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Investment Analysis of a Lake Water Treatment System Into Drinking Water and Design of the Lake Water Management Supply Chain at MAN IC Paser, East Kalimantan

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Abstract**—** The availability of safe and sustainable drinking water is a vital necessity for boarding educational institutions. Madrasah Aliyah Negeri Insan Cendekia (MAN IC) Paser faces limitations in the quantity and continuity of clean water supply from external providers, while at the same time possessing a potential surface water source in the form of a lake with a large storage volume. However, the quality of the lake water does not yet meet drinking water standards, as indicated by high turbidity levels and potential microbiological contamination. This study aims to design a lake water treatment system into drinking water that complies with the Indonesian Ministry of Health Regulation No. 492 of 2010, as well as to design an efficient and sustainable water management supply chain and ecosystem. The research methods include raw water quality analysis, jar test experiments using several types of coagulants, the design of a water treatment plant (WTP) employing a conventional treatment system, and supply chain analysis based on a systems thinking approach. The results show that a complete water treatment system consisting of presedimentation, coagulation–flocculation, sedimentation, filtration, and disinfection is able to reduce turbidity to meet drinking water quality standards. In addition, the integrated supply chain design supports the operational sustainability of drinking water provision within the MAN IC Paser environment. This study is expected to serve as a model for drinking water self-sufficiency based on local resources in educational institutions.

*Keywords***—** lake water, drinking water treatment, water treatment plant, supply chain, sustainability.

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I. INTRODUCTION

Clean water and drinking water are basic human needs. The availability of safe drinking water is not only a public health issue but also an important indicator of sustainable development [1]. The United Nations, through the Sustainable Development Goals (SDGs), particularly Goal 6, targets the achievement of universal access to clean water by 2030. However, to date, many regions still face serious challenges in providing adequate drinking water [2].

The problem of drinking water provision in Indonesia has become increasingly complex along with population growth and the intensification of socio-economic activities. High dependence on groundwater as the primary source of drinking water has led to various environmental impacts. This condition highlights the need for diversification of raw water sources, one of which is through the utilization of surface water. Surface water has great potential in terms of quantity, but generally requires treatment before it can be used as drinking water because it is vulnerable to pollution [3], [4], [5].

As a boarding educational institution, Madrasah Aliyah Negeri Insan Cendekia (MAN IC) Paser has relatively high and continuous water demands. Inadequate water availability or water that does not meet quality standards can directly affect students' health. In the context of a madrasah, water quality also has a religious dimension, as water used for ritual purification must meet the principles of purity and cleanliness [6], [7], [8].

To date, MAN IC Paser still faces limitations in meeting its clean water needs from external providers. Dependence on water sources outside the school area creates vulnerability to supply disruptions. On the other hand, the MAN IC Paser area has the potential of a surface water resource in the form of a lake with a relatively large storage volume and located close to the area of consumption. The existence of this lake has the potential to be utilized as an independent raw water source to enhance the school's water security.

Figure 1. MAN IC Paser Lake

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Nevertheless, the utilization of lake water as a drinking water source cannot be carried out directly without adequate treatment processes. Initial observations and preliminary testing indicate that the lake water at MAN IC Paser has a relatively high turbidity level, at approximately 30 NTU, which far exceeds the maximum allowable turbidity for drinking water set by the Regulation of the Minister of Health of the Republic of Indonesia No. 492 of 2010, namely 5 NTU. In addition to turbidity, the characteristics of surface water in East Kalimantan are generally influenced by local geological and environmental conditions, such as the presence of peatlands and relatively high natural organic matter content, which can affect pH levels and the effectiveness of disinfection processes [9], [10], [11].

High turbidity in lake water poses health risks if used without proper treatment. Moreover, from an operational perspective, raw water with fluctuating quality requires a carefully designed treatment system to ensure the consistent production of drinking water that meets quality standards [12], [13], [14].

However, the success of drinking water provision is not determined solely by technical treatment aspects. System sustainability is strongly influenced by how the water management supply chain is designed and operated, including the availability of treatment chemicals, energy supply, human resources, as well as distribution and maintenance systems. Without an efficient and integrated supply chain design, water treatment systems are at risk of operational disruptions that may ultimately hinder the continuity of drinking water services.

Based on this background, this study focuses on the design of a lake water treatment system at MAN IC Paser to produce drinking water that meets national quality standards, as well as on the design of a water management supply chain that supports the operational sustainability of the system. An integrative approach combining technical and managerial aspects is expected to result in a reliable, sustainable, and replicable model of drinking water provision based on local resources for boarding educational institutions or other areas with similar characteristics.

II. METHOD

This study employs an engineering design approach and descriptive–quantitative analysis to design a lake water treatment system for drinking water production as well as a sustainable water management supply chain system. The study is classified as applied research, focusing on solving real-world problems through the design of technical and managerial systems. The approaches used include: a technical approach to analyze raw water quality and design the water treatment plant (WTP) based on standard design criteria; a managerial approach to design a water management supply chain that supports the operational sustainability of the system; and a systems thinking approach to integrate technical aspects and the supply chain into a comprehensive drinking water supply system.

The research was conducted in the area of Madrasah Aliyah Negeri Insan Cendekia (MAN IC) Paser, East Kalimantan, with a focus on MAN IC Paser Lake as the raw water source. Field data collection and laboratory testing were carried out during the research period in accordance with the existing operational conditions of the school.

The data used in this study consist of primary and secondary data. Primary data include the results of lake water quality measurements (physical, chemical, and microbiological parameters), jar test results to determine the optimum type and dosage of coagulant, and data on water demand and operational conditions at MAN IC Paser. Secondary data include standards and regulations related to drinking water quality (Regulation of the Minister of Health of the Republic of Indonesia No. 492 of 2010), technical literature on water treatment plant design, and references related to supply chain management and sustainable systems.

Raw water quality analysis was conducted to determine the initial characteristics of water from MAN IC Paser Lake as the basis for designing the treatment system. The parameters analyzed included physical parameters consisting of turbidity, color, temperature, and total dissolved solids (TDS); chemical parameters including pH, iron (Fe), manganese (Mn), hardness, and chemical oxygen demand (COD); and microbiological parameters such as Total Coliform and *Escherichia coli*. The results of the raw water quality analysis were compared with drinking water quality standards based on the Regulation of the Minister of Health of the Republic of Indonesia No. 492 of 2010 to determine the required treatment processes.

Coagulation tests were conducted to determine the most effective type and dosage of coagulant in reducing lake water turbidity. The coagulants tested included polyaluminum chloride (PAC), alum (aluminum sulfate), and ferrous sulfate at various dosage levels. The main evaluation parameters in this test were turbidity reduction, floc formation, and water clarity.

Furthermore, data from the layout design and process flow were analyzed to assess the integration of the treatment system and operational efficiency. Supply chain analysis was carried out using a qualitative–descriptive approach through the mapping of upstream, internal, and downstream components, as well as the identification of stakeholder roles and influences in the management of the water treatment plant (WTP). Financial analysis was conducted by calculating projected revenues, operational costs, and net profit to evaluate the economic feasibility of the system.

III. RESULTS AND DISCUSSION

Table 1 shows that the turbidity and color parameters of the water were identified to exceed the required threshold values, namely greater than 5 NTU and 15 TCU, respectively, indicating that they do not meet the drinking water criteria.

TABLE 1.
SUMMARY OF RAW WATER PARAMETERS OF MAN PASER LAKE

Parameter Group	Parameter	Test Method (SNI / APHA)	Sample Container	Preservation & Storage	Drinking Water Quality Standard Reference
Physical	Turbidity	SNI 6989.25:2005 / APHA 2130 B	Plastic/glass bottle	Analyzed immediately, ±4°C	≤ 5 NTU
	Color	SNI 6989.80:2011 / APHA 2120 B	Plastic/glass bottle	Analyzed immediately	≤ 15 TCU
	TDS	SNI 6989.27:2005 / APHA 2540 C	Plastic bottle	±4°C	≤ 500 mg/L
Chemical	pH	SNI 6989.11:2019 / APHA 4500-H^+ B	Plastic bottle	Analyzed directly	6.5 – 8.5
	COD	SNI 6989.73:2009 / APHA 5220 C	Plastic bottle	H_2SO_4, ±4°C	≤ 10 mg/L*
	Heavy metals (Fe, Mn, Pb, etc.)	SNI 6989 metal series / APHA 3111	Plastic/glass bottle	HNO_3 pH < 2, ±4°C	In accordance with Permenkes 492/2010
Microbiological	Total Coliform	SNI 6774:2008 / APHA 9222 B	Sterile bottle	±4°C, ≤ 24 hours	0 /100 mL
	E. coli	SNI 2897:2008 / APHA 9222 G	Sterile bottle	±4°C, ≤ 24 hours	0 /100 mL

* Note: COD values for drinking water are not always explicitly stated in the regulation; however, COD is used as an indicator of organic load in raw water for treatment design purposes.

Meanwhile, the total dissolved solids (TDS) value remains below the maximum limit of 500 mg/L and complies with the established standard. For chemical parameters, the pH value falls within the permissible range of 6.5–8.5, whereas the measured COD concentration exceeds the threshold value of 10 mg/L, indicating the presence of organic matter in the raw water. For heavy metal parameters such as Fe and Mn, the test results show concentrations that are still within safe limits according to the Regulation of the Minister of Health of the Republic of Indonesia No. 492 of 2010. However, the microbiological test results indicate the presence of Total Coliform and *Escherichia coli*, which do not meet the drinking water criteria of 0 per 100 mL. Overall, these results indicate that the lake water at MAN IC Paser is not suitable for direct use as drinking water and requires treatment processes to meet the applicable drinking water quality standards.

TABLE 2.
COAGULATION TEST

Coagulant Type	Dosage Range	Description
Fero Sulfat ($FeSO_4$)	10 - 60 mg/L	Effective for water with high pH
Tawas ($Al_2(SO_4)_3$)	10 - 60 mg/L	Conventional and economical coagulant
PAC (Poly Aluminium Chloride)	10 - 60 mg/L	Efficient, produces less sludge

Table 2 shows that all three coagulants tested were effective within a dosage range of 10–60 mg/L in the lake water treatment process. Ferrous sulfate demonstrated optimal performance under conditions of relatively high pH, while alum, as a conventional coagulant, produced stable results with advantages in terms of availability and cost. PAC exhibited higher efficiency compared to the other coagulants, as indicated by effective performance at relatively lower dosages and the production of less sludge. These findings indicate that PAC is the most suitable coagulant for the MAN IC Paser lake water treatment system, particularly in supporting operational efficiency and facilitating the management of sludge generated from the coagulation process.

TABLE 3.
RESULTS OF THE DESIGN OF WATER TREATMENT PLANT UNITS FOR MAN IC PASER LAKE

No.	Unit	Dimensions	Volume/Area	Detention Time
1	Screen	0.3 m × 0.4 m	–	–
2	Coagulation	1.6 × 1.6 × 1.8 m	3.6 m³	2 minutes
3	Flocculation	7.5 × 2.4 × 3.5 m	54 m³	30 minutes
4	Sedimentation	19 × 4.7 × 4.5 m	346 m³	3.2 hours
5	Rapid Sand Filter (3 units)	2.5 × 2.5 × 3.8 m	6.25 m²	10 minutes
6	GAC Filter (3 units)	3.5 × 3.5 × 3.1 m	12.25 m²	15 minutes
7	Chlorine Contact Tank	18 × 2 × 1.5 m	54 m³	30 minutes
8	Reservoir	9 × 9 × 4.5 m	300 m³	4.2 hours
9	Backwash Tank	Ø 4 × 5.5 m	68 m³	–

Table 3 shows that the coagulation and flocculation units have detention times of 2 minutes and 30 minutes, respectively, which are sufficient for effective floc formation. The sedimentation unit is designed with a detention time of 3.2 hours to ensure the settling of suspended particles, while the rapid sand filtration and granular activated carbon filtration systems have detention times of 10 and 15 minutes, respectively, to enhance water clarity and organoleptic quality. The chlorine contact tank, with a detention time of 30 minutes, is designed to ensure effective disinfection, while the reservoir functions as a buffer with a detention time of 4.2 hours to maintain the continuity of drinking water supply.

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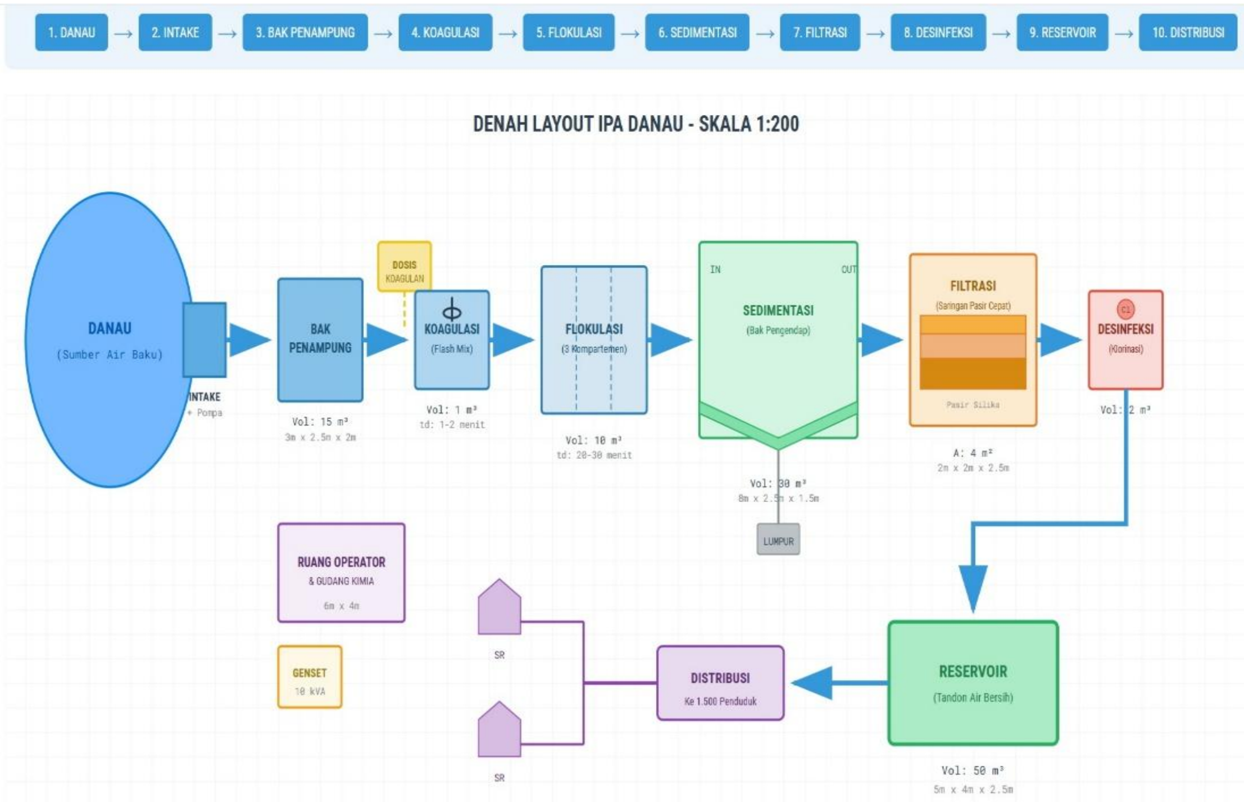

Figure 2. Process Flow Diagram and Layout of the Water Treatment Plant (WTP) for MAN Paser Lake

The layout design of the Water Treatment Plant (WTP) shown in Figure 2 indicates that the total area required for the process units reaches 545 m², which includes the intake and screening unit, coagulation–flocculation, sedimentation, rapid sand filtration, granular activated carbon filtration, disinfection, reservoir, as well as supporting facilities such as the pump room, operator and laboratory rooms, chemical storage, and sludge handling facilities. By considering a circulation area requirement of 40%, the land area increases to 763 m², and with the addition of landscaping and a buffer zone of 30%, the total operational land requirement reaches approximately 992 m², or close to 1,000 m² (0.1 ha). To ensure safety factors, operational convenience, and the potential for future capacity expansion, the recommended land requirement ranges from 1,500 to 2,000 m², equivalent to 0.15–0.2 ha.

TABLE 4.
MAIN COMPONENTS OF THE SUPPLY CHAIN

Component	Description	Related Elements
Upstream	Procurement of resources and raw materials for WTP operations	Lake, chemical suppliers, equipment suppliers, electrical energy
Midstream (Internal)	Water treatment process from raw water to clean water	WTP units, operator human resources, monitoring system, quality control
Downstream	Distribution of clean water to consumers and customer management	Pipeline network, house connections, billing system, customer services

Table 4 shows that the water supply system at MAN IC Paser is composed of three main components consist of upstream, internal (midstream), and downstream which together form an integrated operational flow. In the upstream segment, the availability of lake water as the raw water source, support from chemical and equipment suppliers, and the supply of electrical energy are the key elements sustaining the continuous operation of the water treatment plant. The internal component encompasses the entire water treatment process within the WTP units, supported by operator human resources, monitoring systems, and quality control mechanisms to ensure the quality of the treated water. Meanwhile, in the downstream segment, the water distribution system through pipeline networks, connections to users, and service mechanisms are critical factors in ensuring that clean water is delivered continuously to consumers.
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TABLE 5.
STAKEHOLDER MAP

Stakeholder	Role	Interest	Level of Influence
Local Government	Regulator, licensing authority, supervisor	Public service provision, regulatory compliance	High
Community / Customers	Clean water consumers	Access to clean water, affordable pricing	High
WTP Management	Operator, manager	Operational sustainability, profitability	High
Chemical Suppliers	Providers of coagulants and disinfectants	Long-term contracts, timely payment	Medium
PLN (State Electricity Company)	Electricity provider	Timely payment	Medium
Financial Institutions	Capital/credit providers	Return on investment	Medium
Laboratory	Water quality testing	Periodic testing contracts	Low
Community Around the Lake	Guardians of water source sustainability	Compensation, environmental conservation	Medium

Table 5 shows that the management of the water treatment system at MAN IC Paser involves various stakeholders with different levels of roles, interests, and influence. The local government, the community as customers, and WTP management have a high level of influence because they are directly involved in regulatory aspects, service utilization, and the operational sustainability of the system. Chemical suppliers, electricity providers, financial institutions, and the communities around the lake have a medium level of influence, with interests focused on continuity of cooperation, fulfillment of contractual obligations, and conservation of the water source. Meanwhile, the water quality testing laboratory has a relatively low level of influence and serves as a technical support entity in ensuring compliance with water quality standards. The pattern of relationships among stakeholders is built on principles of partnership and mutual benefit, with WTP management acting as the central coordinator that connects all actors within the water treatment ecosystem to ensure the technical, economic, and environmental sustainability of the system.

TABLE 6.
TREATMENT PROCESS FLOW AT THE MAN PASER LAKE WATER TREATMENT PLANT (WTP)

No.	Process Unit	Function	Process Time
1	Intake	Abstraction of raw water from the lake	Continuous
2	Presedimentation	Settling of coarse particles	1.5 hours
3	Coagulation	Mixing of coagulant (PAC)	30–60 seconds
4	Flocculation	Formation of flocs	20–30 minutes
5	Sedimentation	Settling of flocs	2–3 hours
6	Filtration	Removal of fine particles	Continuous (backwash once/day)
7	Disinfection	Inactivation of microorganisms	30-minute contact time
8	Reservoir	Storage of treated water	Capacity 70 m³

Table 6 shows that each process unit has a specific function and processing time that mutually support one another. The presedimentation stage, with a detention time of 1.5 hours, is intended to reduce the load of coarse particles. This is followed by coagulation with a mixing time of 30–60 seconds using PAC as the coagulant, and flocculation for 20–30 minutes to allow the formation of stable flocs. The sedimentation process is designed with a detention time of 2–3 hours to ensure optimal settling of flocs, followed by filtration that operates continuously with a backwash frequency of once per day. The disinfection stage has a contact time of 30 minutes to ensure effective inactivation of microorganisms, while the reservoir, with a capacity of 70 m³, functions as a buffer to maintain the continuity of clean water supply.

TABLE 7.
CUSTOMER SEGMENTATION

Segment	Number of Service Connections (SC)	Average Consumption	Characteristics
Households	2,100	15–20 m³/month	Main customers, domestic needs
Small Businesses	120	25–40 m³/month	Stalls, shops, workshops
Public Facilities	30	30–50 m³/month	Schools, health centers, mosques

The results of the downstream supply chain analysis in Table 7 show that customers of the MAN IC Paser Lake WTP clean water service are divided into three main segments: households, small businesses, and public facilities, each with different consumption characteristics. The household segment represents the largest group of users, with 2,100 service connections and an average consumption of 15–20 m³ per month, reflecting the dominance of domestic needs within the water distribution system. The small business segment, consisting of stalls, shops, and workshops, has a smaller number of customers but exhibits relatively higher water consumption per connection, ranging from 25–40 m³ per month. Meanwhile, public facilities such as schools, health centers, and mosques have the fewest customers but the highest consumption levels, at 30–50 m³ per month, reflecting their public service functions with intensive water demand.

Monthly Revenue Projection

The projection results indicate that, assuming 350 active household service connections, 20 commercial customers, and 5 social customers, with an average household consumption of 17 m³/month and a collection rate of 90%.

TABLE 8.
PROJECTION OF MONTHLY REVENUE AND OPERATIONAL COSTS

Revenue Component	Quantity	%	Calculation	Amount (IDR)
Household subscription (350 × IDR 10,000)			2100 × 10.000	21.000.000
Household usage Block A (350 × 10 × IDR 3,000)			2100 × 10 × 3.000	63.000.000
Household usage Block B (350 × 7 × IDR 4,500)			2100 × 7 × 4.500	66.150.000
Commercial subscription + usage			120 × (15.000 + 30×7.500)	28.800.000
Social subscription + usage			30 × (5.000 + 40×2.500)	3.150.000
Total Gross Revenue			-	182.100.000
Collection rate 90%			× 90%	163.890.000
Net Revenue			-	163.890.000
Cost Component				
Employee salaries (5 persons)	18.000.000	72%		
Electricity	3.500.000	14%		
Chemicals	2.500.000	10%		
Maintenance & repairs	1.500.000	6%		
Administration & miscellaneous	500.000	2%		
Total Operational Costs	25.000.000	100%		

Table 8 shows that the water management system generates a monthly gross revenue of IDR 182,100,000 and a net revenue of IDR 163,890,000. The largest contribution to revenue comes from the household segment through a combination of subscription fees and water consumption in Block A and Block B. On the cost side, the total monthly operational cost is projected at IDR 25,000,000, with the largest component being employee salaries (72%), followed by electricity costs (14%) and chemical costs (10%). Accordingly, the difference between net revenue and total operational costs indicates an operational net profit of IDR 138,890,000 per month.

Discussion

The results of this study indicate that the characteristics of raw water from MAN IC Paser Lake require the implementation of a complete conventional surface water treatment system in order to meet clean water standards. The potentially fluctuating physical, chemical, and microbiological conditions of the lake water reinforce the need for integrated stages of coagulation, flocculation, sedimentation, filtration, and disinfection. These findings are in line with various previous studies stating that raw water from lake or reservoir sources requires a full treatment train to ensure the stability of treated water quality [15], [16], [17].

The coagulation test results show that ferrous sulfate, alum, and PAC are all effective within a dosage range of 10–60 mg/L. However, PAC offers advantages in terms of process efficiency and the volume of sludge produced. This interpretation is consistent with previous research reporting that PAC tends to require lower effective dosages and produces more compact flocs compared to conventional coagulants [18], [19], [20].

The design of the WTP process units indicates that the dimensions and detention times of each unit fall within the ranges recommended in the surface water treatment literature. The detention times for the coagulation, flocculation, and sedimentation units are designed to ensure the formation of stable flocs and optimal settling processes, while the filtration and disinfection units function as safeguards for the final water quality. These results are consistent with previous studies concluding that appropriate detention times are a key factor in ensuring the effectiveness of conventional water treatment systems, particularly for surface water sources with variable turbidity levels and organic loads [21], [22], [23].

From a layout perspective, the calculation of land requirements shows that the WTP can be operated effectively on an area of approximately 1,000 m², with a recommendation to provide up to 1,500–2,000 m² to account for safety factors and future expansion. This approach aligns with small- to medium-scale WTP design practices that emphasize the importance of circulation space, buffer zones, and expansion flexibility [24], [25].

The integration of supply chain analysis shows that the success of WTP management is determined not only by technical treatment aspects but also by the coherence among upstream, internal, and downstream components. On the upstream side, the sustainability of raw water supply, chemicals, and energy is a key factor in ensuring operational stability. Internally, the effectiveness of process flows and the competence of human resources directly influence the quality of treated water. Meanwhile, on the downstream side, customer segmentation and distribution systems determine the level of service utilization and long-term sustainability. These findings are consistent with previous studies emphasizing that a supply chain approach in clean water management can enhance efficiency and system resilience to operational disruptions [26], [27], [28].

Stakeholder mapping indicates that WTP management acts as a central coordinator linking local government, the community as customers, suppliers, and the communities surrounding the lake. Partnership-based and mutually beneficial relationships are critical in maintaining system sustainability. These results are consistent with earlier studies stating that active stakeholder involvement has a significant influence on the success of clean water supply system management [29], [30], [31].

From a financial perspective, the results of the study show that the water management system generates a monthly net revenue that significantly exceeds operational costs, resulting in a positive operational net profit. This condition indicates that the designed WTP is economically feasible and has the potential to operate independently in the long term. These findings are consistent with previous studies stating that local-scale water supply systems can be financially sustainable when tariff structures, collection rates, and operational efficiency are well managed [32], [33].

Overall, the discussion results demonstrate that integrating technical WTP design with supply chain analysis and financial feasibility provides a more comprehensive approach compared to previous studies that tend to focus solely on technical aspects. Although this study is still limited to the design and analytical stages, the findings offer both theoretical and practical contributions to the development of efficient, adaptive, and sustainable clean water management models, and open opportunities for further research at the implementation and operational performance evaluation stages.

IV. Conclusion

This study concludes that the design of a lake-based Water Treatment Plant (WTP) at MAN IC Paser is technically, operationally, and financially feasible. The characteristics of the raw water require an integrated conventional surface water treatment system, with PAC identified as the most efficient coagulant within the tested dosage range. The design of process units, detention times, and the WTP layout meets design criteria and enables sustainable operation. The integration of supply chain analysis and stakeholder mapping indicates that WTP management requires strong coordination among actors from upstream to downstream. Furthermore, the financial analysis demonstrates a positive operational net profit, confirming that the proposed system is not only capable of meeting clean water needs but also has the potential to operate independently and sustainably in the long term.

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