Determination of carrying and load capacity using QUAL2Kw modeling simulation

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Abstract. This paper analyzes the river’s carrying and load capacity using the QUAL2Kw model approach. The river is located in Bengkalis Regency, Bukit Batu District. Modeling simulations were done with by using a scenario to determine the burden of pollution that occurs. This study consists of 10 survey points. The results of the water quality were compared to the indicators with the class II quality standards which are set by the government regulations. The results of this study shows that the Bukit Batu River needs to reduce pollution loads by more than 70%. However the land carrying capacity is in the surplus category, thus it shows the availability of land in the Bukit Batu sub-district’s sufficiency to meet the needs for agriculture production.

1. Introduction

The Bukit Batu River is one of the rivers in the Bengkalis Regency in Bukit Batu District and used by the people as a source of water for raw water, agriculture, and fisheries. Based on the survey results of the Bukit Batu river, the BOD and COD content of the water has exceeded the quality standard. This actually shows the quality of the river water has decreased. To anticipate the development of the region in the future, it is necessary to carry out the study of carrying and load capacity of the Bukit Batu River.

River water always flows and its quality fluctuates from upstream to downstream which make analyzing the of pollution load capacity a complicated process [1]. Taking a lot of samples with a closer distance can define the river water more accurately, but the cost will certainly be higher [2,3]. Therefore, to minimize the cost of observation, we can use a modeling approach.

A mathematical model will be used as a tool to estimate the causal connection between the pollution load into the river with the water quality in different scenarios [4]. QUAL2Kw which is a developed version of QUAL2E will be used as the model for river water quality. The success of the model depends on the user’s convenience and the quality of the software used for the simulation purposes. In the current scenario, QUAL2Kw is one of the modeling used for river water quality simulation [5]. The QUAL2Kw model has the ability to simulate or predict changes in river quality if the waste stream is reduced or increased. The calculation on QUAL2Kw program uses Visual Basic for Application/VBA which is implemented in Microsoft Excel. In general, this method is used to analyze the contribution ratio of pollutant sources and it is relatively simple and economical [6].
Water quality, quantity, continuity, and water balance are the factors that affect water availability [7]. For example, the fisheries industries really need a sustainable water supply for the sustainability of the fish farming [8].

2. Research methodology

2.1. Area of study
The source of water that flows in the Bukit Batu River comes from several lakes namely Sembilang Lake, Kemenyan Lake, Batu Lake, Terentang Lake and Ranggung Lake. Most of the upstream areas of the Bukit Batu River are located within the Bukit Batu Wildlife Reserve. This research was conducted by taking 10 sample points. The selection of sampling locations is based on the location of the pollution source that is suspected to contribute to the decline in the water quality of the Bukit Batu River, whether it is a point source or a non-point source. Sampling location is shown in Figure 1.

2.2. Data collection
Data collections in this study are divided into primary and secondary data. The primary data will be the water quality data with parameters (BOD, COD) and secondary data will be the data that support the development of the model such as population data and agricultural area. Water quality models are used to look at the impacts on the water quality if a simulated scenario is carried out. The simulation scenario is used to find ways or actions that are fast and appropriate if there are any contaminants [9]. The simulation scenario which will be carried out as follows: 1) Upstream - Existing; Hydrolics data-Existing; Pollutant source - Trial and error; River water quality - Model

2.3. Data analysis
Water quality models are mathematical models that are formulated from the physical, chemical, and biological processes in the water systems. A model is a representation of a complicated system but made simple. Modelling makes it possible to measure and experiment in an easy and inexpensive way when experiments at a laboratory are difficult to do and time-consuming. Calculation of scenario 1 will produce pollution load so that it can calculate the carrying load capacity of the river. Pollution capacity is the ability of water in a water source to receive input pollution without causing the water to become polluted [10]. This research uses the mass balance method to determine the value of the river pollution load capacity.

Pollution load capacity is obtained from QUAL2Kw-based modelling scenarios with maximum pollution loads following Government Regulation No.82/2001. The results of the scenario will be presented in graphs and the pollution load reduction figures will be obtained.

3. Results and discussion

3.1. Sampling location
Based on the results of the observational data, 10 sample point locations were collected along the 22.37 km from the upstream to downstream of the rivers (Table 1, Figure 1). The maximum of the river’s discharge is 183.26 m³/s and the minimum discharge is 26,030 m³/s.

3.2. Calibration model
The QUAL2Kw simulation model is calibrated using trial and error method to produce the closest estimated value to the existing conditions [11]. Indicators of a successful calibration are derived from the value generated fitness is 0.5939. The suitability of the model with the existing data can be assumed as reliable if the value of fitness > 0.5 [12,13]. An increase in fitness value indicates the suitability of the trend line (model) with the input data [13]. The calibration results of the hydraulic model can be seen from Figure 2.
Table 1. Sampling location.

| Segment | Location                              | Coordinate               | Flow (m³/s) |
|---------|---------------------------------------|--------------------------|-------------|
| 1       | Kuala / Muara Sungai Bukit Batu       | N: 01° 27’ 41.6" E: 102° 00’ 11.1 | 183.26      |
| 2       | Pelabuhan PT. Arara Abadi             | N: 01° 27’ 19.6" E: 101° 58’ 21.8" | 30.14       |
| 3       | Jembatan Sungai Bukit Batu 1          | N: 01° 27’ 54.5” E: 101° 58’ 05.9” | 29.41       |
| 4       | Kanal Titik Nol PT. Arara Abadi       | N: 01° 27’ 41.0” E: 101° 58’ 06.2” | 29.03       |
| 5       | Simpang Sungai Raja Beradu            | N: 01° 27’ 47.6” E: 101° 57’ 21.4” | 28.73       |
| 6       | Simpang Sungai Tengok                 | N: 01° 28’ 11.1” E: 101° 56’ 44.6” | 27.90       |
| 7       | Simpang Sungai Rumah Panjang          | N: 01° 27’ 58.7” E: 101° 55’ 53.2” | 27.60       |
| 8       | Simpang Sungai Lubuk Bakung           | N: 01° 26’ 59.3” E: 101° 55’ 58.1” | 27.14       |
| 9       | Pangkalan Tembuyut                    | N: 01° 24’ 35.1” E: 101° 54’ 57.4” | 26.98       |
| 10      | Simpang Sungai Tembuyut               | N: 01° 23’ 56.3” E: 101° 54’ 23.2” | 26.03       |

Figure 1. Sampling location map.

3.3. Simulation of the water quality
The water quality model approach can be used to get an estimation of the load pollution’s capacity [14]. With the available data models and observations that have been calibrated, water quality programs can be simulated with the planned scenarios. In this scenario, it is obtained that the highest value of BOD parameters is in segment 3 and 4, on the other hand, COD parameter in segment 1 that is in the upper reaches of the river. Average of pollution and load of BOD and COD parameters in the Bukit Batu River are 107,220.7 kg/day and 5,425,575 kg/day (Figure 3). From the results of this simulation it can be conclude that we need to reduce pollution load from point source and non-point source by 91% for BOD and 86% for COD. It means that these two parameters needs to be executed by reducing the pollution load more than 70% so that the Bukit Batu River will be included in the category of class II standard water quality.
Figure 2. Comparison of data and models for the parameter flow, velocity and river’s depth.

Figure 3. BOD and COD profiles in Bukit Batu River.

3.4. Land carrying capacity and water carrying capacity

Determination of the carrying capacity of land in the Bukit Batu sub-district can be calculated by land availability (SL) and land demand (DL) based on the data obtained as variables in the following formula [15]:

\[
SL = \frac{P_i \times H_i}{H_b} \times \frac{1}{P_{tvb}}
\] (1)

Information: land availability (SL), actual production of each agricultural commodity (Pi), unit price of each commodity (Hi), rice unit at producer (Hb), rice productivity (Ptvb).
\[ DL = N \times KHL_L \]  

(2)

information: land demand (DL), total population (N), land area needed for decent living needs per population (KHL_L).

The results of the calculation of the carrying capacity of the land in the Bukit Batu District, Bengkalis Regency are shown in Table 2.

| Variable       | Notation | Result (Ha) |
|----------------|----------|-------------|
| Land availability | SL       | 121.976.66  |
| Land demand     | DL       | 15.681.93   |

Table 2. Land carrying capacity.

If SL > DL, it can be comprehended that the carrying capacity of the land in the Bukit Batu sub-district is surplus. Water carrying capacity can be calculated by comparing the water availability and water demand based on the data on the type of land use, runoff coefficient, rainfall, area and population.

\[ SA = 10 \times C \times R \times A \]  

(3)

where: water availability (SA), runoff coefficient (C), rainfall (R), area (A)

\[ DA = N \times KHL_A \]  

(4)

where: population (N), water demand for a decent living (KHL_A)

Table 3. Water carrying capacity.

| Variable       | Notation | Result (m³/year) |
|----------------|----------|------------------|
| Water availability | SA      | 52.567.713.97   |
| Water demand     | DA       | 48.204.800.00   |

If the results of the calculation of SA > DA, the availability of water in the Bukit Batu District area can still meet the water needs for the population or the carrying capacity of water is a surplus. This analysis explains that the Bukit Batu sub-district has opportunities for regional development because it has land carrying capacity and water carrying capacity as a surplus. Therefore the water quality at the Bukit Batu river sources should be protected by reducing waste that causes the river polluted.

4. Conclusion

The results of the QUAL2Kw model simulation represent that the Bukit Batu River is in polluted condition with the excess contamination load of BOD and COD parameters are 107.220.7 kg/day and 5.425.575 kg/day. The action which should be taken is to reduce the pollution load by 91%. The availability of water in terms of quantity is met but the in quality aspect is not met in accordance with its purpose to meet the raw water demand for the population of Bukit Batu District. Water quality of Bukit Batu River needs to be maintained since the carrying land capacity and carrying water capacity in the region is still in the surplus category. It has the potential for regional development and can even improve the economy of the people of Bukit Batu District by utilizing the availability of the land and the availability of the water properly.

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