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IMPACT OF DRINKING WATER TREATMENT PROCESS USING LIFE CYCLE ASSESSMENT (LCA) TO MINIMIZE ENVIRONMENTAL IMPACT RISK

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ABSTRACT

This study aims to analyze the factors causing environmental impacts arising from the clean water treatment process at the PDAM Water Treatment Plant (IPA) and determine policy priorities related to reducing environmental impacts and improving the quality of drinking water treatment at the Water Treatment Plant based on the results of LCA and AHP studies. The Life Cycle Assessment (LCA) method is a method of assessing the potential environmental impact and evaluating the environmental performance of a process on the product. Life Cycle Assessment (LCA) consists of four stages, namely determination of Goal and Scope, Life Cycle Inventory, Life Cycle Impact Assessment, and data interpretation. In research, the scope of LCA used is Gate to Gate, namely in the Coagulation, Flocculation, and Sedimentation process units. From the results of the LCA study, the potential impact of GWP of 12760.76 KgCO2-eq comes from flocculation which produces floc from the addition of chemicals. Meanwhile, the potential impact of eutrophication is 268.55 KgPO4-eq derived from mud generation. The results of the decision in reducing environmental impact at DWTP by optimizing chemicals as a top priority, then the second priority by recycling sludge, and finally making savings and energy alternatives are the last priority. Each respondent's score reached 55%, 23%, and 22%. The results of the implementation of the program if implemented can reduce the impact of GWP 20079.17 kg CO2-eq and the impact of eutrophication can be reduced by 201.401 kg PO4-eq.mportant matters discussed in the paper that significantly contribute to the final result of the research may be noted here, but you have to consider, however, the limited space of the abstract.

Keywords: *Emissions, Drinking Water Treatment Plants, Life Cycle Assessment (LCA)*

INTRODUCTION

The problem of clean water is an important study because water is the source of life for living things. However, in the current condition, the quality of clean water is declining due to human activities that cause pollution due to domestic and industrial activities. The source of raw water that is starting to be polluted requires additional treatment so that the presence of the Regional Drinking Water Company (PDAM) can manage water so that clean water needs can be met. PDAM is an institution responsible for providing clean water to the community. Before being channeled to the community, it needs to be ensured by processing with the right technology. Presedimentation, aeration, coagulation-flocculation, sedimentation, disinfection, and reservoir treatment aims to provide better water quality for consumers. However, to meet the need for raw water, PDAM uses river raw water sources whose water quality fluctuates at all times.

The risk of environmental impacts can also be influenced by the water treatment process from raw water sources, due to chemical, physical, and biological quality improvements. The water treatment process is used to remove impurities in the water source used, for example, organic substances, suspended solids, odors and also pathogenic bacteria, chemicals such as alum, iron salts or coagulants from polymers, alkaline substances and also compounds to kill pathogenic bacteria such as chlorine gas or chlorine or other oxidants (Fauziah & Rudijanto, 2018). Water treatment activities in clean water can have a negative impact from adding coagulants such as PAC (polyaluminium chloride) and chlorine which can cause ozone depletion (Kyung et al., 2013). Water treatment also requires a lot of energy and large costs, because the worse the water source, the more intense treatment technology is needed in improving water quality. The use of electricity can also contribute to CO_2 emissions in the air.(Irawati & Andrian, 2018)

Life Cycle Assessment (LCA) is a method used to analyze environmental impacts, environmental quality, and global warming. The Life Cycle Assessment (LCA) analyzing that the impact shows that the wastewater treatment process can produce environmental impacts in the form of Global Warming, Non-Renewable Energy, and Eutrophication Waters derived from the treatment process and supporting equipment but does not show a magnitude and significant impact (Karnaningroem & Anggraeni, 2021). Drinking water treatment plants are also responsible for global environmental impacts such as the depletion of natural resources as well as pollutants released into water, soil, and air. The environmental impact of drinking water treatment plants is the process of reducing contaminants contained in the raw water treatment process at drinking water treatment plants (Khan et al., 2013). The *Life Cycle Assessment* (LCA) method can also estimate the cumulative environmental impact caused by each stage of the cycle of a process or the life cycle of a product, so that it can find out at what stages will contribute greatly to environmental impacts (Nurbaiti et al., 2022).

By using the LCA method in this study, it is expected to be able to analyze the environmental impacts derived from the PDAM Water Treatment Plant (IPA) process and provide recommendations as an alternative plan for effective and environmentally friendly clean water treatment (Andrian & Irawati, 2019). Then, the achievement of the LCA is able to improve the quality of drinking water treatment and reduce environmental impacts to improve the quality of drinking water treatment plant treatment, namely by improving the quality of raw water and providing the quantity of water that has been treated in accordance with the appropriate water quality for certain needs. Ensure everyone gets equal water quality and good sanitation without sacrificing future needs to provide this capacity and quality(Darise, 2016). Water systems in the field of sustainable development may not literally include water use, but include systems where general water use is required(Riyanty & Indarjanto, 2015).

This study will analyze a water treatment process at a water treatment plant by building an integration model between LCA and AHP as a tool to evaluate water treatment conditions from raw water sources to the end of treatment. Then, the model will be used to analyze the reverse supply in the system that can be used to formulate policy recommendations that support efforts to improve raw water quality. The results of this environmental impact factor analysis are then used as one of the inputs in water resource efficiency management (Park et al., 2015). Every drinking water treatment process will certainly produce environmental impacts that cause greenhouse gases or climate change. On research conducted by (Kyung et al., 2013), there are CO2 emissions of 69,596 kg CO2 e/day from the drinking water treatment process caused by treatment using micro-filtration of membranes, the addition of ozone disinfection, and the addition of coagulants are the causes of the increase in CO_2.

METHOD

The secondary data used are obtained from DWTP which consists of raw water quality and water production with parameters, chemical consumption data, electrical and pump energy consumption resulting from the process performance of the processing unit, and emission data. The scope of this research is on coagulation, flocculation and filtration processing. The secondary data obtained will be processed according to mass balance theory and analyzed using Microsoft Excel to analyze the life cycle or Life Cycle Assessment (LCA). This stage begins with determining the goals and scope (Goal and Scope) with the scope of use of the Ecoinvent System Process (Garfí et al., 2016). The second and third stages are conducting an inventory (Life Cycle Inventory) and conducting a contamination assessment (Life Cycle Impact Assessment). The process of selecting impact assessments in this study is based on the greatest possible environmental impacts resulting from drinking water treatment. The method used is the CML-IA baseline(Supenah et al., 2023). The final stage is the interpretation of the data, which is to evaluate and review a conclusion. Outputs in the form of impacts produced in kilograms of product are then identified how to reduce these impacts through literature review.

Goal and Scope

This section aims to analyze processing processes that contribute to environmental impacts, especially in chemical affixing and electrical energy use based on LCA study analysis. The analysis is carried out by analyzing the inputs and outputs of the activity unit according to the focus of activities, starting from the input process of water treatment entry in coagulation, flocculation, and sedimentation units in drinking water treatment. The scope used in this study is on the gate to gate, which starts from the results of the coagulation unit water treatment to the sedimentation unit treatment process. The functional unit used per m3 of drinking water treatment process was treated in one year, namely 2021. The data used is secondary data including materials, chemical use, and energy use, based on actual company data (Roth et al., 2022).

Life-Cycle Inventory

LCI includes the compilation and quantification of input and output data for a product throughout its life cycle. LCI is based on a predetermined definition of goal and scope. The data inputted is data derived from PDAM archive data during 2021 which is then averaged. The data inputted includes data on raw materials used, chemicals needed and energy data needed (Beeftink et al., 2021).

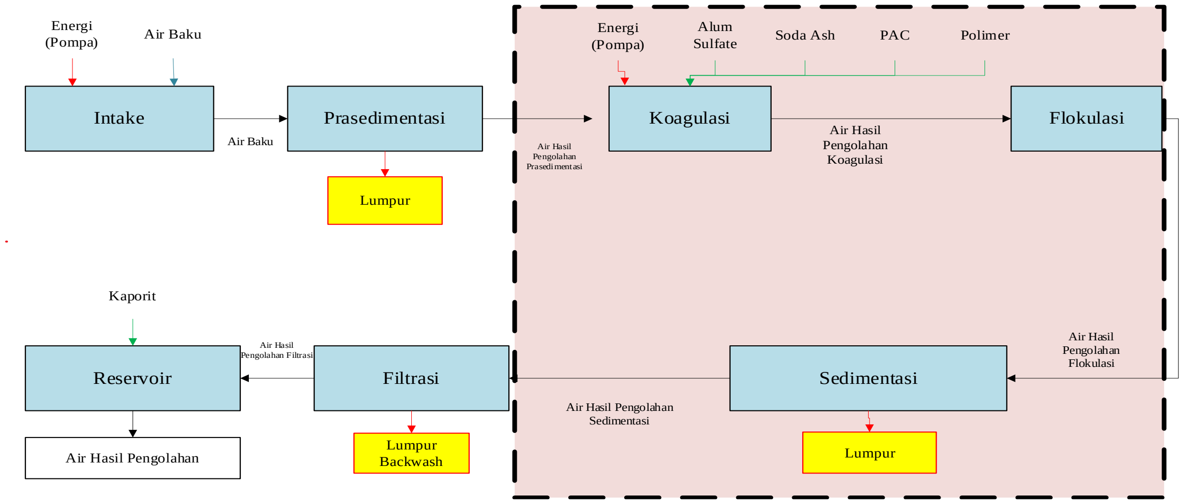

Figure 1. Boundary System of Drinking Water Treatment Process

Life Cycle Impact Assessment

The next stage after carrying out the Life Cycle Inventory stage is to carry out the Life Cycle Impact Assessment stage. At the Impact Assessment stage (Life Cycle Impact Assessment), an impact determination is carried out after inputting values in the Life Cycle Inventory (LCI) process. The impact assessment method used is the CML-IA Method. In the LCA study in this study uses a midpoint approach.

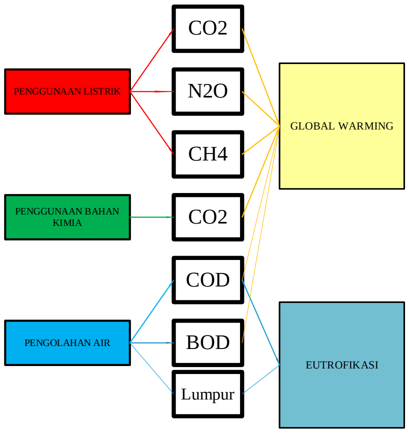

Figure 2. Impact Classification with CML-IA Baseline Method

Data Interpretation

The final stage in LCA produces alternatives for improvement in each production process. The resulting alternatives are not only 1, but there are several alternatives as considerations in making decisions that are analyzed on a production system that has a significant contribution to environmental impact. Then, make conclusions and recommendations. After studying all the impacts of the series of processes, one process that has the most significant influence on LCA is selected.

RESULTS AND DISCUSSION

Analysis of Raw Water Quality and Production Water

Primary data collection is carried out by laboratory analysis of inlet and outlet coagulation, flocculation, and sedimentation. While secondary data from raw water quality, data on the use of chemicals and electricity are based on laboratory documents and interviews with informants who understand treatment activities. DWTP uses raw water from the Kabo River according to its allotment. The quality standard for drinking water is PP No. 82 Of 2001 which is grouped into four classes, for drinking water Quality Standards is class I, but this DWTP is using Quality Standard Class II.

Table 1. Raw Water Quality Monitoring Results

No.	**Parameter**	**Unit**	**Quality standards**	**Test Results**			
				March 2021	***June 2021***	***September 2021***	***December 2021***
1	Ammonia	mg/L	0,5	<0,0141	0,1649	0,1151	0,0910
2	Arsenic	mg/L	0,05	<0,0032	<0,0032	<0,0032	<0,0032
3	Iron	mg/L	0,3	0,6561	1,8767	1,6596	0,4484
4	Chlorine (Cl_2)	mg/L	0,03	0	0	0	0
5	C OD	mg/L	10	26,53	29,29	22,19	54,08
6	Phenol	mg/L	0,001	<0,0006	< 0,006	<0,0006	<0,0006
7	Flourida	mg/L	0,5	<0,04677	<0,0467	<0,0467	<0,0467
8	Cadmium	mg/L	0,01	<0,00002	<0,0002	<0,0002	<0,00020
9	Hardness($CaCO_3$)	mg/L	50	19,5	28	46,94	31,68
10	Chromium Heksavalen	mg/L	0,05	<0,0019	< 0.0019	<0,0019	<0,0019
11	Manganese	mg/L	0,1	<0,0066	0,0731	0,0366	<0,0066
12	Nitrate as N (NO3-N)	mg/L	10	4,397	2,748	4,611	3,918
13	Nitrite as N (NO2-N)	mg/L	0,06	0,042	0,029	0,019	0,023
14	pH	*	6-9	5,67	6,51	7,4	5,74
15	TDS	mg/L	1000	141	142	73	80
16	Seng	mg/L	0,05	0,0033	< 0,008	0,028	0,028
17	Methylene/Detergent Blue Test	mg/L	0,2	0,315	<0,013	32,412	35,138
18	Sulfate	mg/L	400	55,933	49,201	<0,0011	<0,0011
19	Sulfide	mg/L	0,002	<0,0011	<0,0011	<0,0105	<0,0105
20	Copper (Cu)	mg/L	0,02	<0,0105	<0,0105	<0,0017	0,0017
21	Lead (Pb)	mg/L	0,03	<0,0017	<0,0017	0,1544	0,074

No.	Parameter	Unit	Quality standards	Test Results			
				March 2021	***June 2021***	***September 2021***	***December 2021***
22	Color	TCU	100	5,25	50,36	6,64	333,686
23	Suspended substance (TSS)	mg/L	50	202,6	23,72	87,5	109,92

Table 2. Test Results of Each Parameter in the Unit

No	Parameter	Unit	Coagulation		Flocculation		Sedimentation	
			Inlet	***Inlet***	***Inlet***	***Outlet***	***Outlet***	***Outlet***
1	Fe	mg/L	2,5	2,74	1,56	1,32	2,38	2,65
2	Aluminum	mg/L	2,2	0,05	0,04	0,04	0,04	2,2
3	Chlorine	mg/L	3,3	2,5	2,1	2	2,3	3,4
4	TDS	mg/L	52,1	57,4	32,5	25,5	53	57,4
5	TSS	mg/L	36	79	28	20	77	61
6	Turbidity	NTU	83,4	129	59	45	105	112
7	BE	mg/L	9,9	8,9	3,2	3	7,67	7,4
8	COD	mg/L	23,5	17	13,5	12,4	15,43	17,7

Goal Determination and Scope

The first step is to determine the purpose and scope of the study. This stage helps the consistency of LCA research. The purpose of this study is to analyze processing processes that contribute to environmental impacts, especially in chemical affixing and the use of electrical energy based on the analysis of LCA studies. The analysis is carried out by analyzing the inputs and outputs of the activity unit according to the focus of activities, starting from the input process of water treatment entry in coagulation, flocculation, and sedimentation units in drinking water treatment. The scope used in this study is gate-to-gate, which starts from the results of the coagulation unit water treatment to the sedimentation unit treatment process. The functional unit used per m^3 of the drinking water treatment process was treated in one year, namely 2021. The data used is secondary data including materials, chemical use, and energy use, based on actual company data.

Life Cycle Inventory (LCI)

At this stage, data input such as the use of chemicals, electricity usage, processing discharge, and processing process load every month. Data entered in quantities per day and considered data per day in a month is constant. The results of this stage will later be described in the flow sheet. After data collection, the identification process is carried out with the purpose and scope and calculates the inventory life cycle (LCI). The results of this network processing provide relationship information from each process that affects the impact contribution. The data is then normalized with the results of processing. Normalization is the input and output data in each process unit divided by the final product at a specified scope. The normalization process is carried out with the final product in the sedimentation process. Impact calculations are performed after an inventory of data on function units. The value of each impact category is obtained by multiplying the number of function units of each input or output material by the characterization factor as in the following equation (Kholil et al., 2022). The following is the calculation of normalization data for function units (FU), namely:

Normalization of Coagulation input data $= \frac{Coagulation\ unit\ Processing\ water\ input}{Final\ product\ processing\ in\ Sedimentation\ Unit}$

$= \frac{653.958\ m3}{600.072,87\ m3}$

= 1,09 m^3/m^3 processing water

Normalization of Chemical input data $= \frac{Input\ of\ Soda\ Ash}{End\ product\ of\ processing\ in\ Sedimentation\ Unit}$

$= \frac{4900\ \text{Kg}}{600.072,87\ \text{m3}}$

= 0,02733 kg/m3 processing water

Normalization of Electrical input data $= \frac{\text{Input of the Soda Ash dosing pump}}{The\ end\ product\ of\ processing\ in\ the\ sedimentation\ unit}$

$= \frac{186\ \text{Kwh}}{600.072,87\ \text{m3}}$

= 0,00031 kWh electricity/m3

Life Cycle Impact Assessment (LCIA)

Characteristics are the result of inventory data. All elementary flow data in LCI is classified into certain impact categories which are then multiplied by characterization factors or estimates of emissions produced based on reference results. The results are summed and adjusted according to the emissions produced and adjusted for each impact. For example, warning of the potential greenhouse effect by modeling the potential impact ofCO_2 and CH4 on global warming. All relevant interventions generate impact scores in specific impact categories. The impact categories studied in this discussion are Global Warming Potential and Eutrophication.

Global Warming Potential

The use of electricity comes from PLN sources derived from coal fuel. The use of electricity has an impact on the destruction of natural resources. The role of electrical energy is quite large in water treatment (Del Borghi et al., 2013). Characteristic factors in the database contained in the CML-1A Baseline for this water treatment process can be seen in the following tabel 3.

Table 3. Characteristic Factors CML- 1A Baseline Method (Global warming)

Impact Category		Parameter	Faktor emisi	Unit	CF	Unit
Global Warming	PLN	Carbon dioxide (CO_2)	0.77	kgCO_2/kWh	1	kg CO_2 eq
		Methane (CH_4)	1.59E-05	kgCH_4/kWh	28	kg CO_2 eq
		Dinitrogen monoxide (N_2O)	8.77E-06	kgN_2O/kWh	265	kg CO_2 eq

Source: IPCC, 2006

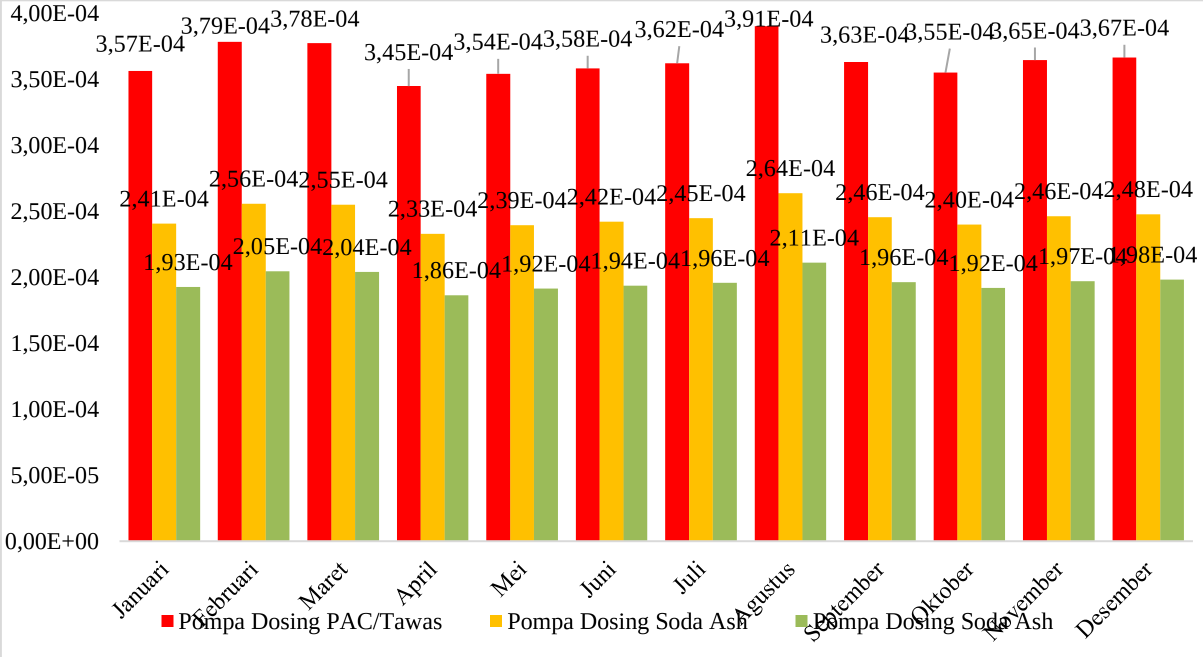

Figure 1. GWP Results on Electricity Use each Month

The use of PAC, Alum, soda Ash and polymers in water treatment processes has a major contribution to air pollution. The calculation of the use of chemicals in water treatment is done by multiplying the amount of chemicals used in the process multiplied by the treatment discharge and emission factor of each chemical. Here is a table of emission factors for each chemical

$$P_{CO2} = (C_{ci} \times Q_{flow} \times 10^3 m3/L^{-1})xEF$$

Information:
C = amount of chemical used (kg/m3)
Qflow = Water discharge that enters the treatment process (L/d)
EF = Emission Factor

Table 4. Emission Factors of chemical use (Global Warming)

Material	Emission Factors	Unit	Source
Aluminum Sulfate	0,395	Kg CO2-eq/g Alum Sulfate	Kyung et al., 2013
PAC	0,131	Kg CO2-eq/kg PAC	Kyung et al., 2013
Soda Ash (NaCO3)	0,059	Kg CO2-eq/kg NaNO3	(winnipeg.ca, 2012)
Polymer	0,015	Kg CO2-eq/kg Polymer	(Chai et al., 2015)

The use of chemicals has a major impact on global warming. The use of alum has the highest impact compared to other chemicals. According to (Kyung et al., 2013)), PACs have relatively small alkalinities (0.15 mg/L as CaCO3) and require doses 15 -20 times lower than other coagulants. Apart from the high CO2 emission factor, a relatively low dose of PAC is needed for better water quality so that PAC becomes the best coagulant and low CO2 emissions. From the results of these calculations, GWP results from the use of chemicals in 2021 reached 26,772 kg CO2-eq.

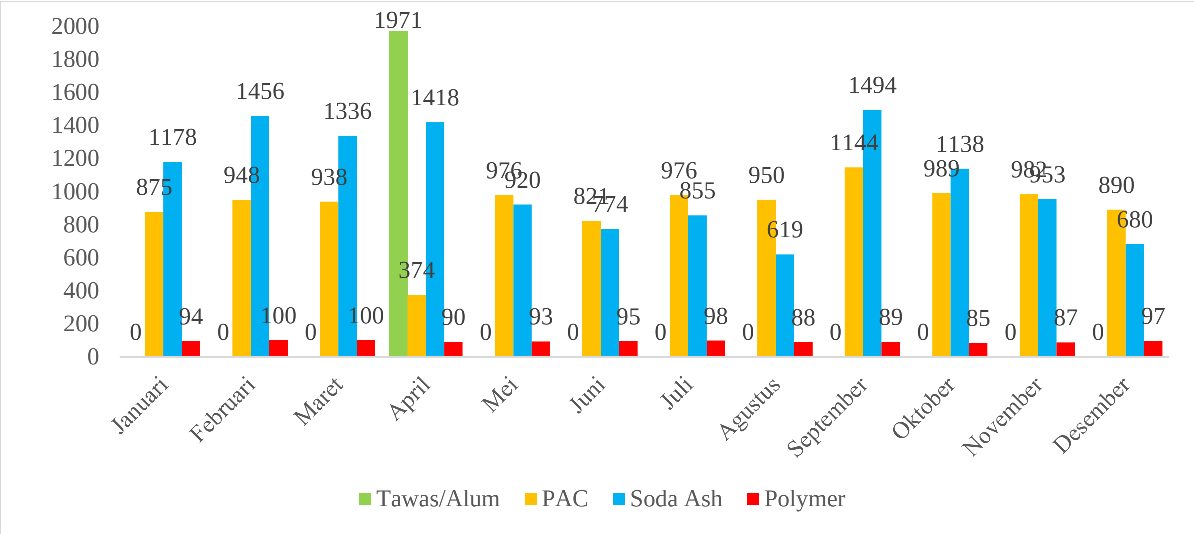

Figure 2. GWP Results Graph from Chemical Use

Water quality monitoring in influent and effluent units is used to measure the level of COD and BOD pollution in water although this monitoring is not carried out in the company's standard in each process unit. The formula used for the calculation of CO2 emissions is based on COD and BOD data. As well as the table of each emission factor presented in table 5 is as follows:

Table 5. Emission Factors on BOD and COD Parameters

Material	**Emission Factor**	**Units**	**Source**
BOD	0,48	Kg CH4/kg BOD	IPCC, 2006
COD	0,25	KgCH4/kg COD	IPCC, 2006

Table 6. GWP Results from COD and BOD Removal per Process Unit

Process Unit	**COD**	**BE**	**TOTAL**
	kg CO2-eq	**kg CO2-eq**	**kg CO2-eq**
Coagulation	4822,05	21420,50	26242,55
Flocculation	14753,52	56985,91	71739,44
Sedimentation	2115,89	738,64	2854,53

Based on the calculation results, emission to water is strongly influenced by the amount of wastewater produced which contains high COD and BOD values. In the flocculation process unit, there is a high potential because it becomes the process of floc formation from the results of the coagulation process. So that the flocculation process unit has the highest GWP impact. After calculating GWP both from the use of electricity and the resulting removal, the total value of GWP characteristics in the process produced in the Coagulation, Flocculation and Sedimentation process is 127608.76 kg CO2-eq.

Table 7. Value of characterization of global warming potential impacts

Process Unit	Total
	kg CO2-eq
Coagulation	53014,79
Flocculation	71739,44
Sedimentation	2854,53
TOTAL	127608,76

Eutrophication

Sludge produced from water treatment contains harmful substances due to chemicals used during the water purification process. In this study, there are two factors studied as the impact of eutrophication, namely COD and mud. For calculations and factor characteristics of COD parameters are presented in table 4.26.

Table 8. Characteristic Factors CML-1A Baseline Method (eutrophication)

Impact Category	Parameter	Factor Eutrophication	Unit
Eutrophication	COD (Chemical oxgen demand)	0,022	kg PO_4 eq

Source: CML-1A Baseline Simapro

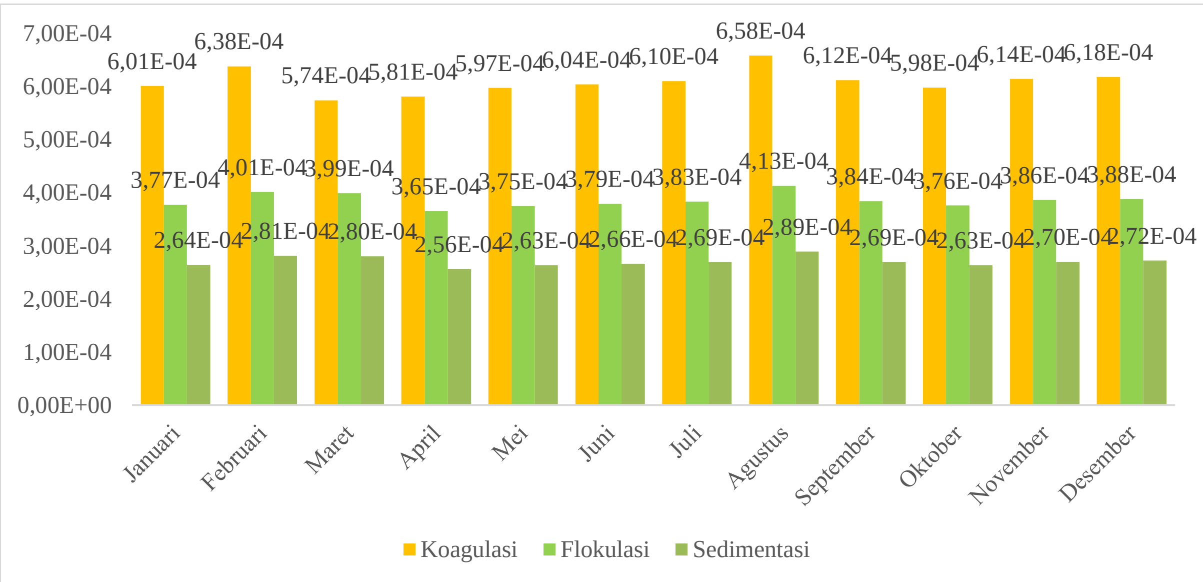

Figure 4. Eutrophication Results Graph of COD Parameters

The results of the calculation show that the greatest impact of eutrophication occurs in the coagulation process. In the process unit, raw water has not been treated perfectly, so the impact of eutrophication is still high compared to other process units. The results are then summed according to their respective process units.

Table 9. Eutrophication Results of COD Parameters

Process Unit	**Total**
	kg CO2-eq
Coagulation	7.31E-03
Flocculation	4.63E-03
Sedimentation	3.24E-03

Apart from being caused by COD parameters, the cause of eutrophication is caused by sludge from the water treatment process. The sludge is discharged back into the water body without any treatment. For the calculation of the eutrophication impact of the resulting sludge using comparisons with existing studies. The calculation of potential emissions produced is based on comparisons from other similar research references. Based on research by Annisa (2022), the sludge produced in the sedimentation process is 18296 kg / year and produces 4460 kg of PO4-eq emissions.

$$\frac{\text{Emisi Kg PO4 eq}}{\text{Emisi Kg PO4 eq Ref}} = \frac{\text{Sludge Produced}}{\text{Sludge Produced Ref}}$$

Each emission source that has an impact on eutrophication is then summed. The largest impact occurred in the sedimentation process unit with an impact magnitude of 268.53 Kg PO4-eq. The overall total of Eutrophication impacts was 268.55 Kg PO4-eq.

Characterization Analysis

Data interpretation in LCA studies is carried out by linking the impact results that arise with the life cycle inventory and also goal and scope. In the flocculation process unit, there is a high potential because it is the floc formation process that has the highest impact on GWP. Overall, the impact of global warming generated during the water treatment process at DWTP has contributed to global warming by producing 127608.76 kg of CO2-eq. Based on the results of characterization calculations on global warming potential, the flocculation unit is the unit that produces the highest impact on this process, amounting to 71739.44 kg CO2-eq. The sedimentation process has the highest impact on eutrophication. This is because the sludge produced from drinking water treatment activities is not treated. Sludge that has been processed before being discharged returns to the river, because the sludge from water treatment has contained chemicals that are harmful to the environment and other living things.

Prioritization of Improvement Alternatives

From a series of analyses carried out that were used to find the best alternative purpose, namely Minimizing the risk of environmental impacts on DWTP drinking water treatment, it is known that the optimization of this chemical has a very large influence whereby reconsidering the dose of coagulant used. do a jar test every day so that the amount used becomes less. Viewed from the aspect of cost and investment, of course, the savings on chemicals will reduce the costs incurred due to the purchase of chemicals, as well as the environmental impact affected by chemicals will be reduced not much to cause the burden of new investment costs (purchase of goods, new equipment). The alternative taken, seen from the aspect of environmental impact, experts agree that this alternative has the greatest influence, and from the aspect of ease in implementing this alternative is very likely to be implemented, this is because the DWTP facility itself already has supporting facilities to do these alternatives and there are experts.

CONCLUSION

The environmental impact (contribution) of the analysis results that occurred in a series of water treatment processes at DWTP was caused by the use of chemicals, sludge and the use of electricity. The results of *Life Cycle Impact Assessment* on a series of water treatment processes at DWTP are *Global Warming* of 127608.76 kg $CO_{2\text{-eq}}$, *Eutrophication* of 268.55 kg PO4-eq. The results of decision selection in reducing environmental impact at DWTP by optimizing chemicals as a top priority by conducting routine dose testing to determine the chemicals needed. Then the second priority is recycling sludge, and finally saving and alternative energy becomes the last priority.

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