Water Quality Modelling of the Cibarani Irrigation Channel, Bandung City

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Abstract. Cikapundung River is the primary source of Bandung City's water supply and has been utilized for various purposes. However, the intensive urban growth has increased the number of people living at the riverbanks, increasing the water pollution. One of the examples is the Cibarani irrigation channel, which function was transformed into domestic sewage. The channel receives excess rainfall and household wastewater from the surrounding residential areas comprised of human waste and detergents. Despite the fact that the water is heavily polluted, the local community still resort to this water for fish farming and washing. Consequently, a study is urgently needed to reduce the impact of the disposed pollutants in the channel and control its water quality to meet the raw water standard. This study focuses on the identification of the water quality profile along the Cibarani irrigation channel. Various scenarios are modeled to estimate the volume and concentration of the domestic waste disposed to the channel. The result shows that the water quality of the Cibarani irrigation channel has not met the Class II Raw Water Standard. It is required to increase the discharge of the irrigation channel and control the effluent concentration to reduce the impact of the pollutants.

1. Introduction
The increasing numbers of population and urbanization have played a vital role in the rapid development of Bandung City for the past decades. Consequently, this phenomenon presents significant challenges for the city to meet the inevitable strains of urban growth like the increased demand for housing, which resulted in the emergence of riverbanks settlements [1]. For instance, such occurrence can be observed in the Cikapundung River that divided the city into two parts, stretches from the Lembang Regency to the southern part of Bandung City. The Cikapundung River serves as the primary source of Bandung City's water supply and has been utilized for various purposes such as drinking water, irrigation, fisheries, and sports. However, its strategic location has led to the increased crowding and housing at the riverbank, which escalates the deteriorating of the environment along the river. Acting as the tributary of Citarum River, it is essential to maintain the adequate water quality of the Cikapundung River to support the revitalization of Citarum River that has been named the dirtiest river in the world by the Blacksmith Institute in 2013 [2].

One example of the water pollution contributing sources is the Cibarani irrigation channel, built from the Cilimus Weir to Plesiran at Taman Sari District. The Cibarani irrigation channel is no longer serve as an irrigation channel and has been transformed into domestic sewage. The irrigation channel receives excess rainfall and household wastewater from the surrounding residential areas, contained...
mostly human waste and detergents. The previous study, located at the upper part of the channel, found that the Cibarani irrigation channel's water quality does not meet the class II raw water standard under Indonesian Government Decree No. 82 Year 2001 [3] [4]. However, even though the water is polluted, the local community still resort to this water for fish farming and washing. Thus, a study is urgently needed to reduce the pollutants' impact on the channel and control its water quality to meet the raw water standard.

This study aims to establish the best recommendation to mitigate the water pollution problems along the irrigation channel. This study identifies the water quality profile under various scenarios to estimate the current and the suggested volume and concentration of the domestic waste disposed to the channel. In this study, the water quality model is simulated by HEC-RAS 5.0.1 program. Moreover, to validate the model, direct samplings and water quality parameters measurements of the irrigation channel in both rainy and dry seasons were conducted.

2. Research Methodology

2.1. Study Area and Sampling Locations

This study took place at the Cibarani Irrigation channel with a total length of 2.8 km stretches from the Cilimus Weir to Plesiran at Taman Sari District. The water samples collection was done during the rainy season on 8 and 9 February 2018, then the dry season on 15 and 21 August 2018. The sampling points consisted of eleven observation stations and three wastewater inlets, as shown in Figure 1. The riverbank was also seen fully surrounded by houses and public facilities along the irrigation channel, as shown in Figure 2.

![Figure 1. Study area and sampling locations](image-url)
2.2. Laboratory Analysis

The laboratory analysis measured various essential parameters of the water samples, as listed in Table 1. These parameters were used to calibrate and validate the model before compared with the class II standard of raw water. During the rainy season, the model calibration and validation used the data collected on 8 and 9 February 2018. Similarly, during the dry season, the model calibration used the data measured on 15 August 2018, while the validation used the data measured on 21 August 2018.

**Table 1. Water quality parameters and measurement methods**

| Parameters                                | Unit   | Method                        |
|-------------------------------------------|--------|-------------------------------|
| pH                                        | -      | pH sensor (Sealed, Gel-filled, Polycarbonate Body, Ag/AgCl) |
| Turbidity                                 | NTU    | Turbidity Sensor              |
| Conductivity                              | TDS    | Conductivity Probe (ABS Body, Parallel Graphite Electrodes) |
| Chemical Oxygen Demand (COD)              | mgL⁻¹  | Reaction Digestion            |
| Dissolved Oxygen (DO)                     | mgL⁻¹  | Dissolved Oxygen Probe (Clark-Type Polarographic Electrode) |
| Total Phosphorus (TP)                     | mgL⁻¹  | Ascorbic Acid                 |
| Nitrate as N (NO₃-N)                      | mgL⁻¹  | Chromatropic Acid             |
| Ammonia as N (NH₃-N)                      | mgL⁻¹  | Nessler                       |
| Total Nitrogen (TN)                       | mgL⁻¹  | Chromatropic Acid             |
| Chromium (Cr)                             | mgL⁻¹  | Diphenylcarbazide, DPC        |
| Copper (Cu)                               | mgL⁻¹  | Bathocuproine                 |
| Iron (Fe)                                 | mgL⁻¹  | Phenanthroline                |
| Zinc (Zn)                                 | mgL⁻¹  | Zincon                        |

**Figure 2.** The condition surrounding the Cibarani irrigation channel
2.3. Water Quality Modeling

In this study, simulation using HEC-RAS modelled both hydraulics and water quality profiles. The HEC-RAS model scheme divided the irrigation channel into 14 cross-sections, as shown in Figure 3. The type of pollutant in the irrigation channel was mostly domestic wastewater; therefore, water quality parameters considered in the modelling were DO and BOD. In this study the BOD concentration was calculated from COD concentration using the COD:BOD ratio [5].

\[ Q_{8.2.18} = 200 \text{ l/s}, \quad Q_{9.2.18} = 180 \text{ l/s}, \quad Q_{15.2.18} = 60 \text{ l/s}, \quad Q_{21.2.18} = 100 \text{ l/s} \]

During the simulation, several model parameters influenced the model outputs, i.e., deoxygenation coefficient \( K_d \), reaeration coefficient \( R_a \), and dispersion coefficient \( E_x \). The parameters used in this study are obtained from various empirical formulas and given values from previous studies. The \( K_d \) follows the deoxygenation rate value from Schnoor (1996) [6], while the \( R_a \) and \( E_x \) values are obtained from the empirical formulas from O’Connor and Dobbins (1958) [7], and Seo and Cheong (1998) [8] [9], as shown in equation (1) and (2) respectively.

\[ R_a = 3.9 \left( \frac{v}{H} \right)^{0.5} \]  

\[ E_x = 5.915 \left( \frac{v^*}{H} \right)^{1.428} \left( \frac{W}{H} \right)^{0.62} \]  

Where:
- \( v \) : surface velocity (ms\(^{-1}\))
- \( H \) : average channel depth (m)
- \( W \) : average channel width (m)
- \( v^* \) : shear velocity (ms\(^{-1}\))

3. Results and Discussion

3.1. Cibarani Irrigation Channel Water Quality

The laboratory analysis shown in Table 2 and Table 3 compares the water quality of the Cibarani irrigation channel during the rainy and dry season with the Class II Raw Water Standard. The result implicates that the DO concentrations do not meet the required value, especially during the dry season. Moreover, the laboratory test shows a high concentration of COD and TP, indicating that the pollutants are mainly comprised of human waste and detergents. Hence, it is evident that the water quality at the Cibarani irrigation channel has been heavily polluted by the domestic wastewater from the surrounding residential areas. The laboratory analysis also found that the water samples' metal concentration appeared to be in low concentration. Therefore, in this study, the water quality simulation focuses only on the DO and BOD profiles.
Table 2. The Cibarani irrigation channel water quality during rainy season

| Sampling Points | Date   | pH  | COD  | DO   | TP  | NO$_3$-N | NH$_3$-N |
|-----------------|--------|-----|------|------|-----|----------|----------|
|                 |        |     | mgL$^{-1}$ | mgL$^{-1}$ | mgL$^{-1}$ | mgL$^{-1}$ | mgL$^{-1}$ |
| 1               | 8/2/20 | 7.33 | 38.89 | 7.4 | 0.995 | 1.27     | -        |
|                 | 9/2/20 | 7.33 | 41.29 | 7   | 1.43  | -        | -        |
| 3               | 8/2/20 | 7.38 | 37.04 | 6.5 | 1.16  | 1.07     | -        |
|                 | 9/2/20 | 7.42 | 46.775| 6.1 | 1.755 | -        | -        |
| 4               | 8/2/20 | 7.42 | 32.615| 6.8 | 1.12  | 1.12     | -        |
|                 | 9/2/20 | 7.45 | 38.355| 7   | 1.285 | 0.59     | -        |
| 6               | 8/2/20 | 7.44 | 52.445| 5.6 | 1.76  | 0.8      | -        |
|                 | 9/2/20 | 7.6  | 42.14 | 6.3 | 1.775 | -        | -        |
| 11              | 8/2/20 | 7.38 | 54.27 | 4.5 | 2.075 | 1.46     | -        |
|                 | 9/2/20 | 7.36 | 62.895| 3   | 1.615 | -        | -        |
| 12              | 8/2/20 | 6.94 | 59.125| 4.3 | 2.335 | 0.65     | -        |
|                 | 9/2/20 | 7.37 | 87.545| 2.6 | 2     | -        | -        |
| WQS$^a$         |        | 6.9  | 25    | 4   | 0.2   | 10       | (-)      |

$^a$Water Quality Standard from Class II of Raw Water Standard (Government Regulation No. 82 Year 2001) [4]

Table 3. The Cibarani irrigation channel water quality during dry season

| Sampling Points | Date   | pH  | COD  | DO   | TP  | NO$_3$-N | NH$_3$-N |
|-----------------|--------|-----|------|------|-----|----------|----------|
|                 |        |     | mgL$^{-1}$ | mgL$^{-1}$ | mgL$^{-1}$ | mgL$^{-1}$ | mgL$^{-1}$ |
| 1               | 15/8/20| 6.79 | 46.22 | 5.8 | 1.31  | 0.9      | 0.335    |
|                 | 21/8/20| 6.25 | 59.955| 3.96 | 0.6   | 0.95     | 1.395    |
| 3               | 15/8/20| 7.15 | 30.735| 6.6 | 1.125 | 0.86     | 2.115    |
|                 | 21/8/20| 6.45 | 55.215| 4.05 | 0.69  | 0.685    | 1.755    |
| 4               | 15/8/20| 7.25 | 38.305| 6   | 1.885 | 1.645    | 2.395    |
|                 | 21/8/20| 6.33 | 47.37 | 3.6 | 0.955 | 1.08     | 4.78     |
| 6               | 15/8/20| 7.3  | 66.485| 5.9 | 2.16  | 1.225    | 2.415    |
|                 | 21/8/20| 6.51 | 56.655| 3.83 | 1.14  | 1.09     | 0.75     |
| 11              | 15/8/20| 7.35 | 87.415| 4.9 | 2.15  | 1.545    | 0.98     |
|                 | 21/8/20| 6.69 | 106.8 | 3.21 | 0.74  | 0.59     | 2.8      |
| 12              | 15/8/20| 7.27 | 63.445| 5.1 | 1.57  | -        | 2.925    |
|                 | 21/8/20| 7.07 | 71.025| 2.6 | 2.46  | -        | 2.815    |
| WQS$^a$         |        | 6.9  | 25    | 4   | 0.2   | 10       | (-)      |

$^a$Water Quality Standard from Class II of Raw Water Standard (Government Regulation No. 82 Year 2001) [4]
3.2. Model Calibration and Validation

3.2.1. Rainy Season

During the rainy season, the calibration model used the data collected on 8 February 2018, with the values of $R_a$, $K_d$, and $E_x$ are $1.465 \text{ day}^{-1}$, $1 \text{ day}^{-1}$, and $6.14 \text{ m}^2\text{s}^{-1}$, respectively. As seen in Figure 4, the results show the detailed profiles with the maximum discrepancy of $0.70 \text{ mgL}^{-1}$ for DO and $7.02 \text{ mgL}^{-1}$ for BOD. Based on the presented graph, it is apparent that on 8 February 2018, the DO concentration profile meets the minimum DO requirement for the Class II Raw Water Standard. On the other hand, the BOD profile shows higher values than the maximum allowed concentration.

Likewise, to validate the model above, the water quality from the data on 9 February 2018 was modelled. Based on the simulation, the maximum discrepancy obtained for the DO and BOD profiles on that day were $1.16 \text{ mgL}^{-1}$ and $12.5 \text{ mgL}^{-1}$, respectively. In contrast with the calibration model, Figure 4 shows that in this model, all profiles do not meet the standard requirement.

![Figure 4](image_url)

**Figure 4.** Model calibration and validation for DO and BOD profiles during rainy season: (a) 8 February 2018 (b) 9 February 2018
3.2.2. Dry Season

Similar to the rainy season simulation, the model was also calibrated and validated using the data collected on 15 and 21 August 2018. The maximum discrepancy for the DO and BOD profiles for the calibration model is 1.13 mgL⁻¹ and 14.9 mgL⁻¹ respectively. Based on the result shown in Figure 5, only the DO concentration meets the minimum required value for the Class II Raw Water Standard.

Conversely, the maximum discrepancies obtained for the validation model are 0.33 mgL⁻¹ and 5.16 mgL⁻¹ for the DO and BOD profiles, respectively. Identical to the rainy season modelling, the results in Figure 5 show that all profiles in the validation model do not meet the standard requirement. By taking the same concentration of domestic wastewater discharged into the irrigation channel, the models show consistent model parameters to obtain good calibration and validation models, as presented in Figure 4 and Figure 5.

![Figure 5](image_url)

**Figure 5.** Model calibration and validation for DO and BOD profiles during dry season:
(a) 15 August 2018 (b) 21 August 2018
3.3. Simulation Scenarios
In this study, several scenarios were modelled in determining the best recommendation to mitigate the water pollution problems. The first scenario determined the allowable maximum waste load or BOD concentration that can be disposed to the channel by maintaining the minimum DO and maximum BOD values according to the Class II of Raw Water Standard. In the second scenario, the simulation focused on the increased total inflow variation and its impact on water pollution control along the channel. Lastly, the third scenario simulated the water quality profile under the pretence that the discharged wastewater fitted the domestic wastewater standard.

3.3.1. First Scenario
In this scenario, the allowed maximum BOD concentration obtained for the irrigation channel is 70 mgL\(^{-1}\) under the normal flow condition. With this value, the DO concentration along the channel can be maintained at the lowest of 4.4 mgL\(^{-1}\), exceeding the minimum requirement of class II of raw water standard at 4.0 mgL\(^{-1}\). Moreover, the BOD concentration gradually decreased to the lowest concentration of 3.0 mgL\(^{-1}\) at the end of the channel, fitted the minimum class II of raw water standard requirement. The results of the first scenario can be seen in Figure 6.

3.3.2. Second Scenario
Under the second scenario, it is expected that by increasing the total inflow, Q, of the Cibarani irrigation channel, water pollution can be significantly reduced. In this scenario, the channel’s water quality concentrations and the discharged waste load are equivalent to the existing condition. The model simulated the water quality profiles with an increased total inflow of 1.5Q and 2Q. The results indicate that the water quality profiles meet the Class II of Raw Water Standard in the rainy season by doubling the total inflow. The model showed that the concentration of DO above 4.0 mgL\(^{-1}\) and BOD lower than 3.0 mgL\(^{-1}\) could be maintained. On the contrary, during the dry season, the BOD concentration cannot fulfil the standard's maximum concentration. The complete simulation results are given in the following Figure 7.

![Figure 6. DO and BOD profiles for scenario 1](image-url)
3.3.3. Third Scenario

In the third scenario, the wastewater that was discharged to the channel is assumed to satisfy the domestic wastewater standard [10]. The maximum BOD concentration (BOD$_w$) of 30 mgL$^{-1}$ is modelled as the domestic pollutants’ waste load. According to the simulation results, the lowest DO concentration under this condition is 5.2 mgL$^{-1}$, surpassing the required minimum DO concentration. Furthermore, the minimum BOD concentration is gradually decreasing to its lowest point at 2.3 mgL$^{-1}$ at the end of the channel. The results illustrate the effectiveness of controlling the wastewater concentration to mitigate the water quality problem during the rainy season.

On the other hand, only the DO concentration meets the class II raw water standard requirement during the dry season. It is found that the lowest DO concentration is 4.83 mgL$^{-1}$, higher than the highest DO concentration of 4.80 mgL$^{-1}$ at the existing condition. However, the lowest BOD concentration after adjusting the waste load concentration is 3.5 mgL$^{-1}$, exceeding the standard requirement. The simulation results are presented in Figure 8.

![Figure 7. DO and BOD profiles for scenario 2 during (a) rainy and (b) dry season](image-url)
Figure 8. DO and BOD profiles for scenario 3 during (a) rainy and (b) dry season

4. Conclusions and Recommendations

4.1. Conclusions
The Cibarani irrigation channel has been polluted with household wastewater from the surrounding residential areas comprised of human waste and detergents. Based on the laboratory analysis, the Cibarani irrigation channel’s water quality exceeded the class II of raw water standard applied for Cikapundung River; thus, it is now not safe for daily human use. According to the model calibration and validation, consistent model parameters provide good fitting in both model calibration and validation either in the rainy or dry season. It is also found that increasing the irrigation channel inflow and controlling the effluent quality according to the applied standard for domestic wastewater may reduce the impact of pollution.
4.2. Recommendations
In addition to the above findings, more research is strongly recommended to be put into the development, i.e.:

1. Although it is generally accepted to calculate BOD concentration from the COD-BOD ratio, the test usually generates a higher concentration reading. Therefore, BOD should be considered an independent test from the COD concentration to get more reliable data.
2. The model parameters sensitivity test is highly suggested to compare various empirical formulas that influence the simulation outputs, i.e., reaeration coefficient (Ra) and dispersion coefficient (Ex).
3. The simulation in this study is limited to the DO and BOD profiles on the irrigation channel. A more thorough analysis with other parameters such as TP and TN should be further investigated to provide adequate water quality modelling.

5. References
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