BOD and DO Models of Krukut River, Jakarta

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Abstract. Urban areas in developing countries, such as Jakarta, have the potential to experience serious river water pollution problems. Pollution control is a measure to maintain water quality in waterways; therefore, this study aims to build a water quality model (based on BOD and DO parameter) in the Krukut River, Jakarta. The model can be used as a tool to simulate pollution control. This study applies the Streeter Phelps principle by adopting the system dynamics method. The research also includes social and economic aspects of the pollution control scenario. The Krukut River water quality model is valid because it has an absolute mean error (AME) values below 30%. In detail, the AME value of each model are 0.7% for the population model, 7.05% for the BOD model, and 4.5% for the DO model. With community participation intervention in the sanitation sector, the simulation results of the model show an improvement in Krukut River water quality compared to the 'business as usual' simulation. However, this improvement still does not meet existing quality standards.

1. Introduction

Water is an essential component of life, and there are undoubtedly serious consequences if it becomes polluted. Not only does water pollution negatively impact the environment, but it also has social and economic impacts. The river is a source of water that is used to meet human needs [1]. The problem of river water pollution has occurred in many countries, including in Indonesia. Where rivers, which are one of the sources of clean water, have also been polluted [2–7]. It should be noted that urban areas in developing countries can experience serious river water pollution problems [8]. Jakarta is one of Indonesia's major cities, with a high population density level of 14,518 people/km² [9]. The problem of pollution that causes a decrease in river water quality is essential because it can affect cities such as Jakarta, which have limited water resources.

Water sources that can be used to meet daily needs are divided into two types, namely surface water, and groundwater. The coverage of clean water network services in Jakarta is currently at 60%, while the other 40% comprises other water sources, including groundwater [10]. However, groundwater cannot be used continuously, lead to negative effects such as land subsidence [11]. In terms of surface water, Jakarta uses rivers as the primary water source. However, most of the natural water sources come from outside the Jakarta area.

Krukut River is one of 13 rivers flowing through Jakarta and is designated as a source of raw water for drinking, although only the upstream part of the river is used for this purpose. Based on monitoring
data from the DKI Jakarta environmental agency, the level of dissolved oxygen in the Krukut River tends to decrease from upstream to downstream every year. The decline in water quality from upstream to downstream is also shown by the BOD value, which has increased and exceeds the class 1 water quality standard (designation for drinking water's raw water), as stated in Government Regulation No. 82 of 2001 [12].

Pollution control is a method to maintain water quality. Contamination in water usually results in a decrease in oxygen content. The entry of organic substances into the water is one of the leading causes of the decline in dissolved oxygen [13]. Biochemical Oxygen Demand (BOD) parameter include key parameters for organic pollutants [14].

Another issue that cannot be separated from the discussion of river pollution is the social aspect. Luo et al. state that population density and the wastewater treatment rate are the main factors affecting river ecosystems [15]. An increase in population-level and density results in an increase in total waste. Therefore, river pollution is also closely related to community sanitation conditions. If wastewater and solid waste are not appropriately managed, it can harm rivers, such as reducing water quality [16]. Concerning the social aspect, community participation can be used to control pollution [17]. Community participation related to sanitation is a social factor that can influence river water pollution control. Van Dusseldrop divides participation into volunteerism, free participation, and forced participation [18]. Free participation can be in the form of induced participation, which arises because of external factors such as government programs, initiatives by non-governmental organizations (for example, religious institutions), and invitations from figures living in the community. It can also be in the form of spontaneous participation, which occurs based on the desire or awareness of individuals, without influence or invitation from other parties.

Considering the dynamic and complex character of river pollution and river water quality, river pollution control can be conducted with system dynamics principles. The use of system dynamics to model water quality and river pollution has been previously made. A study by Novia & Febrina modeled DO and BOD parameters in the upper reaches of the Citarum River, West Java, by taking into account the pollutant load from domestic waste [19]. In addition, Thenu & Karnaningroem's research modeled the water quality of the Remu River (in Sorong City) using DO, BOD, COD, and Fe parameters [20]. This study includes the pollution control scenario's social and economic aspects to enrich the literature related to river water quality management. This study aims to build a water quality (BOD and DO) and pollutant load in the Krukut River, Jakarta.

2. Method
The research was conducted on the Krukut River, which has a drinking water designation in DKI Jakarta (Figure 1). The length of the river, which is the focus of the research, is approximately 15.7 km. The Krukut River watershed, which is the location of this research, is in South Jakarta City (Jagakarsa, Cilandak, Pasar Minggu, and Setiabudi Sub-Districts) and Central Jakarta (Tanah Abang Sub-District). The river sample points were determined by purposive sampling and conditions referring to SNI 03-7016-2004 (concerning Sampling Method in the Context of Monitoring Water Quality in a River Watershed). Sampling was conducted at four points (Figure 1) over eight months, from May 2019 to December 2019.
Figure 1. Research sites and water sampling points for the Krukut River [12].

A mixed-method was employed, namely, quantitative and qualitative. The qualitative method was used to explain social aspects (for example, community participation) and the quantitative method was used to build the model using the system dynamics approach. System dynamics modeling was conducted using Powersim software. System dynamics development includes several stages [21]. The overall research stages (including the system dynamics stages) can be seen in Figure 2.

1. Data collection.
This research used two kinds of data, primary and secondary. The river water quality data and river hydraulic data were used to calculate the BOD and DO loads. The population data, wastewater emission data, and solid waste emission data were used to calculate the estimated potential pollutant load in the Krukut River catchment area.

2. Formulating the problem structure.
The concept is built from phenomena that occur in the real world. By understanding the main problems to be modeled, with the help of existing theories, a causal loop diagram (CLD) is compiled, which can describe the relationships between the variables.

3. Modeling.
Stock flow diagram (SFD) built based on CLD that have been made. In the SFD, the role of each variable is described in more detail.

4. Model Validation.
Validation testing involves calculation of the absolute mean error (AME) from the reference and the simulation results data. If the model results are not valid, iteration or rechecking needs to be performed so that they become valid.

5. Business as Usual (BAU) Simulation.
After the model has been made valid, it can be used to predict future events and the behavior of the model in the long run can be observed.

6. Model Intervention.
Intervention needs to be made if the BAU simulation results are not as expected.

Figure 2. Research Stages.
Regarding river water quality modeling, the approach using the system dynamics refers to the 'River Toxins' by Ruth & Hannon [22]. The distribution of stocks follows the number of river segmentations that want to be modeled. The concentration of water quality parameters to be modeled will function as a stock for each river segment. BOD and DO parameter units in the model are in kg/day or in the form of loads. The model of the pollution load and water quality of the Krukut River was formed based on the Streeter-Phelps principle, which is written as Equation 1.

\[
u \frac{dD}{dx} = k_dL - k_aD + k_nN
\]

In which:
- \(K_d\): Degradation coefficient (day\(^{-1}\))
- \(L\): BOD (mg/l)
- \(K_a\): Re-aeration coefficient (day\(^{-1}\))
- \(D\): Oxygen deficit (mg/l)
- \(N\): Ammonia concentration (mg/l)
- \(K_n\): Nitrification coefficient (day\(^{-1}\))

The pollutant effect model (BOD parameter) on dissolved oxygen (DO) was built using the Streeter-Phelps principle with the system dynamics method. The model can be used as a tool for drafting river pollution control, with its development based on the principle of self-purification of the river. Self-purification is a natural ability possessed by water bodies to clean pollutants utilizing physical-chemical-biological processes that occur naturally. To describe the phenomenon of self-purification mathematically, the Streeter-Phelps model is commonly used [23]. The model describes two phenomena related to dissolved oxygen, namely reaeration and deoxygenation.

3. Results and discussion

The river water quality model focuses on DO and BOD parameters in the river. In the model, the river is divided into three segments. The results and discussion will be explained by the system dynamics stages described previously.

3.1. Causal Loop Diagram (CLD)

In segment 1 of the Krukut River, the DO load is influenced by the upstream DO parameter, the reoxygenation process, the deoxygenation process, and the DO flow in the segment under review. The reoxygenation reaction and the previous segment DO flow increase the DO load. Reoxygenation reaction is influenced by the value of the reaeration coefficient and the value of oxygen deficit. The oxygen deficit value is the discrepancy between the DO saturation concentration and DO concentration in segment 1. The DO load parameter value decreases because of the deoxygenation process, while the deoxygenation process and the DO flow in the next segment reduce the load of the DO parameters. The deoxygenation process is influenced by the nitrification process (a process that will produce NBOD), the decomposition coefficient, and the BOD load.

The BOD load value has the same concept as the DO load value; this value is influenced by the BOD load parameter from upstream, BOD input, and segment 1 BOD flow. Upstream segment BOD flow and BOD input add to the BOD load, while segment 1 BOD flow reduces the BOD load. BOD input is obtained by calculating the estimated BOD load from domestic wastewater and the estimated BOD load from domestic solid waste. The population in one segment influences the estimated value of the two types of BOD load input. The estimated value of domestic wastewater load is closely related to the level of community participation in the form of sanitation. The higher the level of sanitation participation, the lower the estimated value of the domestic wastewater load.

The results of field reviews show that community sanitation participation, as measured by septic tanks, both individually and communally, can be influenced by several factors. Those who are often found not to have septic tanks are those who live along the river. The fact is that even though urban
villages have disseminated the use of septic tanks to residents, the community is still unable to implement their use due to cost and technical constraints (such as limited land area or high groundwater levels). However, the influence of the regional leader may also affect the level of citizen participation. In one case in the Karet Semanggi Village area, in addition to socialization from the urban village regarding sanitation, the Head of the RT of the region actively mobilized the residents to collaborate to collect funds and build a communal septic tank.

A causal loop diagram (CLD) of the model, built on the Streeter-Phelps model, can be seen in Figure 2. Dissolved oxygen in rivers involves a process that increases and decreases its concentration; the process of adding oxygen is known as reoxygenation, and that of reducing it is known as deoxygenation. A reaeration is a form of reoxygenation. In the CLD (Figure 3), there are three balancing loops in the reoxygenation process (B1, B2, and B3) and three reinforcing loops on the variables "population growth" and "population" (R1, R2, and R3). The causal loop diagram of the Krukut River water quality model does not have a large loop. This is related to the river system that flows from upstream to downstream; a large loop in the water quality model is possible only when there is policy intervention.

Figure 3. Causal Loop Diagram Model of Krukut River Water Quality.

3.2. Stock Flow Diagram (SFD)

From the CLD developed, a stock-flow diagram was compiled, as shown in Figure 4. The model is carried out in units of time of day and carried for 29 months or 841 days. The model used reference data for BOD and DO values from the DKI Jakarta environmental agency, with a monitoring period of 2017-2018 and primary data for 2019. Population data were obtained based on 2018 BPS data and 2019 data from each village. Unfortunately, the data over the 841 days were incomplete, so data interpolation was used to fill the gaps.

The model in this study uses several assumptions, namely: all debit values (Q) in each segment are assumed to be constant with time; the value of wastewater emissions and waste emissions in the three
segments is assumed to be the same, namely 0.04 kg/person/day for wastewater and 6.9x10^{-5} kg/person/day for solid waste.

**Figure 4.** Stock Flow Diagram Model of Krukut River Water Quality.

### 3.3. Model Simulation Results

The simulation results are shown in Figure 5. According to the characteristic of the model, the results of population simulations have reinforcing behavior, showing an increase over time. The simulation results of DO parameters in the Krukut River show that it is in accordance with the characteristic of the loop that affects DO, namely balancing or decreasing. The lowest DO load is in segment 3, close to 0 kg/day. The BOD simulation results show an increase in all three segments, with the highest BOD load value in segment 3. The value of BOD loads has increased over time, which is related to the population's size, which also continues to increase.

The DO value behavior of the simulation results then compared with the dissolved oxygen sag curve theory; it can be concluded that there is no self-purification in the Krukut River [24]. If a self-purification process does occur, the DO value from segment 1 to segment 3 should not continue to decline. The absence of self-purification is due to pollutant input's continued occurrence in each Krukut River segment, causing the DO value to continue to decline from upstream to downstream.
3.4. Model validation test

After running the simulation, validation was performed using Absolute Mean Error (AME) calculation on the population, BOD, and DO model in segment 1. A model is considered valid if it has an AME value below 30%. DO, and BOD stock validation was made using DO, BOD parameter concentration data, and river flow data from DKI Jakarta environmental agency monitoring from 2017 and 2018 and the primary data from 2019. Validation of population stocks was made using BPS data (2017 and 2018) and data from the villages (2019). The validation results show that the AME value for the population is 0.7%. The DO model is also demonstrated to be valid, with an AME value of 4.5%. The BOD model has an AME value of 7.05%, so it can also be considered valid. Details of the reference and simulation data used for the validation can be seen in Table 1.

| Day | Population (persons) | DO Load (kg/days) | BOD Load (kg/days) |
|-----|----------------------|-------------------|--------------------|
|     | Reference Data  | Simulation Data  | Reference Data  | Simulation Data  | Reference Data  | Simulation Data  |
| 1   | 77,455              | 77,544            | 1,008.63          | 1,008.60          | 754.79           | 754.79           |
| 181 | 84,839              | 83,482            | 704.42            | 1,059.52          | 1,728.02         | 2,354.92         |
| 361 | 91,200              | 89,875            | 664.33            | 605.89            | 2,718.38         | 2,328.66         |
| 541 | 97,560              | 96,757            | 640.84            | 531.32            | 2,963.54         | 2,403.87         |
| 721 | 103,920             | 104,166           | 624.16            | 473.86            | 2,463.50         | 2,449.49         |
| 841 | 108,161             | 109,418           | 494.21            | 410.32            | 1,347.84         | 2,549.32         |
| AME | 0.69%               | 4.5%              | 7.05%             |

3.6. Business as Usual (BAU) simulation

After the model was successfully validated, a BAU simulation was conducted. BAU simulations are carried out by extending the simulation time to 5 years or 1771 days. The choice of simulation time
based on general policy is applied for 5 years. The BAU simulation results can be seen in Figure 6, which shows that the population increases. In the BOD model, it can also be seen that the BOD load continues to increase. On the other hand, the DO model shows that the DO load decreases until it reaches 0 kg/day.

Referring to the quality standards in Government Regulation No. 82/2001 on Water Quality Management and Pollution Control, the DO load value is required to have a value of more than 1347.84 kg/day. Also referring to the same regulations, the allowed BOD load value is less than 449.28 kg/day. The BAU simulation results show that the DO and BOD loads in the three segments do not meet the specified quality standards. Therefore, it is necessary to intervene to increase the river DO load value and reduce the BOD load value.

![Figure 6. Graph of BAU Simulation Results: (a) Total population; (b) DO load; (c) BOD load.](image)

### 3.7. Pollution control interventions

Pollution control interventions can be carried out in various ways, including by increasing community participation in the sanitation sector. Pollution control can also be carried out by direct intervention on the variable number of people living in the Krukut watershed area. The direct intervention meant is an intervention to reduce the population in the Krukut watershed by relocating the population. However, relocation is not easy to undertake and often has negative social impacts on the community. In addition, it also involves considerable costs, such as during the implementation of the relocation process itself and providing compensation to the community [25].

Interventions in the form of policies can also be made concerning river pollution control. The results regarding water quality in the downstream segment can be used as a basis for decision making to improve water quality or to control pollution in the upstream part of the river. Based on the location of the Krukut River, which crosses DKI Jakarta and West Java provinces, the DO value downstream of the river in DKI Jakarta could be used as a policy reference for controlling pollution or improving water quality in the upstream area of the river, where Depok City, West Java is located. This policy intervention can be described as a large loop in the CLD of the Krukut River water quality model. The CLD of possible pollution control interventions can be seen in Figure 7.
The model simulation, which was performed up to this stage, was an intervention to increase community sanitation participation. This was achieved by building a communal wastewater treatment plant (WWTP). Funding for WWTP which in the simulation came from the Regional Budget (APBD) and community contributions. Interventions that have been listed in the form of SFD can be seen in Figure 8.

**Figure 7.** Causal Loop Diagram Model of Pollution Control Intervention.

**Figure 8.** Stock Flow Diagram Model of Pollution Control Intervention.
In this intervention, an assumption was made based on Prameswari et al.'s research that one unit of communal WWTP that can serve ±600 households costs around Rp. 500,000,000.00 (around 34,000 USD) and requires a space of around 32 m². An additional assumption used in the simulation was that every family routinely allocates Rp. 350.00 per day (Rp. 10,500.00 per month) to the cost of constructing communal WWTP. In addition, there is additional APBD funding assistance of Rp. 210,000,000.00 per month for the construction of the communal WWTP. The simulation results after the intervention of increasing community participation in sanitation can be seen in Figure 9.

It can be seen from Figure 9 that the DO and BOD loads continue to have the same pattern, despite the interventions that have been made in the form of increasing sanitation participation. Based on the simulation data, it can be seen that the DO load value has increased by 18% from the BAU simulation results to the intervention simulation results. In comparison, the BOD load value has decreased by around 6%. The simulation results, which show improvements in the quality of the BOD and DO parameters, are in line with the research of Dani et al., who succeeded in reducing the load of BOD entering the river by using management improvement interventions on pollutants originating from settlements [27].

Even though efforts have been made to control pollution, the DO value cannot be increased until it reaches the quality standard, as well as the value of the BOD load. In turn, this value cannot be lowered until it reaches the quality standard. This is because DO and BOD content levels in the upstream study area do not meet quality standards. Also, every year the population continues to increase.

4. Conclusion
Based on the results and discussion, it can be concluded that pollution control by increasing community participation in sanitation has the effect of improving Krukut River water quality (BOD decreases and DO increases). Still, it cannot reduce pollutants until the river's water quality meets the established quality standards. The Krukut River water quality model is valid, with an AME value of the population model of 0.7%, the BOD model of 7.05%, and the DO model of 4.5%. In further research, a simulation of pollution control scenarios could be conducted in the form of combining interventions through community participation with ones through policies related to downstream river water quality. Besides, intervention through the relocation of the population can also be simulated. To improve the Krukut River water quality model's accuracy, the inclusion of pollutants from activities other than settlements could be taken into account.

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