Study of Life Cycle Assessment (LCA) on Water Treatment

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Abstract. Water Treatment Plant (WTP) with conventional systems uses pumps that work for 24 hours, and chemicals that produce residues or by-products in water processing and have an impact on the environment and humans. This study aims to identify the quality and performance of the WTP treatment. Identify the impacts arising from the drinking water treatment process and determine the efforts made to reduce the impacts identified by the method Life Cycle Assessment (LCA). The Life Cycle Assessment (LCA) method is an assessment method regarding potential environmental impacts and evaluation of the environmental performance of a process to the product. Life Cycle Assessment (LCA) consists of four stages, are Goal and Scope determination, Life Cycle Inventory, Life Cycle Impact Assessment, and data interpretation. The software used in SimaPro 9.0.0 with the impact assessment method is CML-IA Baseline. The impacts discussed in this research are Global Warming, Human Toxicity, and Eutrophication. The way to reduce the impact is based on literature studies. The results of the analysis found that the quality of raw water has not reach the quality standards as drinking water standards. While the quality of produced water has reached the quality standard. The performance of the processing unit at WTP has not worked well, therefore needs improvement with the addition of polymer in clearator, electricity usage in WTP is 11.220.195,47 kWh/yr. The analysis results using Life Cycle Assessment (LCA) method, showed that the highest contribution to environmental impact was Eutrophication of 287,644,1 kg PO₄–eq/yr followed by Global Warming of 23,697,275 kg CO₂eq/yr, and Human Toxicity of 9.190,241 kg 1,4-DBeq/yr. The way to reduce the impact is to take pretreatment on raw water, plan and build sludge treatment, also recycle sludge from clearator unit, replace equipment, replace aluminum sulfate, and liquid chlorine into PAC and hypochlorite salts.

1. Introduction

Some public facilities such as the Waste Water Treatment Plant (WWTP) are categorized as a public facility that produces large amounts of emissions of methane (CH₄) and CO₂ with a large amount of electricity consumption and chemicals (Riyanty and Indarjanto, 2015). The result of research by the method of Life Cycle Assessment (LCA) shows that the wastewater treatment process can result in environmental impacts in the form of Global Warming, Non-Renewable Energy, and Aquatic eutrophication comes from treatment processes and supporting tools but not showing a large and significant impact (Rachmani, 2019). Drinking water treatment plants are categorized as public facilities that are responsible for global environmental impacts such as the depletion of natural resources also pollutants release into the water, soil, and air (Bonton et al., 2012). The environmental impact is produced from the reduction process of contaminants that are contained inside the raw water treatment process in the drinking water treatment plant (Khan et al., 2013). The Drinking Water Treatment Plant
(DWTP) in this research, utilizes the Surabaya River as raw water and the processing unit consists of intake, Pre-Sedimentation, aerator, clearator, filtration, disinfection, and ends at the reservoir. In addition, DWTP uses a pump that works for 24 hours and chemicals, which will produce residues in the processing water. Conventional Drinking Water Treatment Plant produces the total CO₂ emissions from electricity consumption as much as 5.1% of the total emissions, to process 200,000 m³ of raw water requires electricity by 3638 ± 503 kWh per day and the emissions produced by 2031 ± 281 kg CO₂ / day (Kyung et al., 2013).

Based on the explanation above, the identification of the raw water quality, water production, and processing unit performance, as well as the use of electricity, aims to discover the impact that will results from the conventional drinking water treatment process. The analysis can be done through methods of Life Cycle Assessment (LCA), using SimaPro software 9.0.0, which can be used to help determine the basis for environmental improvement.

2. Methods

Secondary data used were obtained from DWTP which consisted of raw water quality and production water with parameters (pH, TDS, TSS, BOD, COD, N, P, turbidity, residual chlorine, and total coliform), chemical consumption data, consumption of electrical energy and pumps generated from the processing unit's process performance, and emission data. The secondary data obtained will be processed according to the mass balance theory and analyzed using the SimaPro 9.0.0 application to analyze the life cycle or Life Cycle Assessment (LCA). This stage begins with determining the objectives and scope (Goal and Scope) with the scope of using the Ecoinvent System Process. The second and third stage is to conduct the inventory (Life Cycle Inventory) and conduct an assessment of the contamination (Life Cycle Impact Assessment). The impact assessment selection process in this study is based on the largest possible environmental impact resulting from drinking water treatment. The method that was used is the CML-IA baseline. The last stage is data interpretation, which is to evaluate and review a conclusion. The output in the form of the impact produced in kilograms of the product then identified how to reduce the impact through a literature review.

3. Result and Discussion

3.1. Analysis of the Quality of Raw Water and Production Water

DWTP uses raw water from the Surabaya 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.

|               | TDS (mg/L) | Total Coliform of Raw Water (MPN/100 ml) | pH of Raw Water | BOD of Raw Water (mg/L) | TSS of Raw Water (mg/L) |
|---------------|------------|----------------------------------------|-----------------|------------------------|-------------------------|
|               | min Average max | min Average max | min Average max | min Average max | min Average max | min Average max |
| January       | 306 24000 422600 1100000 | 7.06 6.88 7.33 | 16 17 18 | 8.00 153,84 668,00 |
| February      | 239 43000 277200 1100000 | 7.31 7.08 7.60 | 11 12 13 | 73,5 189,35 491,00 |
| March         | 234 93000 349200 1100000 | 6.71 7.06 7.66 | 11 13 14 | 88,0 322,67 804,00 |
| April         | 223 43000 416000 1100000 | 7.33 7.12 7.60 | 12 13 14 | 72,0 228,40 664,00 |
| May           | 282 43000 1240600 4600000 | 7.26 7.15 7.60 | 12 14 15 | 32,0 132,91 484,00 |
| June          | 300 15000 284000 1100000 | 7.46 7.06 7.64 | 13 15 16 | 20,0 99,25 484,00 |
| July          | 292 43000 199717 1100000 | 7.16 7.13 7.69 | 11 13 16 | 12,0 14,67 24,00 |
| August        | 332 4600 24120 460000 | 7.28 7.24 7.81 | 12 11 15 | 12,0 15,39 34,00 |
| September     | 324 5300 60383 2800000 | 7.73 7.43 7.91 | 11 13 14 | 4,00 13,20 28,00 |
| October       | 356 17000 144200 2800000 | 7.66 7.52 7.99 | 12 11 15 | 8,00 10,83 28,00 |
| November      | 320 11000 23500 390000 | 7.29 7.32 7.97 | 15 13 17 | 12,0 17,82 28,00 |
| December      | 320 11000 23200 390000 | 7.29 7.73 7.97 | 15 13 17 | 12,0 19,09 28,00 |
| Range         | 223-356 3300-4600000 | 6.71-7.99 | 8.18 | 4.804 |

(a)
quality. The results of the analysis in Table 1 (a) and (b) show that the TDS, pH, and N parameters are in according with the quality standards of PP No. 82 Of 2001 for class I and II, while the others are not. Before the treatment process, raw water flows into the intake through the canal by gravity. According to the design DWTP, detention time is 2.8 hours. TSS, BOD, and COD removal in the intake canal (Metcalf and Eddy, 2014) based on equation (1) is 59.9%, 37.8%, and 37.8%. According to Metcalf et al (2014), COD removal in the primary treatment unit is 30% -40%. Meanwhile, Qasim and Zhu (2018), said that removal for N and P in the primary treatment removal is both 10% -20%. The removal of N and P in this research is 10%.

\[ R = \frac{1}{a+bt} \]  

Where, \( R \) = Removal Efficiency  
\( t \) = Time Detention  
\( a, b \) = The Empirical Constant

Therefore with only the fulfillment of the parameters pH, TDS, and N does not guarantee that the water can be used directly. Surface water needs to be treated properly in any process until following the standard quality. 

**Table 2. (a) and (b) Analysis Result of Water Production in DWTP Laboratory.**
### Table 2. Comparison of DWTP Design with Design Criteria.

| Aspect         | Unit | Design Criteria | DWTP Design |
|----------------|------|-----------------|-------------|
| Time Retention | Hour | 1.5-2.5         | 3.3         |
| Height         | Meter| 3-4.9           | 2.4         |
| Length         | Meter| 15-90           | 106         |
| Width          | Meter| 3-24            | 10.7        |
| BOD Removal    | %    | 30-35           | 39.3        |
| TSS Removal    | %    | 60-65           | 61.5        |

The pre-sedimentation effluent ranges from 6 - 82 NTU so that the % removal of turbidity in the pre-sedimentation is 60.25%. N and P removal is 20% (Qasim and Zhu, 2018).

3.2.2. *Aerator.* The velocity gradient is 771/s, while the DWTP design has a gradient speed of 1000/s (meeting the design criteria, between 100-1000/s) (Kawamura, 1991). The turbidity removal efficiency of the aerator is 89% (Suaidy, 2010). The high turbidity removal indicates that the aerator is performing well.

3.2.3. *Clearator.* Turbidity removal was 87% (based on influent and effluent laboratory data). The removal value of TSS, BOD, and COD on the clearator were 45.3%, 25.4%, and 25.4% (Metcalf and Eddy, 2014). Removal of N is between 30-60% (Suchowska-gratinelewicz et al., 2018). P removal efficiency in this modified unit is 76% (Ismail et al., 2012). The removal efficiency of the flocculation and sedimentation modification unit for TSS and BOD is 70-90% and 50-85% (Subramani, 2012). The addition of Polyacrylamide makes the flocc bigger and settles faster.
3.2.4. Filtration. The backwash discharge is the same as the pump discharge, which is 200 L/s with a duration of 7 minutes for each unit. The blower filter discharge is 15 m$^3$/min. The removal values of TSS, BOD, and COD in the filtration unit with anthracite media are 60%, 50%, and 50% (Ramadhani, 2017). In this study, it is assumed that COD removal is the same as BOD removal and due to data limitations. Removal of N and P was 37.27% and 30.37% (Purnama, 2012).

3.2.5. Reservoir. DWTP has a standard for residual chlorine, which is a maximum of 0.5 mg/L. The total distribution pumps in DWTP are 15 which are divided based on the number of reservoirs. The use of processing electricity comes from the pumps and blowers that are used during the production process. The amount of electricity used by DWTP in 2019 is 11,220,195.47 kWh/year. Based on the description above, it can be concluded that the performance of the DWTP unit in processing raw water into drinking water is in good condition based on the design criteria and literature approach. But the clearator unit has not yet been fulfilled, therefore a chemical in the form of Polyacrylamide is added to increase the removal efficiency. It can be concluded that the performance of the DWTP processing unit has not been good and requires increased efficiency.

3.3. Emission Load Analysis
The process of drinking water treatment can emit greenhouse gases, both from processing, use of supporting equipment, and use of chemicals (Kyung et al., 2013). The calculation of CO$_2$ emissions resulting from the process uses the approach of kg CH$_4$/kg BOD and kg CH$_4$/kg COD which will later be converted into units of greenhouse gases kg CO$_2$eq, where the ratio of CO$_2$ and CH$_4$ is 1:23. The emission factor used is the IPCC default (2006) in wastewater treatment. They are 0.48 kg CH$_4$/kg BOD and 0.25 kg CH$_4$/kg COD (Michiel et al., 2006). The weakness of this calculation method is that it does not take into account the environmental condition in the processing unit. Therefore, it needs direct measurements in the field (Nuraeni and Ashuri, 2018). The calculation of emissions is based on equation (2) as below (Sagala, 2012):

$$\text{Emission Load (E)} = \text{Emission Factor (EF)} \times \text{Activity Data (amount of materials that produce emission)} (A) \quad (2)$$

### Table 4. Emission Factors.

| Emission Factors    | Sources                                      |
|---------------------|----------------------------------------------|
| Electricity         | Emission Factors of Jamali’s Electricity (Jawa-Madura-Bali) |
| Consumptions        |                                              |
| Aluminium Sulphate  | Kyung, 2013                                  |
| Polyacrylamide      | (Chai, 2015)                                 |
| Liquid Chlor        | Winnipeg.ca                                  |
| BOD                 | IPCC, 2006                                   |
| COD                 | IPCC, 2006                                   |

3.4. Life Cycle Inventory (LCI)
The LCI or Life Cycle Inventory (LCI) stage is the process of inputting data on raw materials, chemicals, and electricity use as well as emissions resulting from the production process. Mass Balance or mass balance will be arranged at this stage. The processing load used was TSS, BOD, COD, N, and P. The TSS value used was a maximum value of 804 mg/L. While the maximum BOD value used was 18 mg/L based on DWTP laboratory data in 2019. The COD value used was 59.36 mg/L and 0.53 mg/L. This value is then converted into mass units so that the TSS value becomes 49,616,270.32 kg/year, the influent BOD in raw water is 1,110,812.02 kg/year. The COD value in raw water is 3,663,211.20 kg/year. The N and P values for raw water were 220,863.21 kg/year and 32,548.70 kg/year.
3.5. Life Cycle Impact Assessment (LCIA)

After carrying out the Life Cycle Inventory (LCI) stage, the next stage is the Life Cycle Impact Assessment (LCIA) which is an impact assessment stage based on inventory. The method used in the impact magnitude assessment is the CML-IA baseline. The impact assessment at this stage is to compare the results of the Life Cycle Inventory (LCI) with each category. However, this study focused on three categories of impact assessment, namely Global Warming (GWP 100a), Human Toxicity, and Eutrophication.

3.6. Characterization Analysis

This stage aims to determine and compare the results of the Life Cycle Inventory (LCI) data input in each category.

![Figure 1. Diagram of Impact Contributions.](image)

Figure 1 shows a diagram of the impact contribution generated from each processing unit in DWTP with the overall Impact Assessment results can be seen in Table 5.

| Treatment Process | Global Warming (kg CO₂eq) | Human Toxicity (kg 1,4-DB eq) | Eutrophication (kg PO₄−eq) |
|-------------------|---------------------------|-------------------------------|----------------------------|
| Intake            | 23,814                    | 0.00                          | 49,699.32                  |
| Pre-sedimentation | 333,774.6                 | 280,161.04                    | 54,955.61                  |
| Aerator           | 4,343,514.18              | 2,970,449.46                  | 10,055.84                  |
| Clearator         | 55,519.9                  | 15,334.10                     | 82,408.54                  |
| Filtration        | 375,701.9                 | 115,123.80                    | 36,095.90                  |
| Reservoir         | 18,564,950.4              | 5,809,173                     | 54,428.77                  |
| **TOTAL**         | **23,697,275**            | **9,190,241**                 | **287,644.1**              |

3.7. Normalization Analysis (Normalization)

This stage is the stage to facilitate comparison between Impact Categories by multiplying the Characterization results and the normalization factors. The output from this stage is that all Impact Categories use the same unit or units so that they can be compared.
Figure 2 shows the contribution of the impact per processing unit while the results of normalization can be seen in Table 6. It shows that the greatest environmental impact as a whole comes from the Eutrophication impact category of $2.18 \times 10^{-5}$.

3.8. Process Hotspot Analysis and Impact Hotspot
The process hotspot is the point that has the greatest impact on the processing system. Table 6 shows the hotspots of the processing at DWTP, namely the Reservoir unit of $8.57 \times 10^{-6}$. The order of the largest impact contribution to the DWTP drinking water treatment process is the reservoir unit ($8.57 \times 10^{-6}$), the clearator unit ($6.26 \times 10^{-6}$), the pre-sedimentation unit ($4.27 \times 10^{-6}$), intake ($3.77 \times 10^{-6}$), filtration unit ($2.83 \times 10^{-6}$), and aerator unit ($2.01 \times 10^{-6}$). The impact hotspot is the point that has the greatest impact in this study, which is Eutrophication.

3.9. Data validation
Data validation was carried out by using Sensitivity Check, which is a systematic process to check whether the final results and conclusions are affected by the uncertainty of the data and the selected evaluation method. Variations are carried out by increasing and decreasing the processing load, chemicals used, energy, and emissions by 25% which refers to SNI ISO 14044 (2017).

Table 7. Impact Assessment Results.

| Impact Categories | -25%       | Normal    | +25%     |
|-------------------|------------|-----------|----------|
| Global Warming    | 13,958,372 | 18,564,950| 23,240,846,1 |
| Human Toxicity    | 4,356,880  | 5,809,173 | 7,261,466,3  |
| Eutrophication    | 40,821,57  | 54,428,77 | 68,035,96   |
In Table 7 it is known that by doing variations there is a change in value, so it can be said that the data used in this study is sensitive to change. As for the significance analysis, the deviation value is sought for each data variation. The results of deviation data for all impact categories can be seen in Table 8.

| Impact Categories | Deviation | % Deviation |
|-------------------|-----------|-------------|
| Global Warming    | ±0,00     | 0%          |
| Human Toxicity    | ±0,00     | 0%          |
| Eutrophication    | ±0,00     | 0%          |

Based on Tables 7 and 8, the results of the sensitivity check in this study are ± 0 or 0%. Based on SNI ISO 14044 (2017), because the deviation calculation results are below 10%, it can be concluded that the data processed in SimaPro is sensitive but not significant.

### 3.10. Impact Reduction Efforts

#### 3.10.1. Global Warming

Based on the results of the analysis, that the second biggest impact resulting from the DWTP water treatment process is Global Warming due to CO₂ gas produced from greenhouse gases which have a major contribution to fuel combustion for electricity supply. This impact comes from pumps running for 24 hours and emissions from the use of chemicals. An alternative that can be done to reduce the impact of Global Warming due to high emissions of electricity is to make equipment efficient by replacing equipment with new equipment which can save energy by 22% (Saygin et al., 2012). The impact of CO₂ emissions due to the use of aluminum sulfate chemicals is to replace it with PAC (Poly Aluminum Chloride) which is a coagulant substitute.

#### 3.10.2. Human Toxicity

In this study, Human Toxicity comes from the use of chemicals. The effort to reduce this impact is by substituting the chemical substances. The Hypochlorite salt in liquid form does not cause toxicity effects on humans (Utami, 2019). Chlorine in the form of salt is safest to use as a disinfectant (Hasan, 2006). Meanwhile, a coagulant substitute is PAC (Poly Aluminum Chloride) which produces a denser floc with a high settling rate in a large fluctuation of processing range.

#### 3.10.3. Eutrophication

DWTP's drinking water treatment process contributes to the eutrophication impact that comes from the use of chemicals and processing costs in the form of sludge and contributes to emission. This processing sludge in DWTP is discharged directly into the river, without any treatment. To reduce the impact of eutrophication can be done by adding a sludge treatment unit that aims to remove water content from the sludge, and adding pretreatment to raw water, so that the raw water has a level that is in accordance with the class I and II quality standards in PP. 82 of 2001. Another effort that can be made is by recovering the sludge from the coagulation-flocculation process through the sludge recirculation process. This can reduce the use of coagulants by 60% of the dose (Halifrain and Karnaningroem, 2012).

### 4. Conclusion

The conclusion of this study is: The quality of DWTP raw water is not in accordance with (PP No. 82 of 2001). The water production that is in accordance with (Regulation of the Minister of Health No. 492 of 2010) are TSS, TDS, pH, Turbidity, Total Coliform, BOD, COD, N, and P parameters. DWTP's performance is not good. Consequently, it is necessary to add polymers to the clarator unit to increase removal efficiency. The amount of electrical energy used by DWTP is 11,220,195.47 kWh/year. The biggest environmental impact using the Life Cycle Assessment (LCA) approach is Eutrophication of 287,644.1 kg PO₄ - eq /
year and followed by Global Warming of 23,697.275 kg CO₂eq / year, Human Toxicity of 9,190,241 kg 1.4 - DBeq/year. There are several ways that can be used to reduce the resulting environmental impact, such as pretreatment of raw water, planning sludge treatment buildings and reusing sludge from clarator unit, replacing old equipment with new ones, replacing aluminum sulfate and liquid chlorine into PAC and hypochlorite salt.

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