JPPIPA 11(6) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Design of Clean Water Treatment Installation and Estimation of Capex and Opex in Aek Natonang Lake, Samosir Regency

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Received: April 23, 2025
Revised: May 15, 2025
Accepted: June 25, 2025
Published: June 30, 2025

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DOI: 10.29303/jppipa.v11i6.11137

Abstract: According to the national target, the community must have clean water so that planning for a clean water treatment plant that will serve the sub-district is needed. The clean water used must be in accordance with the Regulation of the Minister of Health of the Republic of Indonesia Number 32/MENKES/2017 concerning Clean Water Quality Requirements. Therefore, raw water is studied in the laboratory and the results of this laboratory are the main consideration for the need for a new clean water treatment plant to improve clean water services. One of the Clean Water Treatment Plant plans is Lake Aek Natonang which is located in Tanjungan Village, Simanindo District. The processing units designed are the intake unit, pre-sedimentation unit, coagulation unit, flocculation unit, sedimentation unit, filtration unit, disinfection and reservoir. In the intake unit, it consists of a pipe carrying raw water to the pre-sedimentation unit. The coagulation unit used is hydraulic coagulation using PAC as a coagulant. The flocculation unit is designed as a hydraulic system with Polymer as a flocculant. The sedimentation unit uses a reservoir with a sedimentation zone. The disinfectant used is chlorine which is directly flowed into the reservoir unit through a pipe. Based on Capex and Opex calculations, this Clean Water Treatment Plant requires a cost of Rp. 725,635,415 and the operation of this installation requires a cost of Rp. 13,150,450/month.

Keywords: Aek natonang lake; Clean water; Clean water treatment; Raw water

Introduction

Clean water is a primary need for humans and other living things, but currently there has been a phenomenon of clean water scarcity due to the uneven distribution of clean water services to the community (Ejiohuo et al., 2025; Shehu & Nazim, 2022; Du Plessis, 2022). Clean water used daily must comply with applicable standards, namely according to the Regulation of the Minister of Health of the Republic of Indonesia Number 32/MENKES/2017 concerning Clean Water Quality Requirements (Sudia et al., 2021). To obtain clean water that meets standards, it is necessary to carry out a raw water treatment process through a clean water treatment installation that will process raw water into clean water that meets standards (Silva, 2023; Cescon & Jiang, 2020; Pakharuddin et al., 2021). The government is encouraging the development of the clean water sector by completing its legal and regulatory instruments and then using them as a basis for implementing strategic policies (George-Williams et al., 2024; Naruetharadhol et al., 2024). Indonesian National Standard (SNI) Number 6728.1 - 2015 concerning the Compilation of Spatial Balance of Natural Resources - Part 1: Water Resources states that the average water requirement for a person per liter per day is reasonably 90 liters for all their needs (Vanham, 2020; Martínez Moscoso et al., 2018).

Samosir Regency is one of the regencies in North Sumatra Province with an area of 2.069.05 km2 and a

How to Cite:
Situmorang, M. T. N. (2025). Design of Clean Water Treatment Installation and Estimation of Capex and Opex in Aek Natonang Lake, Samosir Regency. *Jurnal Penelitian Pendidikan IPA*, *11*(6), 314-323. https://doi.org/10.29303/jppipa.v11i6.11137

population of 141.333. Until now, the provision of clean water for the community in Samosir Regency is still faced with several problems, one of which is the low level of service and production of clean water so that the community is very dependent on rainfall and springs (Harianja et al., 2021; Eriza et al., 2024; Eriza et al., 2024). One area that has not been served is Simanindo District. According to the national target, the Indonesian people must have clean water so that planning for a Clean Water Treatment Plant is needed that will serve all sub-districts in Samosir Regency. The raw water to be processed comes from Lake Aek Natonang.

Based on the background above, a study was conducted on the Design of Clean Water Treatment Installation and Estimation of Capex and Opex in Aek Natonang Lake, Samosir Regency.

Method

Planning Framework

The planning framework is prepared to describe the stages in planning systematically and sequentially. This planning framework is presented as follows:

Planning Idea

Design of Clean Water Treatment Plant in Lake Aek Natonang, Samosir Regency. Literature Study of Clean Water Quality Standards in Indonesia; Study of Raw Water Sources; Design Concept of Clean Water Treatment Units; Construction and Operation Costs of Clean Water Treatment Plants. Primary Data; Field Survey of Available Land Conditions; Quality of Raw Water at the Planning Location; Secondary Data: Population Data of Tanjungan Village, Simanindo District; Clean Water Needs of Residents Around Lake Aek Natonang; Sources of Income for Communities Around Lake Aek Natonang; Unit Price of Basic Activities (HSPK) of Samosir Regency.

Result and Discussion

Planning Idea

The design idea for a clean water treatment plant with raw water from Lake Aek Natonang is based on the fact that there are still villages that have not been served by clean water needs in Simanindo District.

Literature Study

A literature study is a literature review as an activity to collect useful information, understand the design concept and obtain supporting data for design activities from literature. The literature review carried out includes clean water quality standards in Indonesia, the design concept of clean water treatment units, and the costs required to build and manage a clean water treatment plant.

Data Collection

The data to be collected for this planning are:

Primary Data

The data collected are: Field survey of available land conditions, Field survey to find out a general description of the planning area including the availability of land for the design of a clean water treatment plant and the condition of the raw water to be used; Raw water quality at the planning location. Observations made include raw water sources which are carried out by taking raw water samples manually. The sampling location is carried out at the planned intake location to be built. The samples to be taken are grab samples, namely samples taken at ten specific sampling points at the right time. Then the samples were analyzed in the laboratory for the following: Turbidity using the turbidimetry method; TSS using the gravimetry method; Coagulant dosage using the jar-test method.

Secondary Data

Clean water needs of the residents of Tanjungan Village, Simanindo District, Samosir Regency, the plan Clean water needs for the design of clean water treatment installations were obtained from population data; Raw water quality data for Lake Aek Natonang; Clean water treatment installation design plan based on field visits and laboratory results of raw water from Lake Aek Natonang; Samosir Regency's Basic Activity Unit Price (HSPK) to determine the cost of each development activity unit obtained from the Electronic Procurement Service (LPSE) of Samosir Regency. Primary and secondary data that have been obtained are then analyzed as the basis for the design of clean water treatment installations such as: Analysis of Aek Natonang raw water including quality, quantity and continuity:

Raw Water Quality

The quality test of Aek Natonang raw water was obtained by analyzing water at the Samosir Regency Environmental Service Laboratory, including several parameters according to the Regulation of the Minister of Health of the Republic of Indonesia Number 32/ MENKES/2017, determining the optimum dose of coagulant using the jar-test method and turbidity using the turbidimetry method (Istihara et al., 2019).

Raw Water Quantity

The quantity of raw water from Lake Aek Natonang is studied by determining the volume of the water reservoir of Lake Aek Natonang.

Raw Water Continuity

The analysis of the continuity of Lake Aek Natonang is based on the adequacy of the reservoir during the dry season. Determination of continuity is sought by dividing the volume of the reservoir of Lake Aek Natonang by the predetermined intake discharge and the water balance of Lake Aek Natonang.

Determination of Alternative Processing

The planned processing unit is a processing unit that will process raw water parameters that do not meet the clean water quality standards to be processed to meet the clean water quality standards (Hanifa et al., 2021; Singh et al., 2023).

Designing Processing Units

The design of these processing units is carried out based on several considerations including land use, observations of existing field conditions, data analysis results referring to the standard parameters of drinking water quality used in Indonesia, namely PERMENKES RI No. 32/MENKES/2017 concerning Clean Water Quality Requirements, so that the right and efficient processing unit is obtained in its processing, Capex and Opex calculations are based on the construction needs of the Clean Water Treatment Plant design and its management unit. The coefficient of each work unit is referred to the HSPK Samosir Regency (Guth & Herák, 2025; Rosari & Purwanti, 2020).

Water Needs

The Government of the Republic of Indonesia through the Directorate of Clean Water, Department of Public Works has issued guidelines for the preparation of clean water service programs in accordance with national standards for household clean water needs expressed in units of Liters/Person/Day (L/O/H), the amount of need depends on the category of an area based on the number of residents, as presented in table 1:

Table 1. Daily Household Clean Water Needs by Regional Category (Source: SNI 67281 – 2015)

Area Category	Population (People)	Clean water requirements (L/O/H)
Semi urban (sub-district/village capital)	3.000 – 20.000	60 – 90
Small city	20.000 – 100.000	90 – 110
Medium city	100.000 – 500.000	100 – 125
Large city	500.000 – 1.000.000	150 – 200

For water needs, according to the national standard for water use in Tanjungan Village, Simanindo District, Samosir Regency, with a population of 754 people with an average usage of 90 liters/person/day multiplied by 754 people to 67,860 liters/day. (67.86 m3/day).

Raw Water Quality

Raw water quality analysis is carried out to determine which parameters are appropriate or meet and which are not appropriate or do not meet the established quality standards and to determine the most effective and efficient type of processing so that good results are obtained (Khalik et al., 2022; Hassan Omer, 2020; Hu et al., 2022). The selection of parameters in testing raw water is based on the content of substances contained in the raw water from the effluent of Lake Aek Natonang so that it is possible that there is domestic waste content in the raw water. The intake of raw water sources is located in the intake section of the clean water treatment plant design plan located on the edge of Lake Aek Natonang on December 4, 2024 for analysis during the rainy season at the Samosir Regency Environmental Service Laboratory. Then the results were received on December 8, 2024.

Table 2. Clean Water Physical Quality Parameters (Source: Laboratory Results 8 December 2024)

Mandatory Parameters	Unit	Quality Standard (maximum content)	Lab Results
Turbidity	NTU	25	25.18
Color	TCU	50	55
Total dissolved solids (TDS)	mg/l	1000	1065
Temperature		Air temperature ±3	21
Taste		Tasteless	Taste
Odor		Odorless	Smell

Table 3. Clean Water Chemical Quality Parameters (Source: Laboratory Results 8 December 2024)

Mandatory Parameters	Unit	Quality Standard (maximum content)	Lab Results
pH	mg/l	6.50 – 8.50	6.42
Iron	mg/l	1	0.30
Fluoride	mg/l	1.50	0.64
Hardness (CaCO3)	mg/l	500	165

Mandatory Parameters	Unit	Quality Standard (maximum content)	Lab Results
Manganese	mg/l	0.50	0.40
Nitrate, as N	mg/l	10	0.80
Nitrite, as N	mg/l	1	0.40
Cyanide	mg/l	0.10	0
Detergent	mg/l	0.05	0.01
Pesticide Total	mg/l	0.10	0.2

Table 4. Biological Quality Parameters of Clean Water (Source: Laboratory Results December 8, 2024)

Mandatory Parameters	Unit	Quality Standard (maximum content)	Lab Results
Total coliform	CFU/100ml	50	58
E. coli	CFU/100ml	0	2.0

Of the many parameters of raw water quality based on the Regulation of the Minister of Health of the Republic of Indonesia No. 32 of 2017 concerning the requirements for water health for sanitation hygiene purposes, in Aek Natonang Lake there are 6 (six) standard parameters of clean water quality that are not met, namely turbidity parameters of 25.18 NTU (standard 25 NTU), color 55 TCU (Standard 50 TCU), dissolved solids or Total Dissoved Solid 1,065 mg/l (standard 1,000 mg/l), pH 6.42 mg/l (6.6 - 8.5), Total Coliform 58 CFU/100ml (standard 50 CFU/100ml) and E-coli 2.0 CFU/100ml (standard 0 CFU/100ml). For this reason, water treatment is needed to meet quality standards. However, because the value of the standard quality of raw water that is not in accordance with this is not too significant, the clean water treatment installation that is designed is only simple.

Raw Water Quantity

Lake Aek Natonang is one of the alternatives to meet the water needs of the community of Simanindo District, Samosir Regency. The water storage capacity of Lake Aek Natonang is 45x10,000x8 = 3,600,000m3. Currently, the use of Lake Aek Natonang water as irrigation water consists of 3 flap gates, each with a width of 3 m and a height of 1.3 m. In the rainy season, the water discharge of Lake Aek Natonang experiences overflow and much is wasted and often causes flooding .

Continuity of Raw Water

The volume of water storage at Lake Aek Natonang can meet the intake of raw water for the Clean Water Treatment Installation that is being designed. To determine the continuity of raw water, it can be done by dividing the storage volume of Lake Aek Natonang of 3,600,000 m3 by the processing discharge to be taken. The continuity analysis of Lake Aek Natonang is as follows:

Reservoir volume = 3.600.000 m^3

Withdrawal time = storage volume / Q withdrawal

= 3.600.000 m^3 / 67.86 m^3 / second

= 53.731 days

Capacity of Clean Water Treatment Plant

The water requirement for each resident is set at 90 liters/person/day (according to SNI 6728.1:2015). With a population of Tanjungan Village of 754 people, the capacity of the clean water treatment plant is set at 67.86 l/day. The planned operating time is 4 hours/day; so that the water discharge taken from Lake Aek Natonang as raw water is 16.96 l/hour.

Clean Water Treatment Plant Location

The location of the clean water treatment plant (site plant) is planned on the land closest to Lake Aek Natonang and Tanjungan Village with an area of 200 m2. at coordinates 02°36'53.9''N 098°52'08.9''E, approximately 25 meters from Lake Aek Natonang (intake). At this location, the construction of a Clean Water Treatment Plant and supporting facilities such as an office, warehouse, pump room, chemical processing room and power plant is planned.

Figure 1. Land plan for IPAB location

Raw Water Jar-Test Results

The results of laboratory tests on raw water found that there were still several parameters that did not meet the requirements for clean water quality, namely pH, turbidity and TDS, with values that were not too far from the quality standards. For this reason, a jar-test was carried out to simulate the coagulation-flocculation and sedimentation processes in water treatment to reduce turbidity, remove color and odor, adjust pH and

produce sediment. The jar-test method uses NaOH, PAC and Polymer. The results of the jar-test are shown in Table 5.

Table 5 shows that the optimum dose to neutralize pH is 1 ml/l NaOH, reducing turbidity, color and TDS of raw water is PAC 1 ml/l and Polymer (flocculant) 0.5 ml/l which is shown in the 7th experiment. In the 7th experiment, the turbidity value decreased to 25 NTU, the color became clear and odorless, the pH increased to 7, TDS decreased to 1000 mg/l where all of these parameters have met the quality standards. Determination of the dose of NaOH (increasing pH), PAC (coagulant) and Polymer (flocculant) using the Jar Test method is intermittent, so that obtaining the optimum dose requires a relatively long time up to 7 times.

Table 5. Jar-Test Results (Source: Samosir Regency Environmental Service Laboratory)

Treatment	Attempt to						
	1	2	3	4	5	6	7
Sample Volume (L)	1	1	1	1	1	1	1
NaOH Dosage (ml/L)	0	5	4.5	4	3	2	1
PAC Dosage (ml/L)	0	5	4.5	4	3	2	1
Polymer Dosage (ml/L)	0	5	4	3	2	1	0.5
Fast Stirring 100 rpm	1 minute	1 minute	1 minute	1 minute	1 minute	1 minute	1 minute
Slow Stirring 40 rpm	5 minutes	5 minutes	5 minutes	5 minutes	5 minutes	5 minutes	5 minutes
Sedimentation 0 rpm	5 minutes	5 minutes	5 minutes	5 minutes	5 minutes	5 minutes	5 minutes
Ph	6.42	7.30	7.25	7.20	7.10	7.5	7
Turbidity	25.18	30	29	28	27	26	25
TDS	1065	1055	1045	1035	1025	1015	1000

Clean Water Treatment Installation Design

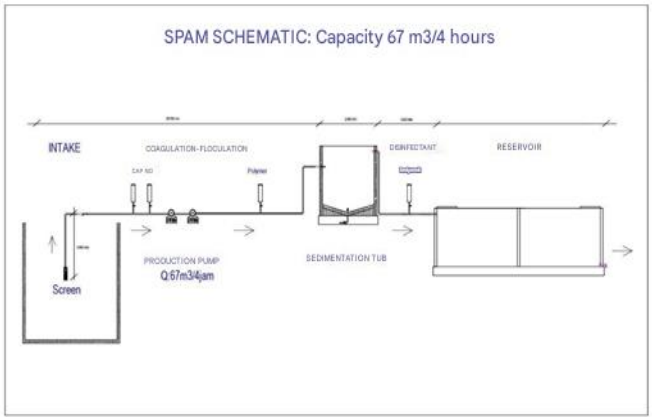

Figure 2. Flowchart of clean water treatment plant

The design of the Clean Water Treatment Installation is planned based on the quality of raw water, land availability, construction costs and operational costs. Based on the results of the Analysis of the quality of raw water of Lake Aek Natonang in the Laboratory, the design of the clean water treatment installation made is a simple clean water treatment installation consisting of: intake, coagulation and flocculation, sedimentation tank, disinfectant and reservoir tank, with the layout in Figure 1. Calculation of the Clean Water Treatment Installation Unit refers to SNI 6774: 2008 concerning the procedures for planning a water treatment installation package unit: Intake, in the form of a pipe that functions to catch water from the lake, the end is given a filter to filter raw water before being flowed using a centrifugal pump to the Sedimentation Tank (Kawamura, 1991); Coagulation-flocculation unit, aims to collect suspended materials in the water; Sedimentation unit, to separate floc particles that have formed; Disinfection unit, aims to eliminate the content of biological compounds in clean water, especially E-coli bacteria; Reservoir, holds water that has been treated before being flowed to people's homes; Supporting buildings, such as offices, Clean Water Treatment Installation rooms, pumps, chemical addition processes and power plants.

Intake Unit

Intake is a pipe that flows raw water from the lake to be processed into clean water. Inserted into the lake 2 m below the surface of the lake with the consideration that the water obtained is relatively clean from dirt and mud, a filter is installed at the end to prevent the entry of solid particles from the lake such as plastic waste, leaves and tree branches. This Raw Water Intake Pipe is 25 meters long from the raw water intake point to the sedimentation tank, pipe diameter (D) = 3 inches, 2 intake pumps each with a capacity of 120l/sec with a power of 1.5 kwh, 1 pump operating and 1 pump for backup with a flow rate of ≈ 1.5 m sec.

Coagulation and Flocculation System

Coagulation is the process of clumping colloidal particles and forming deposits, while flocculation is the combination of unstable particles to form large, dense and easily settled flocs (Tahraoui et al., 2024; Alazaiza et al., 2022; Aragaw & Bogale, 2023). The coagulation and flocculation unit is planned with a hydraulic system, namely utilizing water movement as a stirring force (Vasiljević et al., 2023). The type of stirring is fast stirring

with a water flow that plunges into the sedimentation tank. The coagulant to be used is PAC while the flocculant to be used is Polymer (Anionic Polymer). Both of these chemicals in liquid form will be inserted into the raw water transport pipe through a hole, so that the drops of this solution will cause bonds between particles that collide with each other and transform into macro flox (Boel et al., 2020; Tian et al., 2022; Nasir et al., 2024). The container for storing the 3 materials consists of one container for NaOH (Caustic Soda Liquid) solution as a solution that functions to increase pH, one container for PAC (Poly Aluminum Chloride Liquid) solution as a coagulant and one container for polymer solution (Anionic Polymer) as a flocculant (Youssef et al., 2023; Zarei Mahmudabadi et al., 2018; Kong et al., 2022). Each of these containers is equipped with a valve to regulate the drops of pH-raising solution, coagulant and flocculant so that each solution drips for 4 hours.

Sedimentation Unit

The sedimentation unit aims to reduce turbidity and water contaminants that have been combined in flocs produced in the coagulation and flocculation process. The function of this tank is to separate suspended solid particles (flocs) by gravity (Jover-Smet et al., 2017; Alzoubi et al., 2025; Peng et al., 2020). The sedimentation unit is planned to use a reservoir tank with a length of 10.3 m, a width of 2.06 and a height of 1.5 m + 0.5 m which aims to expand the sedimentation zone and shorten the sedimentation distance so that the sedimentation process effectively occurs in the reservoir tank (Moga et al., 2017).

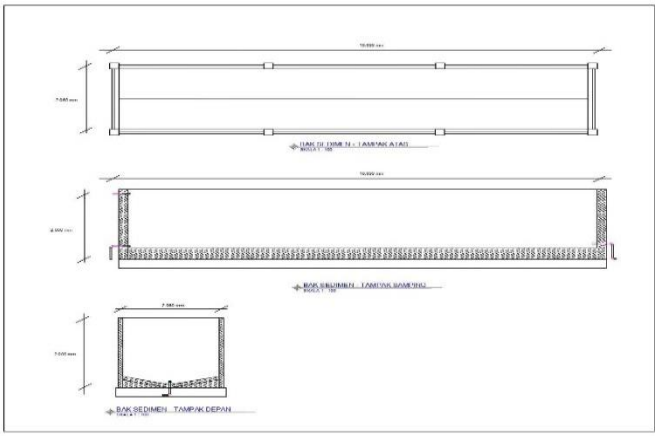

Figure 3. Sedimentation tank design for clean water treatment plant

Disinfection Unit

Providing clean water requires disinfection to protect water users from waterborne diseases (Basuki et al., 2022; Aziz et al., 2022; Mariita et al., 2021). Laboratory results found a total coliform of 58 CFU/100ml while E.coli was 2.0 CFU/100ml, meaning it exceeded the standard quality threshold, although not significant, disinfection must be carried out. The type of disinfection used is Chlorine (CaClO)2. Chlorine is the most commonly used material because it is effective at low concentrations, cheap, and forms residual chlorine if used in sufficient doses (Nielsen et al., 2022; Owoseni et al., 2017). In this planning, chlorine will be dripped through a hole into the raw water intake pipe before the reservoir tank, the drips of which are regulated by the Valve, and supervised and controlled by the operator (security guard) to ensure that the process runs well and is under control.

Reservoir Unit

The reservoir unit is a unit that functions to accommodate water that has been treated and has met the quality requirements for clean water. In the design planning, the reservoir unit is planned to be 6.5 m long, 6.5 m wide and 2 meters + 0.5 meters high with a storage % of 25%.

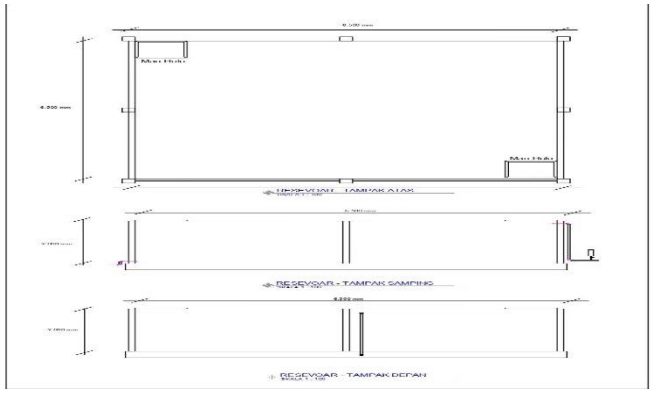

Figure 4. Design of reservoir tank of clean water treatment installation

Layout of Clean Water Treatment Installation

Based on the discussion above, the layout of the clean water treatment installation designed in Lake Aek Natonang is as follows:

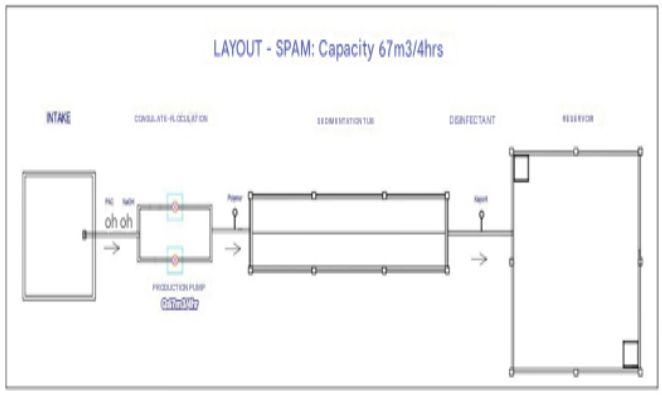

Figure 5. Layout of clean water treatment unit

Figure 6. Layout of clean water treatment unit at Lake Aek Natonang Location

CAPEX and OPEX

In this thesis, the calculation of CAPEX and OPEX is based on the expenditure of funds arising from the construction of the Clean Water Treatment Installation. CAPEX is the expenditure made to build a clean water treatment installation while OPEX is the unit price that must be spent in the operation of the clean water treatment installation in accordance with the basic unit price of activities (HSPK) in Samosir Regency in 2024. CAPEX can be seen in Table 6 and OPEX can be seen in Table 6.

Table 6. CAPEX

Item Name	Volume	Unit	Price Unit	Total price
Permits	1	Ls	50.000.000	Rp. 50.000.000
Activity Board	1	Ls	1.000.000	Rp. 1.000.000
Site Cleaning	1	Ls	10.000.000	Rp. 10.000.000
Working Shed	20	M2	500.000	Rp. 10.000.000
Warehouse	6	M2	500.000	Rp. 3.000.000
Pipes	27	M	250.000	Rp. 6.750.000
Pipe Accessories	5	Unit	200.000	Rp. 1.000.000
Sedimentation Tank	32	M	2.500.000	Rp. 62.500.000
Pumps and Control Panels	2	Unit	15.000.000	Rp. 30.000.000
Reservoir Tanks	105	M3	2.500.000	Rp. 250.000.000
Electrical Installations	1	Ls	10.000.000	Rp. 10.000.000
Installation Roofs	1	Ls	5.000.000	Rp. 5.000.000
Item Name	1	Ls	50.000.000	Rp. 50.000.000
Permits	1	Ls	1.000.000	Rp. 1.000.000
Activity Board	1	Ls	10.000.000	Rp. 10.000.000
Sub total				Rp. 439.250.000

Table 7. OPEX Each Month

Job description	Volume	Unit	Price Unit	Total price
Security guard	3	Orang	2.500.000	Rp. 7.500.000
NaOH 48%	67.86	L	15.000	Rp. 1.017.900
(Caustic Soda Liquid)	67.86	L	7500	Rp. 508.950
PAC 10%	33.93	L	20.000	Rp. 678.600
(Poly Aluminum Chloride Liquid)	8.70	L	11.000	Rp. 95.700
Polymers	1.50	Kwh	100.000	Rp. 3.000.000
(Polymer Anionic Liquid)	1	Unit	1.000.000	Rp. 1.000.000
Chlorine 12%	3	Orang	2.500.000	Rp. 7.500.000
(Sodium Hypochlorite Liquid)	67.86	L	15.000	Rp. 1.017.900
Electricity	67.86	L	7500	Rp. 508.950
Maintenance	33.93	L	20.000	Rp. 678.600
Sub total				Rp. 13.801.150

Based on the calculation results, the total cost of building a Clean Water Treatment Plant (CAPEX) is Rp. 439.250.000. while the management cost (OPEX) each month is Rp. 13.801.150.

Conclusion

There are 6 (six) standard parameters of clean water quality that are not met, namely turbidity parameters of 25.18 NTU (standard 25 NTU), color 55 TCU (Standard 50 TCU), dissolved solids or Total Dissoved Solid 1,065 mg/l (standard 1.000 mg/l), pH 6.42 mg/l (6.6 - 8.5), Total Coliform 58 CFU/100ml (standard 50 CFU/100ml) and E-coli 2.0 CFU/100ml (standard 0 CFU/100ml) with differences that are not too significant to the threshold; The design of the Aek Natonang Lake Clean Water Treatment Plant uses a simple processing system. The designed processing unit consists of intake, pump,

coagulation and flocculation, sedimentation tank, disinfection and reservoir; Estimated cost of making the Installation (CAPEX) is IDR. 439.250,000, while the operational costs (OPEX) each month are Rp. 13.801.150.

Acknowledgments
Thanks to all parties who have supported the implementation of this research. I hope this research can be useful.

Author Contributions
Conceptualization; Methodology; validation; formal analysis; Investigations; resources; data curation: writing—original draft preparation; writing—review and editing; visualization.M. T. N. S. All authors have read and agreed to the published version of the manuscript.

Funding
Researchers independently funded this research.

Conflicts of Interest
The authors declare no conflict of interest.

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