EVALUATION OF DRINKING WATER TREATMENT PLANT DESIGN AT BADAN LAYANAN UMUM DAERAH (BLUD) DRINKING WATER TREATMENT PLANT

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Abstract

This study evaluated the performance of the BLUD Drinking Water Treatment Plant (WTP) in Cimahi to identify parameters exceeding national standards and assess design and operational adequacy. Raw water quality did not comply with PP No. 22/2021 for BOD (11.9 mg/L), COD (24.1 mg/L), detergent (0.426 mg/L), fecal coliform (4.27×10^7 MPN/100 mL), total coliform (1.14×10^6 MPN/100 mL), nitrite (0.093 mg/L), sulfate (0.328 mg/L), TSS (88 mg/L), and zinc (0.061 mg/L). Treated water failed Permenkes No. 2/2023 for color (22.5 TCU) and residual chlorine (0.16 mg/L), while negative removals were observed for fluoride, manganese, nitrite, TDS, and color. Evaluation revealed several design flaws: bar screen spacing of 25 mm and thickness of 10 mm (required 4–8 mm and 25–50 mm); coagulation with constant PAC dosing (18 mg/L) without jar testing; flocculation detention time of 22 min with constant velocity gradients (30.5 s^{-1}) instead of 30–45 min with decreasing gradients; sedimentation with detention time of 0.97 h and surface loading of 3.75 $m^3/m^2 \cdot h$ (required 1.5–3 h and 3.8–7.5 $m^3/m^2 \cdot h$); filtration with backwash velocity of 41.86 m/h and duration of 5 min (required 46–50 m/h and 10–15 min); and disinfection with velocity gradient of 111 s^{-1} (required ~500 s^{-1}). Revised designs included reducing bar spacing to 8 mm and thickness to 50 mm, implementing routine jar testing, extending flocculation detention to 30.1 min with step-down gradients (34–26 s^{-1}), deepening sedimentation basins to 6 m (detention 1.54 h, surface loading 3.87 $m^3/m^2 \cdot h$), increasing backwash velocity to 46.56 m/h for 10 min, and installing a static mixer (G = 1427 s^{-1}) for chlorine application. These improvements are expected to enhance removal efficiency, eliminate negative removals, and ensure compliance with Indonesian drinking water standards.

Keywords: *drinking water, water treatment plant, water quality, treatment process, design evaluation*

Introduction

The City of Cimahi, located in West Java, Indonesia, covers an area of 42.48 km² and has a population of approximately 575,000 people (Badan Pusat Statistik Kota Cimahi, 2023). The Cimahi River is the only river in the city. It supplies water at an average maximum discharge of 1,070 l/s during the rainy season and 800 l/s during the dry season (BLUD Air Minum Kota Cimahi, 2023). Government monitoring conducted between 2011 and 2018 recorded a peak-to-minimum discharge ratio of 1.33, which is considered stable with low fluctuation (Staddal et al., 2016).

However, the water quality of the Cimahi River is severely threatened by pollution (Rafianto, 2021). The river flows through areas dominated by domestic, industrial, and agricultural land uses, accounting for 51%, 17%, and 30%, respectively (Badan Pusat Statistik Kota Cimahi, 2019). The lack of sufficient buffer zones between residential settlements and the

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riverbanks increases the risk of contamination, making the raw water unsuitable for direct use without treatment (Yogafanny, 2015).

Previous studies have confirmed that the Cimahi River is heavily polluted. Fifteen parameters, including TDS, TSS, BOD, COD, DO, phosphate, lead, zinc, sulfide, nitrite, free chlorine, total coliform, fecal coliform, oil and grease, phenol, and MBAS, exceed the permissible limits set by Government Regulation No. 22 of 2021. The Pollution Index ranges from 16.722 to 22.507, classifying the river as heavily polluted. Total coliform and fecal coliform, primarily originating from domestic wastewater, are among the major pollutants (Rafianto, 2021). To ensure a safe water supply, effective treatment is essential. The treatment process must include the removal of coarse, suspended, and dissolved substances, as well as neutralization and disinfection. Although BLUD in Cimahi has installed a full treatment system, including coagulation, flocculation, sedimentation, filtration, and disinfection units, no comprehensive performance assessment has been carried out to date. However, several operational challenges remain. These include debris intrusion, rising flocs in the sedimentation basin, and frequent backwashing of filters. These issues emphasize the need for a thorough evaluation of design and operational performance to enhance water quality outcomes and ensure compliance with drinking water standards. With this study, the water quality parameters that do not meet the quality standards can be identified and the flaws of the water treatment plant can be found.

Research Methodology

An evaluation was conducted on the water treatment unit at BLUD Air Minum Cimahi, which serves approximately 2.3 percent of the total population of Cimahi City. The treatment plant withdraws raw water from the Cimahi River at a rate of 50 l/s and processes it into drinking water through a series of treatment stages, including bar screening, coagulation, flocculation, sedimentation, filtration, and disinfection, before the treated water is stored in a reservoir.

The raw water quality was evaluated based on the raw water quality standards from *Peraturan Pemerintah (PP) Nomor 2 Tahun 2021*, and the drinking water quality was evaluated based on the drinking water quality standards from *Peraturan Menteri Kesehatan (Permenkes) Nomor 2 Tahun 2023*. Also, the design of the water treatment plant was assessed based on the design criteria in SNI:6774:2008. The treatment process operates continuously for 24 hours per day, except during maintenance periods.

The study was conducted over a period of 22 days, from July 10, 2023, to August 18, 2023. The raw water quality and drinking water quality data are obtained through the results of laboratory tests from BLUD documentation. The design of the water treatment plant is obtained through the water treatment plant design drawing. To evaluate the units, the main mathematical equations are used for each unit. Equation (1) is used to evaluate the bar screen unit (Turget et al., 2023). Equations (2) and (3) are used to evaluate the coagulation unit, Equations (4), (5), and (6) are used to evaluate the flocculation unit, Equations (7), (8), (9), (10), and (11) are used to evaluate the sedimentation unit, Equations (12) and (13) are used to evaluate the filtration unit, and Equations (14) and (15) are used to evaluate the disinfection unit (WHO, 2017).

$$v' = \frac{Av}{A'} \quad (1)$$

Where:
v’= velocity through the bar (m/s)
v = velocity before the bar (m/s)
A = cross area of the bar (m)
A’ = cross area of the opening (m)

$$t = \frac{V}{Q} \quad (2)$$

$$G = \sqrt{\frac{gh}{\mu t}} \quad (3)$$

Where:
t = time detention (s)
V = volume of coagulation unit (m^3)
Q = discharge (m^3/s)
G = velocity gradient (s^{-1})
g = gravity acceleration (m/s^2)
h = headloss (m)
μ = viscosity (m^2/s)

$$t = \frac{V}{Q} \quad (4)$$

$$v = \frac{Q}{A} \quad (5)$$

$$G = \sqrt{\frac{gh}{\mu t}} \quad (6)$$

Where:
t = time detention (s)
V = volume of coagulation unit (m^3)
Q = discharge (m^3/s)
G = velocity gradient (s^{-1})
g = gravity acceleration (m/s^2)
h = headloss (m)
μ = viscosity (m^2/s)
v = velocity
A = cross area of flocculation unit

$$S = \frac{Q}{A} \quad (7)$$

$$t = \frac{Q}{V} \quad (8)$$

$$v_s = \frac{Q}{A\sin(\theta)} \quad (9)$$

$$N_R = \frac{v_s D^2}{4D\mu} \quad (10)$$

$$N_F = \frac{v_s}{\frac{D^2}{4D}g} \quad (11)$$

Where:
Q = discharge (m^3/s)
A = surface area of sedimentation unit (m^2)
V = volume of sedimentation unit (m^3)
T = time detention (s)
Vs = settling velocity (m/s)
N_R = reynold number
D = diameter of tube (m)
N_F = Froude number
μ = viscosity (m^2/s)
G= gravity acceleration (m/s^2)

$$v_f = \frac{Q_f}{A} \quad (12)$$

$$v_b = \frac{Q_b}{A} \quad (13)$$

Where:
Vf = filtration velocity
Qf = filtration discharge
Vb = backwash velocity
Qf = backwash discharge

$$t = \frac{V}{Q} \quad (14)$$

$$G = \sqrt{\frac{gh}{vt}} \quad (15)$$

Where:
t = time detention (s)
V = volume of coagulation unit (m^3)
Q = discharge (m^3/s)
G = velocity gradient (s^{-1})
g = gravity acceleration (m/s^2)
h = headloss (m)
μ = viscosity (m^2/s)

Results and Discussion

Raw and Drinking Water Analysis

The Cimahi River is located in an area surrounded by residential settlements, agricultural land, and plantations upstream of the intake structure. These land uses are potential sources of contamination of the raw water used for drinking water production. Field observations revealed the presence of wastewater discharge pipes embedded in the riverbanks, indicating the entry of domestic and agricultural waste into the river (Pertiwi, 2023).

Water quality measurements show that several parameters do not meet the water quality standards, as shown in Table 1, namely BOD at 11.9 mg/L, COD at 24.1 mg/L, detergent at

0.426 mg/L, fecal coliform at 4.269 × 10^7 MPN/100 mL, total coliform at 1.14 × 10^6 MPN/100 mL, NO_2^- at 0.093 mg/L, SO_4^{2-} at 0.328 mg/L, and TSS at 88 mg/L.

The levels of COD, BOD, detergent, total coliform, and fecal coliform that do not meet the standards indicate pollution from anthropogenic activities around the Cimahi River, which is closely related to the high proportion of domestic land use, around 51%. The levels of NO_2^-, SO_4^{2-}, and TSS indicate pollution from agricultural activities along the banks of the Cimahi River. The proportion of agricultural land use is also high, accounting for about 30%, following the urban region. Therefore, the water treatment plant places emphasis on the removal of these key contaminants to ensure the production of safe drinking water (Roesmeliana, 2021).

Table 1. Raw Water Quality

No	Parameter	Result	PP 22/2021
1	BOD (mg/L)	11.9	2
2	COD (mg/L)	24.1	10
3	Detergent (mg/L)	0.426	0.2
4	Fecal Coliform (mg/L)	$4.269×10^7$	100
5	NO_2^- (mg/L) (mg/L)	0.093	0.06
6	Zn (mg/L)	0.061	0.05
7	Total Coliform (MPN/100mL)	$1.14×10^6$	1000
8	SO_4^{2-} (mg/L)	0.328	0.2
9	TSS (mg/L)	88	40

source: BLUD Laboratory Analysis, 2024

The produced drinking water exhibits two parameters that do not comply with the quality standards, as shown in Table 2. These include color with a value of 22.5 TCU and residual chlorine at 0.16 mg/L. Due to the limited data, there are not many parameters to check in the drinking water, but based on the color and residual chlorine, the water treatment plant indicates some inefficiency in maintaining the water quality standard, especially for color and residual chlorine. The flaws of the treatment plant will be evaluated to trace these non-compliant parameters. Besides that, some parameters also show poor removal, as shown in Table 3, including F^-, NO_2^-, and color.

Table 2. Drinking Water Quality

No	Parameter	Result	Permenkes 2/2023
1	Residual chlor (mg/L)	0.16	0.2
2	Color (TCU)	22.5	10

source: BLUD Laboratory Analysis, 2024

Table 3. Negative Removal Efficiencies

No	Parameter	Removal
1	Fecal Coliform (MPN/100mL)	100%
2	Total Coliform (MPN/100mL)	100%
3	Fe (mg/L)	78%
4	F- (mg/L)	5%
6	NO_2^- (mg/L)	-853%
8	TDS (mg/L)	44%
9	Warna (TCU)	-137%

Disturbing Factors of Drinking Water Treatment Plant

The factors influencing water quality are closely related to the sequence of treatment units. The treatment units used at the BLUD facility includes bar screen, pre-sedimentation, coagulation, flocculation, sedimentation, filtration, and disinfection. Each of these units has specific design criteria. Parameters that do not meet the design criteria may contribute to the negative removal efficiencies observed in the system or non-compliant parameters for the drinking water.

Bar Screen

As can be seen in Table 4, the width and thickness of the bar do not meet the requirements. The bar is too wide at 25 mm, causing rags to accumulate quickly, and the thickness is too small at 10 mm, causing the bars to bend and break. With the accumulation of rags from the urban area, this might be one of the factors contributing to the increase in the color parameter up to 22.5 TCU, as shown in Table 3. This could be supported by the fact that nitrate levels are increasing as one of the organic degradation products (Zaman et al., 2023). Although these mismatches still make the velocity through the bars meet the requirement at 0.54 m/s, the thin and narrow bars cause them to bend and break. To revise the thickness and width of the bars to 8 mm and 50 mm, the velocity needs to be checked again using Equation (1). The calculation result shows that the velocity through the bars still meets the required standard at 0.32 m/s. Thus, all of the design parameters of the bar screen meet the required standards and could optimize the quality of the produced water.

Table 4. Bar Screen Evaluation

Parameters	Criteria	Result	Revised
Velocity (m/s)	0.3 – 0.6	0.54	0.32
Width of bar racks (mm)	4 - 8	25	8
Thickness of bar racks (mm)	25-50	10	50
Bar opening (mm)	25 - 75	25	25

Coagulation

As shown in Table 5, the design of the coagulation unit meets the required standards in terms of both detention time and velocity gradient, at 1.41 s and 1427 s^{-1}. Although the design meets the standards, one of the most important aspects of the coagulation unit is the setting of the coagulant dosage. The coagulant dosage needs to be determined through jar testing. The operator rarely performed jar test procedures during the 22-day observation, and the dosage was constantly set at 18 mg/L of PAC. The constant dosage could be a factor contributing to the poor color removal, with values reaching as low as −137%, considering that this parameter can be effectively reduced by coagulation (Ramadhan et al., 2024). NO_2^- and F^- might not be significantly affected by this factor, since they are dissolved ions that have limited interaction with coagulants (Hamamoto et al., 2015).

Table 5. Coagulation Evaluation

Parameters	Criteria	Result	Revised
Detention time (m/s)	1 - 5	1.41	Jar test to optimize coagulant dose is recommended
Velocity gradient (s^{-1})	>750	1427	

Flocculation

As shown in Table 6, the detention time does not meet the required standard, being only 22 min. The detention time is too short, causing the microflocs not to aggregate effectively, which leads to suboptimal floc size for settling. The velocity gradient also does not decrease and remains constant at 30.5 s^{-1}. This could make the flocs formed in the last basin break apart, and eventually the added coagulant only becomes a contaminant. This may explain the increase in the color parameter from 9 TCU to 22.5 TCU, considering that PAC has a dark brown-yellow color. This factor, however, does not contribute to the increase in NO_2^-, since PAC does not contain such substances.To revise the unit by increasing the detention time and gradually lowering the velocity gradient, the volume of the basin must be increased and the openings of the flocculation unit must be adjusted gradually. The volume is increased from 2.96 m^3 to 4.1 m^3, and using Equation (4), the detention time rises to 30.1 min. To lower the velocity gradient gradually, the openings are changed from 0.49 m², 0.36 m², 0.25 m², 0.16 m², 0.09 m², and 0.04 m². Using Equation (6), these improvements make the velocity gradient decrease gradually from 34 s^{-1}, 33 s^{-1}, 31 s^{-1}, 30 s^{-1}, 28 s^{-1}, and 26 s^{-1}. Thus, all of the design parameters of the flocculation unit meet the required standards and could optimize the quality of the produced water.

Table 6. Flocculation Evaluation

Parameter	Criteria	Result	Revised
Velocity gradient (s^1)	60 - 5	30.3	34-33-31-30-28-26
Time detention (min)	30-45	22	30.1
Flocculation stage	6-10	6	6
Maximum velocity (m/s)	<0.9	0.013	0.013

Sedimentation

As shown in Table 7, the sedimentation unit currently operates with a surface loading rate that is too low, calculated at 3.75 m³/m²/hour, and the detention time also does not meet the required standard. Nevertheless, the settling velocity is higher than the surface loading, which allows sedimentation to be completed. However, the low detention time, as shown in Table 7, causes the water to flow too quickly before the flocs can settle. To revise the unit by increasing the surface loading and detention time, the surface area must be decreased and the volume of the basin must be increased. These improvements must also maintain the settling velocity, Reynolds number, and Froude number. The surface loading is increased by narrowing the surface area from 48 m² (6 m wide and 8 m long) to 46.4 m² (5.8 m wide and 8 m long), using Equation (7). This improvement increases the surface loading rate to 3.87 m³/m²/hour. The volume is increased by raising the depth from 3.65 m to 6 m, and using Equation (8), the detention time rises to 1.54 hours. These improvements keep the Reynolds and Froude numbers within laminar and subcritical ranges at 18.12 and 1.26×10^{-5}, respectively. The settling velocity is not significantly affected and remains at 0.0012 m/s.

Table 7. Sedimentation Evaluation

Parameter	Criteria	Result	Revised
Surface loading ($m^3/m^2/h$)	3.8 - 7.5	3.75	3.87
Depth (m)	3-6	3.65	6
Detention time (h)	1.5-3	0.97	1.54
Reynold number	<2000	17.52	18.12
Settling velocity (m/s)	<0.15	0.0012	0.012
Froude number	$>10^{-5}$	1.18×10^{-5}	1.26×10^{-5}

Filtration

As shown in Table 8, the filtration unit does not meet the requirements, such as backwash velocity at 41,86 m/s and backwash duration at 5 min. Low backwash velocity decreases media expansion, and the contaminants adsorbed by the media, especially dissolved matter, might not be removed completely. This might explain the accumulation of NO_2^- and F^- that are adsorbed onto the filter media and not effectively removed during backwash. Moreover, the duration is not long enough, which can lead to greater contamination of the produced water. This retained contamination might be a factor in the negative removal of NO_2^- and F^-, up to –853% and –5%, as shown in Table 3. To revise the unit by increasing the backwash velocity and duration, the nozzle surface area must be reduced and the backwash duration extended. By narrowing the nozzle area from 1,05 m² to 0,81 m² and using Equation (13), the backwash velocity increases from 41,86 m/s to 46,85 m/s. The duration must also be increased from 5 min to 10 min. With these improvements, the retained contaminants on the filter media surface can be removed effectively, and negative removal can be avoided (Camellia, 2020).

Table 8. Filtration Evaluation

Parameter	Criteria	Result	Revised
Basin	At least 5	5	5
Filtration velocity (m/h)	6-11	10	10
Rate of *backwash* (m/h)	46-50	41.86	46.56
Backwash duration (min)	10-15	5	10
Backwash period	18-24	12	18
Sand thickness	70 cm	70 cm	

Disinfection

As shown in Table 9, the detention time does not meet the required standard. The velocity gradient is too low. This leads to non-compliant residual chlorine in the reservoir at 0,16 mg/L. Mixing only happens due to pipe friction without any proper mixing facilities. To improve this, mixing facilities must be added, such as a static mixer. Using Equation (15), a static mixer with a pipe length of 1 m, a diameter of 0,5 m, and equipped with 11 baffles, like the coagulation unit, will increase the velocity gradient to 1427 s^{-1}. With this improvement, the residual chlorine can be elevated. Determining the optimum chlorine dosage is also important, and this is an operational procedure that is rarely conducted at the BLUD treatment plant. Currently, the disinfection process uses 7,1 mg/L of dissolved chlorine, and the dosage stays constant. To optimize the disinfection process, an operational procedure to determine chlorine dosage through jar tests and breakpoint chlorination can be added.

Table 9. Disinfection Evaluation

Parameter	Criteria	Result	Revised
Contact time (min)	30	57	-
Velocity gradient (s^{-1})	500	111	1427

Conclusions

The evaluation of the BLUD Drinking Water Treatment Plant in Cimahi showed that raw water quality exceeded standards for BOD, COD, detergent, fecal and total coliforms, nitrite, sulfate, TSS, and zinc, while the treated water still failed to meet drinking water standards for color and residual chlorine, with poor removal for fluoride, nitrite, and color. These problems were linked to design and operational weaknesses, including oversized bar screen spacing, constant coagulant dosing without jar tests, short flocculation time with uniform gradients, undersized sedimentation capacity, inadequate filter backwashing, and poor mixing during disinfection. Revised designs were proposed to address these issues, such as narrowing bar spacing, implementing routine jar testing, extending flocculation detention time with decreasing gradients, enlarging sedimentation depth, increasing backwash velocity and duration, and adding a static mixer to improve chlorine contact. By applying these corrections, the plant can significantly improve removal efficiency, eliminate negative removals, and achieve compliance with national drinking water standards.

References

Badan Pusat Statistik Kota Cimahi. (2023). *Kota Cimahi dalam angka 2023 (Cimahi Municipality in Figures 2023)*. Badan Pusat Statistik Kota Cimahi. https://cimahikota.bps.go.id

Badan Standardisasi Nasional. (2008). *SNI 6774:2008: Tata cara perencanaan unit paket instalasi pengolahan air*. Jakarta: Badan Standardisasi Nasional.

BLUD Air Minum Kota Cimahi. (2023). *Tentang Kami*. https://bludamcimahi.com/about Accessed 13 July 2025.

Camellia, A., & Marsono, B. D. (2020). Evaluasi kinerja unit filter IPAM Karangpilang III PDAM Surya Sembada Kota Surabaya. *Jurnal Teknik ITS, 9*(2), C99–C106.

Hamamoto, S., Kishimoto, N., & Ueki, M. (2015). Mechanistic consideration of fluoride removal using aluminum sulfate. *Journal of Water and Environment Technology, 13*(1), 15–24. https://doi.org/10.2965/jwet.2015.15

Pertiwi, B. N. R., & Sururi, M. R. (2023). Analisis kualitas air baku untuk sumber air minum BLUD Cimahi. *Prosiding Seminar Nasional dan Diseminasi Tugas Akhir FTSP 2023*, 1–5. Institut Teknologi Nasional Bandung.

Ramadhan, F., Maleiva, L. T. N., & Nugraheni, P. W. (2024). A study of the effects of aluminum sulfate (alum) and poly aluminum chloride (PAC) on the coagulation process of dug well water. *Indonesian Journal of Fundamental and Applied Chemistry, 9*(1), 55–65. https://doi.org/10.24845/ijfac.v9.i1.55

Ramadhani, N. R., Alim, M. S., Husin, M., & Firdausy, M. A. (2024). Analisis pH, kekeruhan dan jarak air bersih terhadap sisa klor pada jaringan distribusi pelanggan IPA 1 A. Yani PTAM Bandarmasih zona Banjarmasin Barat. *JTAM Teknik Lingkungan Universitas Lambung Mangkurat, 7*(2), 53–68.

Staddal, I., Haridjaja, O., & Hidayat, Y. (2016). Analisis debit aliran sungai DAS Bila Sulawesi Selatan. *Jurnal Sumber Daya Air, 12*(2), 117–130.

Turgut, S., Yenisoy, Y., Mohamadi, Y., & Torun, K. (2023). *Sizing and structural analysis of mechanical bar screen*. In *Proceedings of the International Conference on Basic Sciences, Engineering and Technology (ICBASET 2023)*, (Vol. 22, pp. 268–273). https://doi.org/10.55549/epstem.1350960

World Health Organization, Regional Office for South-East Asia. (2017). *Principles and practices of drinking-water chlorination: A guide to strengthening chlorination practices in small- to medium-sized water supplies (p.28)*. World Health Organization.

Yogafanny, E. (2015). Pengaruh aktifitas warga di sempadan sungai terhadap kualitas air Sungai Winongo. *Jurnal Sains dan Teknologi Lingkungan, 7*(1), 41–50.

Zaman, N., Nasution, N. H., Iswahyudi, Susilawaty, A., Sitorus, E., Mohamad, E., Rodhiyah, Z., Syam, M. A., Murtini, S., Rois, I., Tangio, J. S., Rudiansyah, & Haryanti, S. (2023). *Manajemen kualitas air*. Yayasan Kita Menulis.