuma Dwipa Lake, and WoW (Water of Wonder) Lake. Water from these three lakes is processed at Water Treatment Plant 2 (WTP 2) into clean water, which is then distributed to customers. The number of customers increases annually in line with the expansion of residential areas. During the rainy season, the lake water volume becomes abundant, necessitating drainage to ensure the lakes can accommodate rainwater and water flow from drainage channels, including domestic wastewater.

However, during the dry season, clean water production decreases, which negatively impacts customers. To consistently meet clean water needs, the volume of water managed must align with demand at all times. Optimization techniques are therefore essential in managing raw water and clean water resources [9-13]. This study aims to analyze the water balance and optimize the management of water resources from the three conservation lakes.

Our analysis involves calculating the clean water demand, assessing water availability in the lakes from rainwater and domestic wastewater, determining the mainstay discharge of lake water to be processed into clean water, and evaluating the volume of reservoir water available for optimization. We hope the findings of this study will provide alternative solutions for managing available water resources, ensuring the continuous fulfillment of clean water needs for the residents of the Citra Raya housing community.

II. RESEARCH METHOD

This research employs a case study approach, utilizing quantitative descriptive, analytical, and optimization methods aimed at evaluating conditions during a specific period as a basis for future predictions [14] to meet the community's clean water needs. The research stages include determining the study location, collecting data, processing and analyzing data, optimizing using linear programming, and conducting a comparative evaluation of the optimization model results with field conditions.

1. Study location

The study location is the Citra Raya Tangerang residential area, which spans 2,760 hectares. The clean water needs of the residents are met using raw water sourced from three conservation lakes: Chimanceuri, Kusuma Dwipa, and WoW

Lakes. This raw water is processed into clean water at Water Treatment Plant Sector 2 (WTP 2) and distributed to 51 clusters. A map of the study location, including the three lakes and WTP 2, is presented in Figure 1. Chimanceuri Lake is a newly developed lake, completed in 2020.

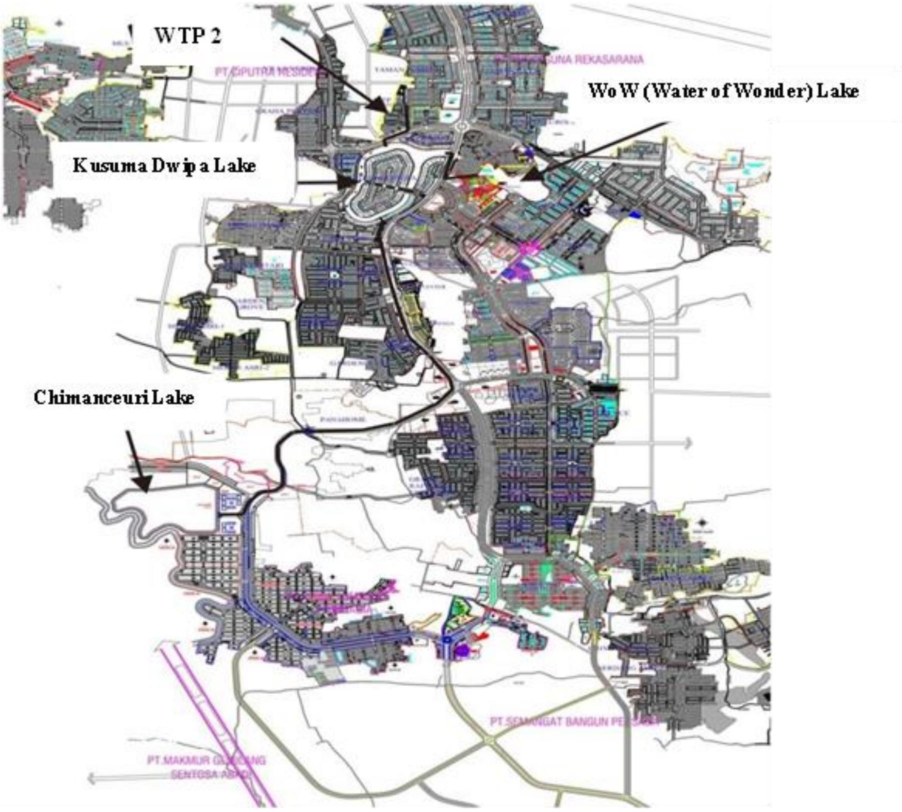

Figure 1. Study location

2. Data collection

The research data includes rainfall data, existing drainage channel dimensions, WTP 2 clean water production data, and clean water customer data in the Citra Raya Tangerang residential area. Rainfall data was obtained by mapping the distribution of rain station locations around the study area using the ArcGIS software application (see Figure 2). Figure 2 shows that only one rainfall station represents the study area, namely the Budiarto Curug rain station. Rainfall data for the period 2010–2019 was obtained from Meteorology, Climatology, and Geophysics Agency, as shown in Table 1.

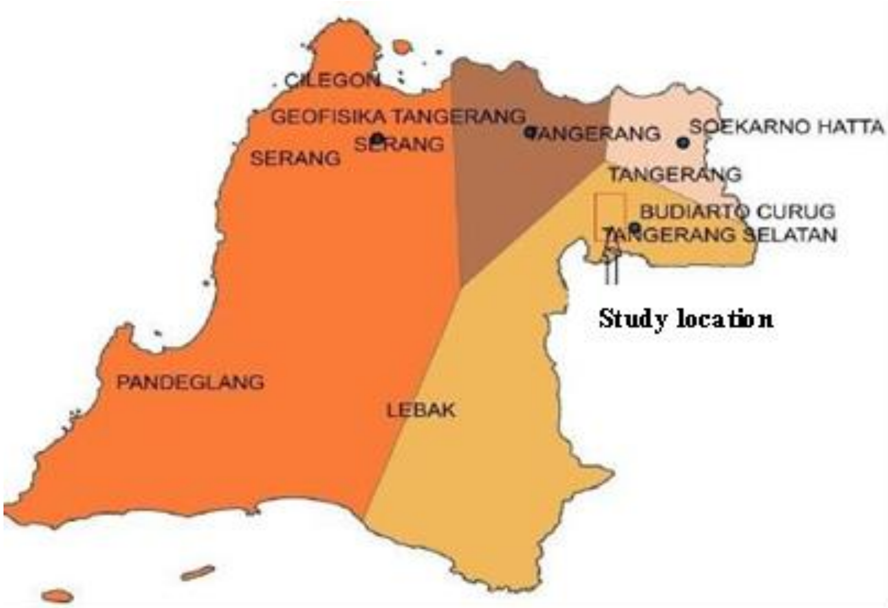

Figure 2. Rainfall Station Map

Table 1. Rainfall data of Budiarto Curug station (Meteorology, Climatology, And Geophysics Agency, 2020)

No.	Year	Rainfall (mm)
1	2010	70.80
2	2011	83.40
3	2012	120.00
4	2013	103.40
5	2014	86.00
6	2015	121.97
7	2016	103.50
8	2017	85.50
9	2018	78.00
10	2019	127.00

3. Data processing stages

The calculation and analysis stages are as follows:

- Calculate the number of active clean water customers at WTP 2 (data from Citra Raya Management).
- Calculate the total clean water needs of each customer (Qd),

$$Qd = Hc \times Wc \quad (1)$$

where Qd is the total need for clean water, Hc is a home connection (assumed = 6 people) and Wc is water consumption = 130 l/s.

- Frequency distribution analysis and suitability tests (Chi-Square and Smirnov Kolmogorof), followed by calculation of planned return period rainfall. Because the Cittra Raya residential area is 2760 ha (more than 500 ha) and is located in a metropolitan city, the planned rainfall calculation uses a return period of 25 years.
- Calculate rain intensity using the Mononobe method (I),

$$I = (R_{24}/24) \times (24/t)^{(2/3)} \quad (2)$$

Where I is rainfall intensity (mm/hour), is R24 maximum rainfall in 24 hours and t is the duration (hours).

- Calculate the rainwater runoff discharge, usually called the planned flood discharge (Q), using the rational method formula because the area of the study location is less than 300 km²,

$$Q = 0.278 \times C \times I \times A \quad (3)$$

Where Q is the planned flood discharge (l/s), C is the runoff coefficient depending on the type of soil or land use, I is the rainfall intensity (mm/hour) and A is the catchment area (ha).

- Calculate the volume of wastewater (Qr),

$$Qr = 80\% \times Qd \quad (4)$$

Where Qr is domestic wastewater discharge (l/s), Qd is clean water demand discharge (l/s).

- Calculate the mainstay discharge for water availability in the three lakes.
- Calculate the total need for clean water in the Citra Raya residential area.
- Water balance analysis, namely comparing available discharge with water demand discharge.
- Optimization with linear programming (using the solver application in Ms. Excel).
- Evaluate the results of the optimization model compared to events in the field.

III. RESULT AND DISCUSSION

1. Number of customers and clean water needs

Data on the number of customers was obtained from Citra Raya Management. The calculation of clean water needs uses 2020 data as the reference (Table 2). Based on Table 2, the total clean water demand in the Citra Raya residential area is 0.099 m³/s.

Table 2. Number of Customers and Clean Water Needs (Qd)

No.	Customer type	Hc (Year 2020)	Wc (l/day)	Qd (l/s)	Customer type	Qd (l/s)	Qd (m³/s)
1	General Social	18	3000	0.625	Social	0.688	0.001
2	Special social	3	1800	0.063	Domestic	66.518	0.067
3	Household-1	4675	600	32.465	Non-domestic	8.046	0.008
4	Household-2	1576	780	14.228	Water lose	23.52	0.024
5	Household-3	1373	780	12.395			
6	Household-4	823	780	7.43	Total	98.772	0.099
7	Medium commerce	968	600	6.722			
8	Large commerce	22	5200	1.324			

2. Analysis of frequency distribution and planned rainfall

Frequency distribution analysis was conducted using the Normal, Gumbel, Log-Normal, and Log-Pearson III distribution methods with rainfall data from the Budiarto Curug rain station (see Table 1). Based on the analysis, only the Log-Pearson III distribution meets the requirements (Table 3). Subsequently, a suitability test was performed using the Chi-Square method (Table 4) and the Kolmogorov-Smirnov method (Table 5). Chi-Square test, for DK = 2 and α = 5%, obtained X^2cr = 5,991 and X^2 test = 4,00. Due to X^2 test < $X2\ cr$, the Log Pearson III distribution is acceptable. In the Smirnov Kolmogorof test (table 5), the value obtained Δ Max = 0.12 and Δ Max = 0.409, due to Δ Max < Δ Max so the Log Pearson III distribution is accepted.

Table 3. Result of frequency distribution analysis

Distribution method	Requirement	Result	Conclusion
Normal	Cs=0	0.33	not ok
Gumbel	Cs≈1.14	0.33	not ok
	Ck≈5.40	33.17	not ok
Log-Normal	Cs=3Cv	0.14	not ok
Log Pearson III	-	-0.83	ok

Table 4. Result of Chi-Square test

Class	Fe	Ft	Fe - Ft	(Fe-Ft)²/Ft
< 76.645	3	2	1	0.5
76.645-81.887	1	2	-1	0.5
81.887-104.037	4	2	2	2
104.037-109.761	1	2	-1	0.5
> 109.76	1	2	-1	0.5

Table 5. Smirnov-Kolmogorov distribution fit test

No.	Year	P(X)	X	Log X	G	Pr (%)	Pt(X)	P(X) – Pt(X)
1	2014	0.091	65.70	1.818	-1.378	90.427	0.096	-0.005
2	2018	0.182	69.10	1.839	-1.149	86.663	0.133	0.049
3	2010	0.273	70.80	1.850	-1.038	84.691	0.153	0.12
4	2017	0.364	81.80	1.913	-0.382	58.454	0.415	-0.051
5	2011	0.455	83.40	1.921	-0.294	56.989	0.430	0.025
6	2012	0.546	99.00	1.996	0.484	42.625	0.574	-0.028
7	2016	0.636	103.50	2.015	0.686	34.26	0.657	-0.021
8	2013	0.727	103.40	2.015	0.682	33.898	0.661	0.066
9	2015	0.818	105.50	2.023	0.773	26.751	0.732	0.086
10	2019	0.909	127.00	2.104	1.615	1.734	0.983	-0.074

Based on the frequency distribution analysis and suitability test results, the planned return period rainfall calculation uses the Log-Pearson III distribution method. Since the Citra Raya area exceeds 500 hectares (Directorate of Drinking Water and Environmental Sanitation/PU PLP Cipta Karya, 2012) a return period of 25 years was chosen. Determine the planned rainfall for a 25-year return period (R25), with n = 10, the average rainfall = Rr = 90.2 mm, Sd = 19.86, Yt = 3.1985, Yn = 0.4952 and Sn = 0.9496:

$$Kt = \frac{Yt - Yn}{Sn} = \frac{3.1985 - 0.4952}{0.9496} = 2.88$$

$$Rt = Rr + (Kt \times Sd) \Rightarrow R25 = 90.92 + (2.88 \times 19.86) = 147\ mm$$

The study location is a residential area, so the runoff coefficient value, C = 0.4, means the amount of rain is effective (Reff) is:

$$Reff = C \times R25 = 0.4 \times 147 = 59\ mm$$

3. Planned flood discharge

The water stored in the three conservation lakes originates from rainwater as well as domestic and non-domestic wastewater flows. The volume of rainwater entering the lakes is calculated by determining the planned flood discharge based on frequency analysis of rainfall data [15–16]. The planned flood discharge is estimated using the maximum daily rainfall over a 25-year return period and is calculated using the Rational method. The results of the planned flood discharge calculations for the three lakes are presented in Table 6.

Table 6. Flood discharge plan for Chimanceuri, Kusuma Dwipa, and WoW lakes

Lake	A km²	S	G	Tr %	K	Log R24	R24	C	I	Q (m^3/s)
Chimanceuri	3.04	0.096	0.04	4	1.75	2.15	141.35	0.4	19.45	6.59
Kusuma Dwipa	1.07	0.096	0.04	4	1.75	2.15	141.35	0.4	19.45	2.3
WoW	2.96	0.096	0.04	4	1.75	2.15	141.35	0.4	19.45	6.4
									Total	15.29

4. Calculation of household waste as lake inflow discharge

Domestic and non-domestic wastewater from the Citra Raya residential area is directly channeled into the drainage system leading to the Citra Raya Conservation Lake. The volume of wastewater is estimated to be 80% of the clean water demand. The calculations of wastewater flowing into each lake are presented in Table 7.

Table 7. Water demand and wastewater at Kusuma Dwipa and WoW Lake

		Kusuma Dwipa Lake		WoW Lake	
No.	Customer type	Water demand (l/s)	Wastewater (m^3/s)	Water demand (l/s)	Wastewater (m^3/s)
1	General-social	0.625	0.00050	0.000	0.00000
2	Special-social	0.063	0.00005	0.003	0.00003
3	Domestic	28.443	0.02275	37.180	0.02974
4	Non-domestic	2.058	0.00165	5.963	0.00477
5	Large commerce	0.12	0.00009	1.940	0.00009
	Total	31.309	0.025	45.086	0.035

Table 7 shows that the wastewater flowing into Kusuma Dwipa Lake is 0.025 m^3/s, and into WoW Lake is 0.035 m^3/s. This calculation is based on 2020 data, so there is no wastewater flow into Chimanceuri Lake yet, as it is still under construction.

5. Reliable discharge in the lake

The reliability of water discharge in the lakes is analyzed to assess their capacity as raw water sources for clean water processing. According to Limantara [17], there are four methods for calculating reliable discharge: the minimum average discharge method, flow characteristics, basic planning year, and basic planning month. In this study, we use the basic planning month method by dividing discharge reliability into four conditions:

- Dry season water discharge, reliability is (355/365) x 100% = 97,3%.
- Low water flow, reliability is (275/365) x 100% = 75.3%.
- Normal water flow, reliability is (185/365) x 100% = 50.7%.
- Water flow is sufficient, reliability is (95/365) x 100% = 26%.
- To determine the reliability of raw water availability for each month, calculations were carried out using the four reliability conditions mentioned above, applied to the three conservation lakes. The results of the mainstay discharge calculations for each lake are presented in Table 8, while the total mainstay discharge is shown in Table 9.

Table 8. Reliability of discharge (Q reliable) at Chimanceuri, Kusuma Dwipa, and WoW Lake

Qreliable	Chimanceuri Lake				Kusuma Dwipa Lake				WoW Lake			
	97.3%	75.3%	50.7%	26.0%	97.3%	75.3%	50.7%	26.0%	97.3%	75.3%	50.7%	26.0%
January	0.76	1.69	2.36	3.11	0.29	0.62	0.85	1.11	0.77	1.68	2.33	3.06
February	1.2	1.63	2.39	3.34	0.44	0.6	0.86	1.19	1.2	1.62	2.36	3.28
March	1.1	1.77	2.28	2.97	0.41	0.64	0.82	3	1.11	1.76	2.25	2.93
April	0.17	0.92	1.81	3.15	0.08	0.35	0.66	1.13	0.2	0.93	1.8	3.1
May	0.47	1.53	2.46	3.63	0.19	0.56	0.89	1.29	0.49	1.52	2.43	3.56
June	0.66	1.33	1.85	2.61	0.26	0.49	0.67	0.94	0.68	1.33	1.84	2.58
July	0.01	0.33	1.24	2.97	0.03	0.14	0.46	1.07	0.04	0.36	1.24	2.93
August	0.04	0.37	0.91	1.92	0.04	0.15	0.34	0.7	0.08	0.39	0.92	1.9
September	0.01	0.43	1.32	2.55	0.03	0.18	0.49	0.92	0.05	0.45	1.32	2.52
October	0.01	0.11	0.87	1.73	0.03	0.13	0.33	0.63	0.05	0.34	0.89	1.71
November	0.08	1.32	3.51	6.72	0.05	0.49	1.25	2.37	0.12	1.32	3.45	6.57
December	0.12	0.36	2.14	3.49	0.07	0.38	0.77	1.25	0.15	1.03	2.12	3.43

Table 9. Calculation results of total reliable discharge (Qtot. reliable) for the three lakes

Qreliable	Qreliable total			
	97.30%	75.30%	50.70%	26.00%
January	1.82	3.99	5.54	7.28
February	2.84	3.85	5.61	7.81
March	2.62	4.17	5.35	8.9
April	0.45	2.2	4.27	7.38
May	1.15	3.61	5.78	8.48
June	1.6	3.15	4.36	6.13
July	0.08	0.83	2.94	6.97
August	0.16	0.91	2.17	4.52
September	0.09	1.06	3.13	5.99
October	0.09	0.58	2.09	4.07
November	0.25	3.13	8.21	15.66
December	0.34	1.77	5.03	8.17

Based on the calculation data above, if the discharge in the three lakes corresponds to the dry-season discharge (97.3% reliability), the water needs can be met. To ensure that the water needs of the Citra Raya residential community are fulfilled every month, we optimize the operation of the three lakes using a linear programming optimization model.

6. Analisis water balance

The water balance analysis in this study compares the amount of raw water available in the three conservation lakes to the clean water needs of the community in the Citra Raya residential area. This analysis also includes predictions of water availability and demand until 2025 (Table 10) and the water balance (Table 11).

Table 10. Results of debit calculations for availability and demand as well as predictions until 2025

Reliability	Q availability (m^3/s)						Q demand (m^3/s)					
(%)	2020	2021	2022	2023	2024	2025	2020	2021	2022	2023	2024	2025
97.30%	0.957	0.96	0.964	0.967	0.97	0.974	0.099	0.104	0.109	0.114	0.12	0.126
75.30%	2.436	2.439	2.442	2.446	2.449	2.453	0.099	0.104	0.109	0.114	0.12	0.126
50.70%	4.542	4.545	4.548	4.551	4.555	4.559	0.099	0.104	0.109	0.114	0.12	0.126
26.00%	7.611	7.614	7.617	7.62	7.624	7.628	0.099	0.104	0.109	0.114	0.12	0.126

Table 11. Water balance dan prediksi sampai tahun 2025

% Reliability	Water balance (m³/s) 2020	2021	2022	2023	2024	2025
97.30%	0.859	0.857	0.855	0.853	0.851	0.848
75.30%	2.337	2.336	2.334	2.332	2.329	2.327
50.70%	4.443	4.441	4.439	4.437	4.435	4.433
26.00%	7.512	7.51	7.508	7.506	7.504	7.502

7. Optimizing the demand and availability of clean water

Optimization is a process aimed at achieving ideal results. In this study, we use a linear programming optimization technique, specifically the Solver tool in Microsoft Excel. The water demand issue in the Citra Raya Tangerang housing complex arises during the dry season when the water flow supplied to residents' houses decreases. The clean water requirement in the Citra Raya area is 0.156 m³/sec, and the total storage capacity of the three lakes is 917,687 m³. Therefore, it is necessary to determine the raw water allocation for each lake to produce clean water every month.

As an example of optimization calculations, we use a reliability value of 97.3% and data on clean water needs from January 2020. The formulation of variables, objectives, and constraints is based on the results of previous calculations, as outlined below:

- Variabel function: X1 = Chimanceuri Lake, X2 = Kusuma Dwipa Lake, X3 = WoW Lake
- The reliable discharge is 97.3% for each lake, namely: 0.76 m³/s, 0.29 m³/s, and 0.77 m³/s, the maximum capacity for each lake is 593793 m³, 147685 m³, and 176209 m³, while the need for clean water in January is 0.099 m³/s.
- Objective function: Max = (593793 x X1) + (147685 x X2) + (176209 x X3)
- Constraint: $X1 + X2 + X3 = 0.99$, $X1 \leq 0.76$, $X2 \leq 0.29$, $X3 \leq 0.77$

Solving the values for variables X1, X2, and X3 is done using the solver program as follows:

January	Qreliability = 97.3%	Qdemand total	
Constraint:			X1 0.099 X2 0.000 X3 0.000
X1+X2+X3	= 0.099	0.099 <= 0.156	
X1	<= 1.196	0.099	
X2	<= 0.443	0.000	
X3	<= 1.108	0.000	

Maximum = 593793 × X1 + 147685 × X2 + 176209 × X3 = 58647.46 ⇒ raw water requirements for clean water production (m³).

A recapitulation of optimization calculations is shown in table 12.

Table 12. Results of optimizing raw water availability and clean water demand

Month	Q-Clean water demand (m³/s)	Q-Raw water availability Chimanceuri (m³/s)	Q-Raw water availability Kusuma Dwipa (m³/s)	Q-Raw water availability WoW (m³/s)	Q-Raw water production Chimanceuri (m³/s)	Q-Raw water production Kusuma Dwipa (m³/s)	Q-Raw water production WoW (m³/s)	Total raw water requirement (m³)	Lake capacity (m³)
January	0.0988	1.1956	0.4433	1.1083	0.0988	0.0000	0.0000	58647.46	Ok
February	0.0988	0.7571	0.2899	0.7720	0.0988	0.0000	0.0000	58647.46	Ok
March	0.0988	1.1030	0.4109	1.1083	0.0988	0.0000	0.0000	58647.46	Ok
April	0.0988	0.0841	0.2001	0.1687	0.0000	0.0000	0.0988	58647.46	Ok
May	0.0988	0.1888	0.4911	0.4681	0.0000	0.0000	0.0988	58647.46	Ok
June	0.0988	0.2560	0.6780	0.6603	0.0000	0.0000	0.0988	58647.46	Ok
July	0.0988	0.0439	0.0081	0.0279	0.0449	0.0081	0.0279	16834.80	Ok
August	0.0988	0.0777	0.0428	0.0400	0.0560	0.0000	0.0000	35268.60	Ok
September	0.0988	0.0496	0.0139	0.0299	0.0505	0.0139	0.0299	21569.39	Ok
October	0.0988	0.0137	0.0298	0.0494	0.0137	0.0428	0.0504	21426.66	Ok

November	0.0988	0.0846	0.0546	0.11830.0329	0.0329	0.032930212.54	Ok
December	0.0988	0.1159	0.0656	0.14870.0988	0.0000	0.000058647.46	Ok

Table 12 indicates that the availability of raw water in the conservation lakes is sufficient to meet the clean water needs of the Citra Raya Tangerang area each month. However, several field issues, such as leaks in pipe networks, illegal connections, and unregistered usage, result in a shortage of clean water. Below, we present Table 13, which contains clean water usage reports from the Citra Raya Tangerang management as material for further research analysis.

Table 13. WTP 2 report in January 2020

No	WTP 2 monthly report	Volume (m^3)
1	Raw water production	299140
2	Water used for cleaning	74362
3	Water distribution recorded by the WTP 2 water meter	224778
4	Total water distributed to customers from WTP 2	224778
5	Water recorded on the customer's water meter	200000
6	Draining water for cleaning	2500
7	Water usage for company facilities	25350
8	Total water usage	227850

Table 13 shows that the raw water production of WTP 2 Citra Raya is 299,140 m^3, the clean water distributed to customers is 224,778 m^3, the volume recorded in customer water meters is 200,000 m^3, and the clean water used for company facilities amounts to 227,850 m^3. Based on the production and usage data, there is a water shortage of 3,072 m^3, caused by insufficient clean water production. Additionally, the Word of Wonder (WoW) lake cannot accommodate its maximum capacity because commercial areas within its vicinity would experience disruptions if the lake's water level is too high.

IV. CONCLUSIONS

The issue of clean water shortages in the Citra Raya area during the dry season is not due to a lack of raw water from the conservation lakes but rather other contributing factors. This study has demonstrated through calculations, analysis, and linear programming optimization modeling (Solver) that the raw water capacity in the conservation lakes is sufficient to meet the clean water production needs every month. If, in practice, clean water shortages still occur during the dry season, this represents a specific issue that requires further integrated research.

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