Effectiveness of Wastewater Treatment Plant (WWTP) in Semanggi, Surakarta City

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Abstract
The increase in pollution load from domestic activities demands the existence of an effective wastewater treatment system to protect environmental quality and public health. Therefore, this study was conducted to evaluate the effectiveness of the Semanggi Wastewater Treatment Plant (WWTP), Surakarta City, in improving the quality of domestic wastewater. Wastewater samples were taken at the influent and effluent points, then analyzed based on physicochemical and biological parameters, including pH, BOD, COD, TSS, ammonia, total detergent, oil and grease, residual chlorine, and fecal coliform. The results showed that the influent wastewater exceeded quality standards in several parameters, indicating a high load of organic and biological pollutants. After the treatment process, all parameters met the quality standards for domestic wastewater according to Regulation No. 11/2025. The efficiency of BOD, COD, TSS, and fecal coliform removal reached over 80%, categorizing it as very effective, while ammonia and residual chlorine were also effectively reduced. Oil and grease experienced moderate reduction, and total detergent showed low removal efficiency, but the effluent concentration remained within safe limits. Overall, the results confirm that the Semanggi Wastewater Treatment Plant operates well in reducing domestic wastewater pollutants and plays an important role in environmental protection efforts and improving public health.

Keywords: *Domestic Wastewater; WWTP; Treatment Effectiveness and Water Quality.*

I. INTRODUCTION

The rapid population growth in Indonesia, especially in urban areas, has put significant pressure on environmental carrying capacity. Ongoing urbanization has led to a sharp increase in the urban population, and it is projected that by 2025, most Indonesians will live in urban areas [1]. This increase in population is directly proportional to the rising consumption of clean water, which in turn generates a larger volume of domestic wastewater. The disposal of untreated wastewater has the potential to pollute surface water and groundwater sources, posing health risks to the community [2]. Environmental statistical data shows that most households in Indonesia still dispose of domestic wastewater into open channels or soak pits, while the use of wastewater treatment plants (WWTP) remains limited [3]. To address this issue, the government has developed a domestic wastewater treatment system (WWTP) considering population density, environmental conditions, and funding capabilities. The effectiveness of wastewater treatment is greatly influenced by the characteristics of the wastewater, treatment methods, system design, and proper operation [4]. Environmental pollution resulting from the increasing volume of wastewater poses serious risks to human health. These impacts do not always appear immediately but can arise after several years. Pollution occurs due to the imbalance between human activities and the declining capacity of the environment, thus reducing nature's ability to support human life [5]. Furthermore, various epidemiological studies show a relationship between wastewater pollution and the increased incidence of waterborne diseases. Water contaminated with pathogens such as bacteria, viruses, and parasites can cause diarrhea and cholera [6].

Long-term exposure to water contaminated with hazardous chemicals, such as heavy metals and organic compounds, can even lead to respiratory disorders, neurological disorders, reproductive disorders, and cancer. This condition highlights the critical importance of effective wastewater management in reducing public health risks. One of the domestic wastewater treatment plants operating in Indonesia is the Semanggi WWTP in Surakarta City, which serves thousands of households with an initial capacity of 30 liters per second. As of August 2025, this WWTP has served 11,932 household connections with a wastewater flow rate of 64.62 liters per second. Although it has been operating for more than two decades, previous research has shown that treatment efficiency, particularly in reducing ammonia levels, was still not optimal [7]. This condition indicates the need for further evaluation of the performance and operational challenges of the WWTP to minimize potential environmental pollution and ensure that the effluent quality meets the established standards. Based on this background, this study aims to analyze the effectiveness of the Semanggi WWTP in managing domestic wastewater in Surakarta City and to identify the constraints and improvement strategies needed to enhance wastewater treatment performance.

II. METHODS

This study uses a quantitative descriptive approach to evaluate the effectiveness of the Semanggi Wastewater Treatment Plant (WWTP) in Surakarta City. The research was conducted in October 2025 at the Semanggi WWTP facility, while laboratory analysis was carried out at the Environmental Laboratory of Perum Jasa Tirta I. The object of this research is the domestic wastewater treated at the WWTP, focusing on the comparison of wastewater quality before and after treatment to determine the level of treatment effectiveness. The research population includes all domestic wastewater flowing through the Semanggi WWTP system, while the samples consist of wastewater taken at the influent (inlet) and effluent (outlet) points. Wastewater sampling was conducted using the grab sampling method in accordance with the Indonesian National Standard (SNI) 6989.59:2008 on water and wastewater sampling. Sampling was conducted at one time and one location for each sampling point, ensuring that the wastewater was perfectly mixed in the system.

To obtain representative samples, sampling was conducted during peak influent flow conditions, specifically between 06:00–10:00 WIB (UTC+7). In this study, two samples were obtained, namely one influent sample and one effluent sample. The collected samples were then preserved and taken to the laboratory for further analysis. Laboratory testing was conducted to analyze the physicochemical and biological characteristics of the wastewater. The parameters tested include pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), ammonia (NH_3), fecal coliform, oil and grease, total detergent, and residual chlorine. These parameters were chosen because they are the main indicators of domestic wastewater pollution and are regulated in Indonesian environmental standards. All analyses were conducted using standard laboratory methods based on SNI and Standard Methods for the Examination of Water and Wastewater to ensure the accuracy and reliability of the results. Data analysis was performed by comparing laboratory results of influent and effluent wastewater with the quality standards for domestic wastewater as stated in the Regulation of the Minister of Environment and the Environmental Control Agency of the Republic of Indonesia Number 11 of 2025.

The effectiveness of the Semanggi WWTP was calculated based on the percentage reduction in concentration of each parameters between the inlet and outlet, using the following formula [8]:

$$\mathbf{E = \frac{Si - So}{Si} \times 100\%}$$

Description:

E = Effectiveness of wastewater treatment (%)
Si = Inlet concentration (mg/L)
So = Outlet concentration (mg/L)

The effectiveness values obtained were then categorized based on the criteria according to Soeparman & Suparmin (2001) as follows [8]:

1. Very effective : $E > 80\%$
2. Effective : $60\% < E \leq 80\%$
3. Moderately effective : $40\% < E \leq 60\%$
4. Less effective : $20\% < E \leq 40\%$
5. Not effective : $E \leq 20\%$

The classification is used to assess the performance of the wastewater treatment system in reducing pollutant loads. The results of the analysis are then presented descriptively in the form of tables and narrative descriptions to facilitate interpretation and discussion regarding the overall effectiveness of domestic wastewater treatment at the Semanggi Wastewater Treatment Plant (WWTP), Surakarta City.

III. RESULT AND DISCUSSION

This section presents the results of the evaluation of domestic wastewater treatment performance at the Semanggi Wastewater Treatment Plant (WWTP), Surakarta City. The analysis was conducted by comparing the quality of influent and effluent wastewater to assess changes in key physicochemical and biological parameters, including pH, BOD, COD, TSS, ammonia, total detergent, oil and grease, residual chlorine, and fecal coliform, and comparing them with the applicable domestic wastewater quality standards. This research focuses on the Semanggi Wastewater Treatment Plant (WWTP) in Surakarta City, which is a centralized domestic wastewater treatment facility owned by the Surakarta City Government and managed by PERUMDA Toya Wening.

This Wastewater Treatment Plant (WWTP) is located in the Jamparing area, Pasar Kliwon District, with a strategic position downstream of the domestic wastewater disposal network and has direct access to the Premulung River as the receiving water body. The wastewater entering the Wastewater Treatment Plant (WWTP) comes from various sources, namely septic tank waste, communal waste from residential areas, and hotel waste. The wastewater treatment technology used at the Semanggi Wastewater Treatment Plant (WWTP) is the Activated Sludge system with aeration biofilter, which operates similarly to a Moving Bed Biofilm Reactor (MBBR). This system utilizes the activity of aerobic microorganisms attached to the biofilter media to decompose organic materials contained in domestic wastewater. Aeration is carried out continuously to maintain the availability of dissolved oxygen needed by microorganisms in the biodegradation process. The existence of the Semanggi Wastewater Treatment Plant (WWTP) is very important in efforts to reduce water pollution loads due to the increasing volume of domestic waste in urban areas.

Wastewater Treatment Process

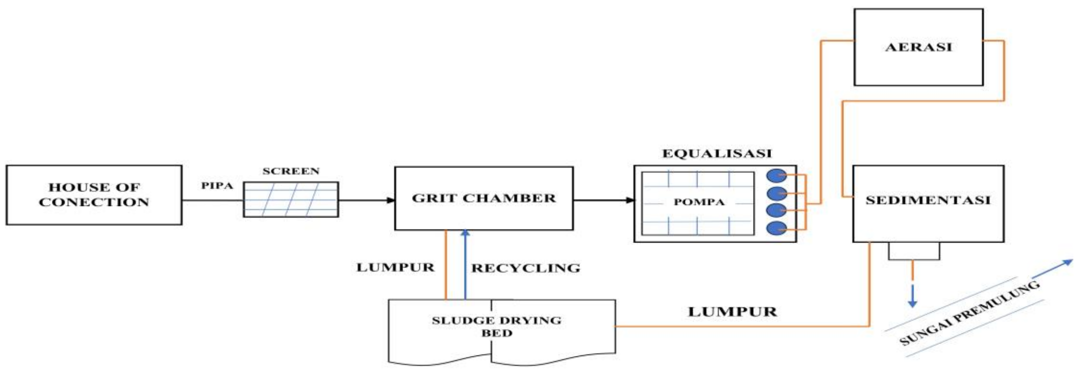

Fig. 1. Flow Diagram and Process of Semanggi Wastewater Treatment Plant, Surakarta City
(Source: Researcher, 2026)

1. Grit Chamber Tank/Inlet

Wastewater from the piping network enters the grit chamber for initial screening. At this stage, the bar screen filters out coarse debris, while the sludge pump removes sand and heavy materials. The flow of water is regulated through the sluice gate and V-notch before proceeding to the equalization tank.

2. Equalization Tank

This unit functions to stabilize daily flow fluctuations so that the flow and pollutant load become constant. Water from the equalization tank is continuously pumped to the aeration tank so that the biological process can occur optimally. There are 6 pumps in the equalization tank and 1 bypass pump that continuously flows to the aeration tank 24 hours a day.

3. Aeration Tank

In the aeration tank, air is pumped through a blower to provide oxygen for aerobic microorganisms. Inside the aeration tank, biofilter balls are placed in the aeration tank but are enclosed in wire boxes. The biofilter media is placed in wire boxes so that microorganisms can grow attached and decompose organic materials. The mixing and biological oxidation process occurs intensively before the water is channeled to the sedimentation tank. Water that has completed the aeration tank is gravity-fed to the sedimentation tank, and the floc that settles at the bottom of the aeration tank will be pumped to the sludge drying tank.

4. Sedimentation Tank

Water from aeration enters the sedimentation unit, which functions to settle the floc that has formed. The settled sludge is pumped to the sludge drying tank, while the clearer water flows to the next process.

5. Sludge Drying Bed

Sludge from various treatment units is collected in the sludge drying bed. Here, water from the sludge is filtered through a media layer (gravel-sand), while the remaining solid sludge can be further utilized, for example, as compost. The sludge drying bed functions to reduce the water content in the sludge or as a drying tool for the sludge produced from the screen and grit chamber. This bed collects liquid sludge from the grit chamber unit, aeration unit, and sedimentation unit, where the sludge will settle and the sludge water will seep into the gravel filter that will flow to the grit chamber unit. The settled sludge can be used as compost.

6. Outlet

Treated water that meets quality standards is discharged into the Premulung River towards the Bengawan Solo. At this stage, the effluent is ensured to be safe for the environment according to the established quality standards. The water can then be discharged into the Premulung River 600 m to the Bengawan Solo if the domestic wastewater parameters meet the established quality standards.

Table 1. Wastewater Quality Analysis at Influent and Effluent Points

Parameters	Unit	Quality Standard (Regulation of the Minister of Environment and Environmental Control Agency No. 11/2025)	Test Results		Testing Method
			Inlet	Outlet	
pH	-	6 – 9	6.54	7.35	SNI 06-6989.11.2019
BOD	mg/L	30	59.36	9.10	SM APHA 23rd Ed., 5210 B,2017
COD	mg/L	100	247.2	39.21	SNI 6989.2:2019
TSS	mg/L	30	49.0	9.00	SM APHA 23rd Ed., 2540 D, 2017
Ammonia	mg/L	10	12.34	3.374	SM APHA 23rd Ed., 4500-NH_3 F, 2017
Detergent Total ***	mg/L	5	0.0479	0.0443	SNI 06-6989.51-2005
Oil and Grease	mg/L	5	5.50	3.00	SM APHA 23rd Ed., 5520 B,2017
Residual Chlorine *)	mg/L	1	0.21	0.08	QI/LKA/108
Fecal Coliform	MPN/100 ml	1.000	4300	700	QI/LKA/53 (Tabung Ganda)

Based on Table 1, the influent wastewater quality at the Semanggi Wastewater Treatment Plant did not meet domestic wastewater quality standards for most parameters. While pH remained within the permissible range, concentrations of BOD, COD, TSS, ammonia, oil and grease, and fecal coliform exceeded regulatory limits, indicating a high organic and biological pollution load. In contrast, total detergent and residual chlorine levels were within acceptable standards. These findings indicate that the influent wastewater exhibited typical characteristics of heavily polluted domestic wastewater, requiring effective treatment processes. Following treatment, effluent wastewater quality showed a substantial reduction in nearly all parameters. pH values remained within the standard range, and concentrations of BOD, COD, TSS, ammonia, oil and grease, and fecal coliform decreased to levels below the regulatory limits. All analyzed parameters in the effluent complied with the Indonesian domestic wastewater quality standards stipulated in Regulation No. 11/2025, demonstrating that the Semanggi Wastewater Treatment Plant operates effectively in reducing pollutant loads and improving domestic wastewater quality.

Table 2. Treatment Effectiveness of the Semanggi Wastewater Treatment Plant, Surakarta City

Parameters	Unit	Test Result		Reduction	Effectiveness (%)	Remarks
		Inlet	Outlet			
pH	-	6.54	7.35	-	-	Complies with Quality Standards
BOD	mg/L	59.36	9.10	50.26	84.67	Very Effective
COD	mg/L	247.2	39.21	207.99	84.18	Very Effective
TSS	mg/L	49.0	9.00	40	81.63	Very Effective
Ammonia	mg/L	12.34	3.374	8.966	72.65	Effective
Detergent Total ***	mg/L	0.0479	0.0443	0.0036	7.52	Not Effective
Oil and Grease	mg/L	5.50	3.00	2.50	45.45	Moderately Effective
Residual Chlorine *)	mg/L	0.21	0.08	0.13	61.90	Effective
Fecal Coliform	MPN/100 ml	4300	700	3600	83.72	Very Effective

Based on Table 2, the effectiveness of the Semanggi WWTP is evaluated by comparing the pollutant concentrations in influent and effluent wastewater. The results show that the removal efficiency of BOD, COD, TSS, and fecal coliform exceeds 80%, thus categorized as very effective. Ammonia and residual chlorine show effective reductions, while oil and grease experience moderate reductions. Conversely, total detergent shows low efficiency due to low influent concentrations. However, the effluent levels remain within safe limits. This section discusses the interpretation of the wastewater quality testing results and the measurement of the effectiveness of the Semanggi WWTP by linking theoretical concepts, research results, and previous studies.

1. pH Parameters

pH is a critical parameters in wastewater treatment because it affects microbial activity in biological processes [9]. The accepted pH range for domestic wastewater is 6–9. This ensures that the treated effluent does not adversely affect the ecological balance of the receiving water body. In this study, the pH increased from 6.54 at the inlet to 7.35 at the outlet, remaining within the quality standard limits. This indicates that the Semanggi Wastewater Treatment Plant (WWTP) is effective in stabilizing pH, creating conditions that support microbial degradation and are safe for discharge into water bodies.

2. BOD and COD Parameters

BOD and COD are the main indicators of organic pollutants in domestic wastewater. High values indicate a high load of organic materials that require oxygen for degradation [10]. At the Semanggi wastewater treatment plant (WWTP), BOD decreased from 59.36 mg/L to 9.10 mg/L (effectiveness 84.67%), while COD decreased from 247.2 mg/L to 39.21 mg/L (removal efficiency 84.18%). All outlet values have met quality standards and demonstrate very effective treatment performance. The decrease in BOD is supported by the success of the biofilter process, adequate detention time, and the availability of dissolved oxygen for microbes [11]. Meanwhile, the decrease in COD is influenced by the aeration process that enhances microbial activity in breaking down organic compounds, as well as the sedimentation process that aids in the separation of suspended particles [12].

3. TSS Parameters

Total Suspended Solids (TSS) reflect suspended particles that can carry other pollutants in wastewater. The decrease in TSS at the Semanggi Wastewater Treatment Plant (WWTP) is supported by sequential processes, including grit chamber, bar screening, sedimentation, and microbial activity in the biofilter. TSS decreased from 49.0 mg/L at the inlet to 9.00 mg/L at the outlet, with an effectiveness of 81.63%, indicating very effective performance in reducing suspended solids. Additionally, the efficiency of TSS reduction in domestic Wastewater Treatment Plant (WWTP) has the potential to be further improved by optimizing the aerobic biofilter process and adjusting the detention time in the sedimentation tank. This finding is consistent with previous studies, as this step is expected to increase TSS reduction efficiency by more than 65% [11].

4. Ammonia Parameters

Ammonia, a toxic byproduct of nitrogen waste decomposition, is primarily removed through the nitrification process aided by adequate aeration. Aeration rate can influence core bacteria to reduce nitrogen loss [13]. The significant decrease in ammonia concentration indicates that adequate aeration effectively supports the activity of nitrifying microorganism, consistent with previous findings regarding the role of oxygen availability in ammonia removal [9].

5. Total Detergent

Detergents, particularly surfactants from domestic washing activities, are chemically stable and difficult to degrade biologically [10]. Minimal reduction indicates that the conventional Semanggi Wastewater Treatment Plant (WWTP) process is not optimal in removing surfactants, although the effluent concentration still meets quality standards. This is consistent with evidence that surfactant removal generally requires physical-chemical treatment technology or tertiary stages [10].

6. Oil and Grease Parameters

Hydrophobic compounds such as oil and grease can inhibit biological processes [11]. Concentration decreased from 5.50 mg/L to 3.00 mg/L, with an effectiveness of 45.45%, categorized as fairly effective. Aerobic microorganism are capable of partially degrading oil and grease compounds, consistent with the performance of conventional WWTP. However, the remaining oil and grease in the effluent is likely due to limitations in the treatment process within the aerobic system [14].

7. Residual Chlorine

Residual chlorine, as a fraction of disinfectant agents, must be reduced to prevent toxicity in the receiving water body. Suspended particles in water can carry bacteria on their surfaces, which protect them from the cleaning action of chlorine [15]. The treatment process reduces chlorine through reactions with organic materials and microbial activity, reflecting the system's ability to maintain chlorine levels within safe limits.

8. Fecal Coliform

Fecal coliform becomes an indicator of fecal contamination and the presence of pathogens. The decrease indicates the effectiveness of the wastewater treatment process. The count decreased from 4,300 MPN/100 ml at the inlet to 700 MPN/100 ml at the outlet, with an effectiveness of 83.72%, categorized as very effective. This reduction was achieved through sedimentation and biological contact processes, consistent with previous studies stating that centralized domestic WWTPs are capable of significantly reducing fecal coliform through these mechanisms [16].

Overall, the Semanggi Wastewater Treatment Plant (WWTP) showed good performance in reducing most pollutants, thus meeting quality standards. However, continuous operational monitoring and targeted improvements are still needed to ensure consistent compliance and minimize environmental impacts on receiving water bodies. These findings emphasize the importance of adaptive management and system optimization in urban wastewater treatment.

IV. CONCLUSION

Domestic wastewater entering the Semanggi Wastewater Treatment Plant (WWTP) shows a high organic and biological pollutant load, thus requiring effective treatment to meet applicable quality standards. Therefore, treatment performance is evaluated using key physicochemical and biological parameters to provide a comprehensive assessment of the effectiveness of the WWTP. High removal efficiency was achieved for BOD, COD, TSS, and fecal coliform, indicating that the biological and physical treatment units operate very effectively. Ammonia and residual chlorine were also successfully reduced effectively, while oil and grease showed moderate reduction. Total detergents had low removal efficiency due to low influent concentrations, although effluent levels remained within permissible limits. In conclusion, this study demonstrates that the Semanggi Wastewater Treatment Plant is effective in improving domestic wastewater quality and producing effluent that meets national standards, supporting environmental pollution control and public health protection. Therefore, future improvement efforts should focus on evaluating and optimizing treatment process for total detergent removal, through the implementation of advanced treatment units. One solution that can be implemented is the addition of more effective coagulation and flocculation processes.

V. ACKNOWLEDGMENTS

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