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Evaluation of The Bantar Water Treatment Plant (WTP) at PDAB Tirtatama Special Region of Yogyakarta

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ABSTRACT
The Bantar Water Treatment Plant (WTP) operated by PDAB Tirtatama is a key infrastructure for clean water supply in the Special Region of Yogyakarta. This study evaluates the performance of the Bantar WTP by assessing treatment unit compliance with design criteria and water quality standards. The evaluation was conducted through field observations, hydraulic calculations, and laboratory water quality analyses during a one-month internship period. The results show that several raw water parameters from the Progo River, including color, turbidity, and zinc, do not meet the Regional Regulation of the Special Region of Yogyakarta No. 20 of 2008. While the coagulation, flocculation, and filtration units comply with SNI 6774:2008, the pre-sedimentation and sedimentation units fail to meet Reynolds and Froude number criteria, resulting in non-laminar flow conditions that hinder particle settling. Despite these limitations, treated water quality in the reservoir complies with the Ministry of Health Regulation No. 2 of 2023. Operational improvements and enhanced maintenance are recommended to ensure sustainable performance.

Keywords: water treatment plant; performance evaluation; water quality standards

BACKGROUND

Water serves as an essential resource across various human activities. In everyday life, it is indispensable for drinking, cooking, washing, bathing, and sanitation [1]. Moreover, significant quantities of water are required to fulfill the demands of economic and social activities, including those of industries, healthcare facilities, hospitality establishments, commerce, corporate offices, and educational institutions. The volume of clean water needed varies according to each specific activity, and the quality standards are contingent upon the nature of the activity in question [2].

With the expansion of the population and the increase in economic activities within the community, the water demand is intensifying in terms of both quantity and quality. The availability of groundwater is becoming increasingly constrained, while surface water is deteriorating in quality due to pollution. The presence of water that possesses adequate quality and quantity is a vital factor for facilitating economic and industrial growth in the region [3]. Water treatment is crucial for several reasons. First, the availability of water can diminish during certain periods, such as the dry season. Secondly, the quality of raw water frequently falls short of the standards required for safe use [4]. Additionally, pollution from various sources, including industrial, residential, agricultural, and livestock activities, contaminates raw water sources.

The establishment of a water treatment plant, such as the IPA at PDAB Tirtatama in the Special Region of Yogyakarta, is imperative to fulfill the needs of clean water around the Special Region of Yogyakarta. A water treatment facility must effectively eliminate various contaminants, including physical, chemical, and biological pollutants, to ensure that the water quality adheres to the standards established by the Ministry of Health. Furthermore, the reliability of a water treatment plant is evaluated based on three critical criteria: the quality, quantity, and continuity of the water produced. Achieving these criteria is contingent upon the proper fulfillment of both technical and non-technical requirements.

On the other hand, evaluating the performance of the Bantar Water Treatment Plant (WTP) is therefore essential to ensure that the treatment processes operate effectively and sustainably in meeting regional water demands. Performance evaluation enables the identification of operational inefficiencies, equipment limitations, and deviations from design criteria that may compromise water quality, production capacity, or service continuity. Moreover, regular assessment provides a basis for optimizing treatment unit performance, ensuring compliance with applicable water quality regulations, and supporting informed decision-making for maintenance, rehabilitation, or system upgrades [5], [6].

Through systematic performance evaluation, the Bantar WTP can continue to function reliably as a key infrastructure in supplying safe and sufficient clean water for the Special Region of Yogyakarta.

MATERIALS AND METHODS

The evaluation of the Bantar WTP follows the internship program that was conducted for one month, from January 8 to February 9, 2024, at the PDAB Tirtatama DIY Production Unit located in Klangon, Argosari Village, Sedayu District, Bantul Regency, in the Special Region of Yogyakarta.

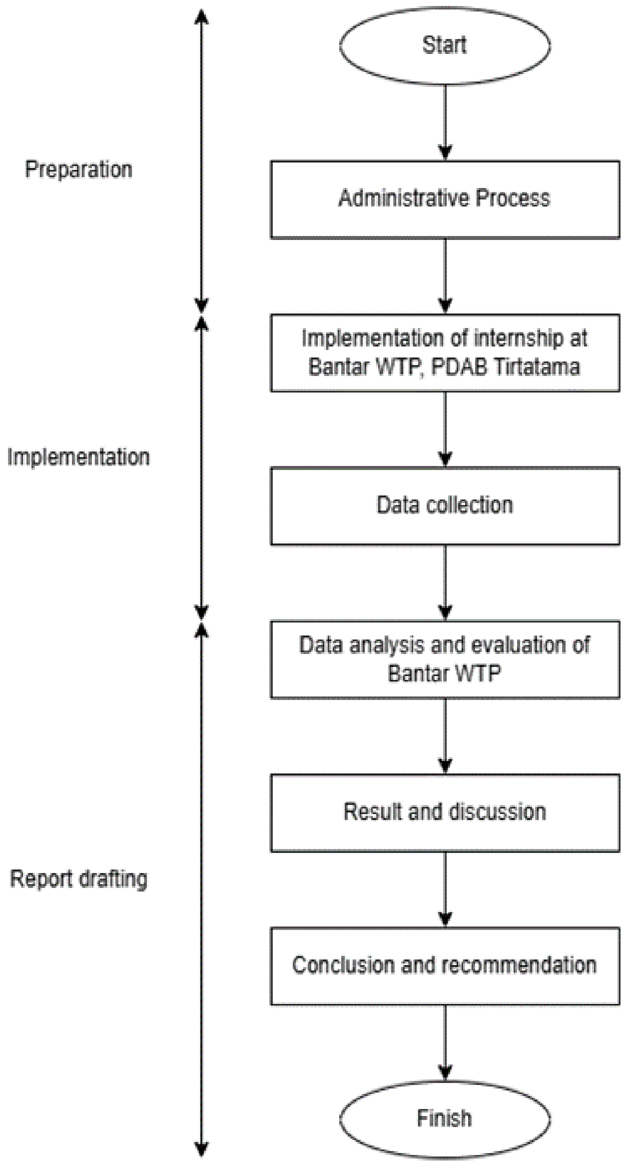

FIGURE 1: Internship Flow Diagram.

The internship was divided into three stages: the preparation stage, the implementation stage, and the report preparation stage. A flow diagram illustrating these three stages is shown in Figure 1. In daily life, proper processing methods ensure safety for consumption. The internship program analyses the performance of WTP, including pre-sedimentation, coagulation, flocculation, sedimentation, and filtration.

RESULT AND DISCUSSION

A. Observation Results on Internship Objects

The Bantar WTP of SPAM Regional Kartamantul primarily functions through manual operation, though several pumps can be controlled from the operator's room. The operational framework of The Bantar IPA, encompassing the processes from intake to the clear well, is monitored via a SCADA system that provides real-time data for each unit. This observation focuses on the comprehensive water treatment process, which includes the stages of intake, pre-sedimentation, coagulation, flocculation, sedimentation, filtration, and the reservoir.

B. Raw Water Intake Unit

When evaluating the feasibility of providing clean water, key parameters typically include quality, quantity, accessibility, affordability, and continuity. A significant concern is the availability of water resources, as they are the primary source of clean water. The consistency of clean water services heavily relies on having a sufficient supply of raw water.

TABLE 1: Raw Water Quality Test Result.

Parameter	Unit	Maximum level	Test result
Odor	-	Odorless	Odorless
Temperature	°C	Air Temperature ±3	25.9
Color	TCU Scale	50	1100
Turbidity	NTU Scale	5	134.2
Total Dissolved Solids (TDS)	mg/L	1000	146.6
pH	-	6-8.5	8.07
Chloride (Cl)	mg/L	600	12.65
Total Ammonia (NH_3N)	mg/L	0.5	< detectionlimit
Sulfate (SO_4)	mg/L	400	25.75
Flouride (F-)	mg/L	0.5	< detectionlimit
Nitrite as N	mg/L	0.06	0.025
Nitrate (NO3-N)	mg/L	10	5.136
Iron (Fe)	mg/L	0.3	2.89
COD	mg/L	10	-
Arsen (As)	mg/L	0.05	0.005
Cadmium (Cd)	mg/L	0.01	0.03
Hexavalent chromium (Cr^{6+})	mg/L	0.05	0.137
Manganese (Mn)	mg/L	0.1	0.359
Cyanide (CN-)	mg/L	0.02	0
Zinc (Zn)	mg/L	0.05	0.292
Total Coliform	CFU/100ml	1000	TNTC
E.Coli	CFU/100ml	100	95

The internal test results report for raw water quality at The Bantar water treatment plant (Table 1) reveals that certain parameters do not conform to the quality standards established by the Governor of the Special Region of Yogyakarta, in accordance with Regulation Number 20 of 2008 concerning Water Quality Standards[7]. The specific parameters identified as non-compliant include color, turbidity, and levels of zinc.

To guarantee that raw water is suitable for everyday use and safe for consumption, it is essential to undertake a thorough treatment and processing regimen. This process encompasses several critical steps, including pre-sedimentation, coagulation, flocculation, sedimentation, and filtration. These methods work collaboratively to ensure the water meets safety and quality standards for all users.

C. Production Unit

- ***Intake***

The Bantar Water Treatment Plant operates using a river intake system, strategically positioned in proximity to the Progo River, which serves as its raw water source. A coarse screen is installed at the pump's inlet. However, observations from the field have revealed that plastic waste continues to be transported by the pump to the filtration unit. This issue highlights the need for ongoing monitoring and potential improvements in waste management practices.

The Bantar Water Treatment Plant has four pumps: three intake pumps and one drain pump. To prevent damage from simultaneous operation, only one pump is used at a time, alternating usage daily. The pumps are submersible types with a capacity of 270 to 350 liters per second.

The raw water carrier channel from the intake to the pre-sedimentation tank has a total length of approximately 920 meters, with intake pipe diameters of 300 mm and 600 mm. The pipes used are made of galvanized material.

- ***Pre-Sedimentation***

The Pre-sedimentation Unit is designed with a capacity of 400 liters per second. However, the current incoming water discharge is approximately 300 liters per second, as only one pump is currently operational. The facility comprises four pre-sedimentation tanks, each with a depth of 6.5 meters. Prior to entering the tanks, water is screened through a mesh measuring approximately 1 cm to effectively remove debris from the intake. Each tank is scheduled to be drained monthly. It is noteworthy that the turbidity levels in the Pre-sedimentation Unit vary seasonally: during the dry season, turbidity levels typically range from 20 to 30 NTU, whereas during the rainy season, turbidity can escalate to between 30 and 2,000 NTU.

Given:
- Length of Each Column = 24 m
- Width of Each Pool = 4 m
- Depth = 6,5 m
- Kinematic viscosity of water at 26°C (μ) = 0.893 × 10^{-6} m^2/s
- Gravitational acceleration (g) = 9.81 m/s^2

Calculation:
- Hydraulic Radius

$$R = \frac{L \times H}{L + 2H}$$

$$R = \frac{4m \times 6.5m}{4m + 2(6.5m)} = 1.53 \text{ m}$$

- Reynolds Number

$$N_{Re} = \frac{V_h \times R}{\mu}$$

$$N_{Re} = \frac{0.01 \text{ m/s} \times 1.53\text{m}}{0.893 \times 10^{-6}\text{m}^2/\text{s}}$$

$$\mathbf{N_{Re} = 6,587 > 2,000 \text{ (does not satisfy)}}$$

- Froude Number

$$N_{Fr} = \frac{{V_h}^2}{g \times R}$$

$$N_{Fr} = \frac{(0.01 \text{ m/s})^2}{9.81 \text{ m/s}^2 \times 1.53 \text{ m}}$$

$$\mathbf{N_{Fr} = 9.86 \times 10^{-7} < 10^{-5} \text{ (does not satisfy)}}$$

Based on the aforementioned calculations, it is evident that the pre-sedimentation unit does not meet the criteria for the Reynolds number and Froude number. Consequently, the flow within the pre-sedimentation basin is not laminar, which hinders prolonged particle settling and can result in elevated water turbidity from the pre-sedimentation basin.

- ***Coagulation***

At the Bantar Water Treatment Plant (WTP), the coagulation process does not employ mechanical mixers. Instead, it relies solely on hydraulic jumps and mixing within the coagulation basin. The coagulant chemical used at The Bantar WTP is PAC (Poly-Aluminum Chloride).

Given:
- Design flow rate = 400 L/second = 0.4 m^3/s
- Outer side length = 3.21 m
- Inner side length = 2.7 m
- Tank depth = 2.4 m
- Coagulation tower height = 7.5 m

Calculation:
- Volume

$$V = \text{base area} \times \text{height}$$

$$V = \frac{3\sqrt{3 \times s^2}}{2} \times \text{height}$$

$$V = \left(\frac{3\sqrt{3 \times (3.21 \text{ m})^2}}{2} - \frac{3\sqrt{3 \times (2.7 \text{ m})^2}}{2}\right) \times 2.4 \text{ m}$$

$$= 18.79 \text{ m}^3$$

- Detention time

$$td = \frac{V}{Q}$$

$$td = \frac{18.79 \text{ m}^3}{0.4 \text{ m}^3/\text{s}}$$

$$\mathbf{td = 47 \text{ second} < 60 \text{ second (satisfy)}}$$

- Velocity gradient

$$G = \left(\frac{g \times h}{\mu \times td}\right)$$

$$G = \left(\frac{9.81 \text{ m/s}^2 \times 7.5 \, m}{0.893 \times 10^{-6}\text{m}^2/\text{s} \times 47 \, s}\right)$$

$$\mathbf{G = 1,324/s > 750/s \text{ (satisfy)}}$$

The calculated G-value of 1,324 /second was obtained, exceeding the design criterion of 750 /second, thereby fulfilling the design requirements. Furthermore, the detention time was determined to be 47 seconds, which is less than the 60-second limit, thus also meeting the design criteria as specified by SNI 6774:2008 [8].

- ***Flocculation***

In the water purification process at IPA The Bantar, the flocculation process is carried out through six stages (compartments) using a hydraulic method. The water flow is conditioned to move vertically and rotationally to ensure uniform floc collisions. The flocculation basin is designed in a hexagonal (helicoidal) shape, intended to provide sufficient water circulation for thorough mixing. The bottom of the flocculator is also equipped with a drain valve to remove settled flocs.

Given:
- Hexagonal Flocculator, side = 1.25 m
- Flow rate per flocculation unit = 0.2 $m3/detik$
- Flocculator cross-sectional area (A) = 4.06 m^2
- Inlet Velocity = 0.098 m/s
- Headloss baffle = 0,02 m

Calculation:

Calculations and measurements were conducted at Water Treatment Plant One, under the assumption that the flow rate from the coagulation unit is evenly distributed between Water Treatment Plant One and Water Treatment Plant Two.

- Compartment 1

$$V = A \times H$$

$$V = 4.06 \text{ m}^2 \times 6.18 \text{ m} = 25.08 \, m^3$$

$$\text{td} = \frac{V}{Q}$$

$$\text{td} = \frac{25.08\, m^3}{0.2\ \text{m}^3/s} = 125{,}44\, s$$

$$\text{G}^2 = \frac{g \times Hf}{\mu \times td}$$

$$\text{G}^2 = \frac{9.81\ \text{m/s}^2\ \times\ 0{,}02\, m}{0.893\ \times\ 10^{-6}\text{m}^2/\text{s}\ \times 125{,}44\, s}$$

$$\boldsymbol{G = 42/s}\ \textbf{(satisfy)}$$

Calculations proceeded identically through compartment 6, after which the total detention time was determined.

$$td_{total} = td_1 + td_2 + td_3 + td_4 + td_5 + td_6$$

$$\boldsymbol{td_{total} = 12.45\ minutes}\ \textbf{(satisfy)}$$

Based on SNI 6774:2008 [8], the G-value in flocculation ranges from 5 to 60 /second, which is satisfied as the G-value in the flocculation unit is 29.6 to 42 /second. Regarding detention time, the detention time in the flocculation unit ranges from 10 to 15 minutes. From the detention time calculations of each compartment, the total detention time of the flocculation unit is 12.45 minutes, thus meeting the design criteria.

- ***Sedimentation***

The sedimentation unit at each Bantar WTP consists of a basin with 4 clarifiers (sludge basins) and utilizes plate settlers with a 60° inclination angle. Water from the flocculation process enters the sedimentation inlet channel, which is equipped with outlet pipes along the channel. Water exits through these outlet pipes, allowing flocs to settle into the clarifiers, resulting in clearer water at the sedimentation surface. According to Kolhe et al. (2018), plate settlers are effective in trapping fine flocs that escape the clarifier zone and facilitating the sedimentation of larger flocs towards the sludge zone.

Given:

- Flowrate = 0.2 m^3/second
- Sedimentation basin length = 9.5 m
- Sedimentation basin width = 8 m
- Sedimentation basin depth = 6 m
- Plate settler inclination = 60°

Calculation:

- Hydraulic spokes

$$\text{td} = \frac{V}{Q}$$

$$\text{td} = \frac{9.5\, m \times 8\, m \times 6\, m}{0.2\, m^3/s}$$

$$\textbf{td} = \boldsymbol{37\ minutes < 42\ minutes}\ \textbf{(satisfy)}$$

- Sedimentation basin velocity

$$\text{v} = \frac{Q}{A}$$

$$v = \frac{0.2\, m^3/s}{8\, m \times 6\, m} = 0.00416\, m/s$$

- Reynolds Number

$$\text{N}_{Re} = \frac{\text{v}_{basin}\ \times \text{R}}{\mu}$$

$$\text{N}_{Re} = \frac{0.00416\ \text{m/s}\ \times 2.4\text{m}}{0.893\ \times\ 10^{-6}\text{m}^2/\text{s}}$$

$$\boldsymbol{\text{N}_{Re} = 11{,}198 > 2{,}000}\ \textbf{(does not satisfy)}$$

- Froude Number

$$\text{N}_{Fr} = \frac{\text{v}_{basin}{}^2}{\text{g}\ \times \text{R}}$$

$$\text{N}_{Fr} = \frac{(0.00416\ \text{m/s})^2}{9.81\ \text{m/s}^2 \times\ 2.4\ \text{m}}$$

$$\boldsymbol{\text{N}_{Fr} = 4.24\ \times 10^{-6} < 10^{-5}}\ \textbf{(does not satisfy)}$$

From the calculations above, it is determined that the Reynolds number of the sedimentation unit is 11.198, which is greater than 2000, thus not meeting the criteria. The Froude number shows 4.24 x 10^{-6}, which is less than 10^{-5}, also not meeting the criteria. However, the detention time of 38 minutes meets the criteria.

- ***Filtration***

In this process, water undergoes filtration by passing through layers of silica sand, whereby flocs that have escaped the sedimentation process are further filtered within the filtration basins. The Bantar WTP possesses a total of 16 filtration units operating in parallel. The filtration type employed is a rapid sand filter utilizing a downflow mechanism. The filtered water then flows towards the reservoir. The evaluation of the filtration unit can be seen in Table 2.

TABLE 2: Evaluation of Filtration Unit.

Description	Criteria	Existing	Finding
Number of filter tanks	≥5 basins	8 basins	satisfy
Washing system	without/with blower and/or surface wash	with a blower and/or surface wash	satisfy
Sand media thickness	300 – 700 mm	300 mm	satisfy
Anthracite media thickness	400 – 600 mm	600 mm	satisfy

○ ***Reservoir***
The Bantar WTP has a clean water reservoir/clear well with a capacity of 1000 m^3. Water from this clear well will subsequently be distributed to the Guwo Reservoir and the Sidomulyo Reservoir. The average water level in the clear well is 2.5 meters. When the clear well reaches its maximum water level, the intake pump must be turned off. The following are the results of the water quality testing of the Bantar WTP clear well.

Based on the results of water quality testing conducted at The Bantar WTP laboratory (Table 3), it can be observed that most parameters comply with the quality standards stipulated in Permenkes No. 2 of 2023, with the exception of the residual chlorine parameter. It is evident that the residual chlorine in the clear well exceeds the quality standard outlined in Permenkes No. 2 of 2023 [9], which specifies a residual chlorine range of 0.2-0.5 mg/L. The test results of the residual chlorine in the clear well indicate a value of 0.86 mg/L, thus exceeding the quality standard.

However, this is still considered safe as the residual chlorine content of 0.86 mg/L in the clear well can decrease to 0.5 mg/L during the distribution process to the Guwo Reservoir. Meanwhile, upon the water's arrival from the clear well to the Sidomulyo Reservoir, there is no residual chlorine detected in the water. Therefore, at the Sidomulyo Reservoir, a chlorination process is carried out to ensure the residual chlorine parameter in the water complies with the quality standards of Permenkes No. 2 of 2023. When water flows through pipes, chlorine concentration can decrease due to chlorine reacting with organic and inorganic compounds present in the water and on the pipe walls [10].

TABLE 3: Clean Water Quality Test Result.

Parameter	Unit	Maximum level	Test result
Odor	-	Odorless	Odorless
Temperature	°C	Air Temperature ±3	25.7
Color	TCU Scale	10	0
Turbidity	NTU Scale	<3	0
pH	-	6-8.5	8.04
Total Dissolved Solids	mg/L	<300	155.4
Flouride (F-)	mg/L	1.5	0.06
Nitrite as N	mg/L	3	< Detection Limit
Nitrate (NO3-N)	mg/L	20	3.574
Arsen (As)	mg/L	0.01	0.005
Cadmium (Cd)	mg/L	0.003	< Detection Limit
Hexavalent chromium (Cr^{6+})	mg/L	0.01	0
Manganese (Mn) (dissolved)	mg/L	0.01	0.015
Aluminium	mg/L	0.1	0.04
Iron (Fe) (dissolved)	mg/L	0.2	0.06
Residual Chlorine (dissolved)	mg/L	0.2	0.86
Total Coliform	CFU/100ml	0	0
E.Coli	CFU/100ml	0	0

D. Discussion

○ ***Pre-sedimentation***
The pre-sedimentation unit does not meet the criteria for Reynolds number and Froude number. Consequently, the flow within the pre-sedimentation tank is not laminar, preventing particles from settling for an extended period and potentially resulting in high water turbidity from the pre-sedimentation tank. To achieve laminar flow in the pre-sedimentation tank, a fine-mesh screen is required to reduce the inlet water velocity, thereby calming the water flow and facilitating the transition to laminar flow.

○ ***Coagulation***
The coagulation unit of The Bantar Water Treatment Plant (IPA The Bantar) has met the design criteria according to SNI 6774:2008, enabling the unit to operate optimally. Routine monitoring and maintenance are essential to sustain the performance of the coagulation unit.

○ ***Flocculation***
The flocculation unit of The Bantar Water Treatment Plant (IPA The Bantar) has met the design criteria according to SNI 6774:2008, enabling the unit to operate optimally. Routine monitoring and maintenance are essential, for example, cleaning debris that remains lodged on the plate settlers to prevent water outlet blockage. These actions are consistently performed to sustain the performance of the flocculation unit.

○ ***Sedimentation***
The sedimentation unit does not yet meet the design criteria according to SNI 6774:2008, particularly

concerning the Reynolds number and Froude number. Failures in the preceding processes can cause light flocs to be carried over to the filters, leading to filter clogging. On several occasions, fine flocs have been observed rising to the sedimentation surface and being carried into the gutters. To ensure the sedimentation unit meets the Reynolds number and Froude number criteria, it is necessary to address the issues occurring in the preceding stages, particularly in the pre-sedimentation unit. A Reynolds number exceeding 2000 in the calculations indicates turbulence in the sedimentation process, potentially causing light flocs to rise to the surface, which should ideally be retained by the plate settlers. However, the rise of these flocs to the surface could also be attributed to a full sludge basin, necessitating drainage.

- ***Filtration***

The filtration unit of The Bantar Water Treatment Plant complies with the design criteria stipulated in SNI 6774:2008, enabling the unit to operate optimally. Routine monitoring and maintenance are therefore essential, including conducting backwashing in accordance with the established schedule and periodically replacing the filter media. These measures are consistently implemented to maintain the performance of the filtration unit.

CONCLUSION

The evaluation of the Bantar Water Treatment Plant indicates several operational and technical challenges that affect the efficiency of the treatment process. Persistent pump operational issues at the intake, where only one pump functions optimally, have reduced the raw water flow rate and allowed debris to enter the treatment basins. In addition, the quality of raw water from the Progo River does not fully comply with the standards set by the Regional Regulation of the Special Region of Yogyakarta No. 20 of 2008, particularly in terms of color, turbidity, and zinc concentration.

Despite these challenges, the treatment process at The Bantar Water Treatment Plant remains effective in producing safe, clean water. Laboratory test results confirm that the treated water stored in the reservoir meets the quality standards stipulated in the Ministry of Health Regulation No. 2 of 2023. However, several treatment units, especially the pre-sedimentation and sedimentation units, do not meet design criteria due to non-laminar flow conditions, which reduce particle settling efficiency and may affect long-term operational performance.
To improve operational reliability and ensure workplace safety, the implementation of Occupational Health and Safety (K3) procedures for operators and laboratory personnel should be strictly enforced. Proper safety training, use of personal protective equipment, and adherence to standard operating procedures are essential to minimize occupational risks and maintain a safe working environment.

Furthermore, enhanced monitoring and routine maintenance of critical processing units, particularly the pre-sedimentation and sedimentation units, are strongly recommended. Special attention should be given to flow conditions to ensure compliance with design criteria, as well as regular debris removal to prevent performance degradation. Timely maintenance and continuous monitoring will help optimize treatment efficiency, reduce operational disruptions, and sustain compliance with clean water quality standards.

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