Simulation of pollution load capacity using QUAL2Kw model in Kali Surabaya River (Cangkir-Sepanjang segment)

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Simulation of pollution load capacity using QUAL2Kw model in Kali Surabaya River (Cangkir-Sepanjang segment)

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Abstract. The Utilization of Kali Surabaya River as water resources for drinking water is constrained by pollution from domestic and industrial waste and agricultural activities around the river banks. This study was aimed to calculate the pollution load capacity using QUAL2Kw model which presented the water quality. Study area from upstream (Cangkir) to downstream (Sepanjang) of the river was divided into 3 segments. The required data included primary data by sampling at determined points representing the condition of pollutant source. Secondary data included climatology, population, river hydraulic, and discharge and quality of pollution obtained from related institution. The water quality parameters analysed were BOD and COD, where the result exceeded the water quality standard of class I, while the DO was less than the standard requirement. Based on the simulation result, the value of pollutant load in each segment for BOD was 12,416 kg/day, 23,180 kg/day, and 17,759 kg/day while COD was 56,158 kg/day, 99,188 kg/day, and 74,316 kg/day. Then, the capacity of BOD in each segment was 1,681 kg/day, 1,138 kg/day, and 1,398 kg/day while COD is 12,396 kg/day, 8,150 kg/day, and 9,681 kg/day. This means that the pollutant load has exceeded the capacity of the river.

1. Introduction

Kali Surabaya River was used as primary source for drinking water, irrigation, farming, fishery, as well as industrial, business, and transportation activity. Those activities increase the people's economic growth, indicated by the increasing number of industrial and housings around the river bank. However, people's economy grows inversely to the river water quality. Based on STORET index value, Kali Surabaya River is heavily polluted [1]. The major source of pollutants along the river come from domestic, industrial, and agricultural activities.

Pollution load capacity analysis is a complicated process because river water always flows and the quality fluctuates from upstream to downstream. More sampling point with closer distances can describe the river water more accurately, but the cost will go way too high [2]. Moreover, water runoff of a river bank is affected by a lot of factors along with its each component through complex hydrological process [3]. Therefore, mathematical model can be used as an alternative.

Mathematic model is a tool to estimate the pollution load entering the river and it can form a cause-and-effect relationship between pollution loads with the water quality in different scenario [4]. River water quality model based on Keputusan Menteri Negara Lingkungan Hidup No. 110 Tahun 2003 regulation may use QUAL2Kw which is a developed version of QUAL2E. QUAL2Kw is a program that models river water quality, represents river in one dimensioned form with non-uniform flow and simulates the effects of point source and non-point source pollutions [5].

QUAL2Kw is a Visual Basic for Application (VBA) program implemented into Microsoft Excel. Excel is used as a medium tool to display graphic data result from the input and running model. In this study, QUAL2Kw model is applied to Kali Surabaya River to calculate the pollution load entering the river and to determine the pollution load capacity of the river with 3 scenarios. This study is expected to result in appropriate recommendation of strategy to improve the quality of Kali Surabaya River as befitting its class

2. Methods

2.1. Study area

Study was done by dividing Kali Surabaya from Cangkir to Sepanjang into 3 (three) segments with 4 sampling points. Sampling location selection was based on pollution source location, whether it was point sources or non-point sources, which allegedly contributed to Kali Surabaya river pollution. Water quality sampling point selection was based on Standar Nasional Indonesia SNI 6989.57:2008 regulation [6].

Table 1. Kali Surabaya river segmentation.

Segment Name	Km	Coordinates	
		Upstream	Downstream
Cangkir - Bambe	9.15 – 5.55	7˚21,57,76" LS 112˚37'58,52" BT	7˚21,57,76" LS 112˚37'58,52" BT
Bambe - Karangpilang	5.55 – 1.80	7˚21,57,76' LS 112˚37'58,52" BT	7˚20,54,54" LS 112˚40'52,52" BT
Karangpilang - Sepanjang	1.80 – 0.00	7˚20,54,54" LS 112˚40'52,52" BT	7˚20,56,00" LS 112˚41'42,60" BT

River sample taking point was determined from river debit. Based on the data from Perum Jasa Tirta 1, it was known that the debit of Kali Surabaya river was ranged 20-50 m^3/second. For river with debit between 5-150 m^3/second, sample was taken from two points, 1/3 and 2/3 of river width from half the depth of the river or using integrated sampler tool to obtain even sample from surface to bottom and then to be mixed.

2.2. Data collection

This study used descriptive quantitative analysis method by collecting primary and secondary data. Primary data used was river water quality (pH, temperature, DO, BOD, and COD) and river hydraulic data (length, width, debit, depth, and velocity). Secondary data needed to support model developing was water quality from related institution. Secondary data collecting, including Kali Surabaya River map, population rate and infrastructure, climatology data, debit and quality of industrial waste water pollution (point sources), and debit and quality of domestic waste water pollution (diffuse sources).

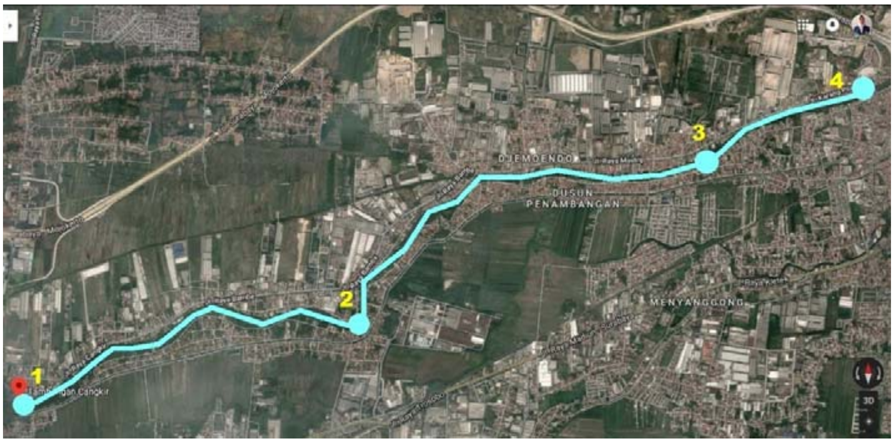

Figure 1. Map of study area and segmentation

2.3. *QUAL2Kw model description*

This study used one dimensional mathematic model with QUAL2Kw program. This program could simulate the movement and transformation of various constituent including dissolved oxygen, temperature, biochemical oxygen demand, organic nitrogen, ammonia nitrogen, nitrate nitrogen, total nitrogen, organic phosphorus, inorganic phosphorus, total phosphorus, phytoplankton and algae [7]. Moreover, geometric data of river property was also needed, such as channel slope, channel width, side slope, and manning roughness coefficient [8].

QUAL2Kw is a model framework of modern river water quality. The user of this model are free to choose water quality parameter according to the analysis necessity in a research. QUAL2Kw model uses mass balance general equation for constituent concentration (ci) in every points (i) (see Fig.2) as follows [9]:

$$\frac{dc_i}{dt} = \frac{Q_{i-1}}{V_i}c_{i-1} - \frac{Q_i}{V_i}c_i - \frac{Q_{ab,i}}{V_i}c_i + \frac{E_{i-1}}{V_i}(c_{i-1} - c_i) + \frac{E_i}{V_i}(c_{i+1} - c_i) + \frac{W_i}{V_i} + S_i \quad (1)$$

where: Ci is the constituent concentration at reach i (g/m3); Qi is the flow at reach i (m3/d); Vi is the reach volume (m3); Qab,i is the flow abstraction from reach i (m3/d); Ei is the bulk dispersion coefficients between reaches i and i+1 (m3/d); Ei-1 is the bulk dispersion coefficients between reaches i-1 and i (m3/d); Wi is the external loading of the constituent to reach i (g/d or mg/d); Si are sources/sinks of the constituent (g/m3/day or mg/m3/day).

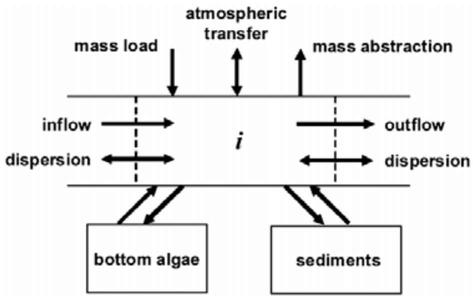

Figure 2. Mass balance in a reach segment i

2.4. Model calibration and validation

2.4.1. Input data. The measured river geometrics and river velocities were used to determine the hydraulic characteristics at each sampling locations. The model allows the input of the river reach hydraulic characteristics such as discharge of water, velocity, depth, and river width. The water quality input parameters included flow, temperature, conductivity (EC), pH, DO, BOD, COD (as generic constituent). The water qualities for the point and diffuse source of pollutions were other input to the model. The data were collected for four times in a month and average data was used as the input data.

2.4.2. Data calibration. In this study, calibration was done by trial and error and repeated running until the model result resembled real condition. Trial and error was done on Worksheet reach and Worksheet reach rates by determining the coefficient of each parameter.

2.4.3. Data validation. Validation was done by Root Mean Square Percent Error (RMSPE) method to quantify the value and characteristic of errors. RMSPE measured the average percentage of the difference between actual data and simulation, by the following formula [10]:

$$RMSPE = \sqrt{\frac{1}{n}\left[\sum_{n=1}^{n}\left(\frac{St - At}{At}\right)^2\right]} \times 100\% \tag{2}$$

Where: St is simulation Value at time t; At is actual Value at time t; and n is the frequency of observation (t=1, 2, ….n).

RMSPE value nearing 100% shows that the conformity between the model and field data is very bad. If RMSPE is under 20%, it can be said that the model is acceptable [11]. If the RMSPE in model is higher than 20%, re-calibration is needed until the model is conformed or close with inputted data.

2.5. Simulation techniques

Simulation is a process to estimate river water quality with scenario. Simulation in this study was divided in to 3 simulations (see Table 2). Simulation 1 was to calculate pollution load entering the river while simulation 2 and 3 was to calculate the load capacity of Kali Surabaya River. Capacity load of pollution was used to determine the maximum ability of Kali Surabaya River in receiving pollution load. The calculation was obtained from the pollution load difference value in simulation 3 and 2. Simulation 3 was a condition where the maximum pollution load or pollution load condition was allowed to enter the river without it being categorized as polluted. While simulation 2 was an initial condition of a river without pollution load.

Table 2. Scenario of simulation.

Simulation	Scenario			
	Upstream Treatment	Point Sources Treatment	Diffuse Source Treatment	Simulation Goal
1	According to real situation	According to real situation	According to real situation	Calculating pollution load entering the river
2	Meeting Class I Water Standard[a]	Removed	Removed	Observing self-purification process in the river without polluting load entering
3	Meeting Class I Water Standard[a]	Trial and Error until meeting Class I Water Standard[a]	Trial and Error until meeting Class I Water Standard[a]	Observing pollution load without polluting the river

[a] Water quality standard based on PP RI 82/2001

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3. Results and discussion

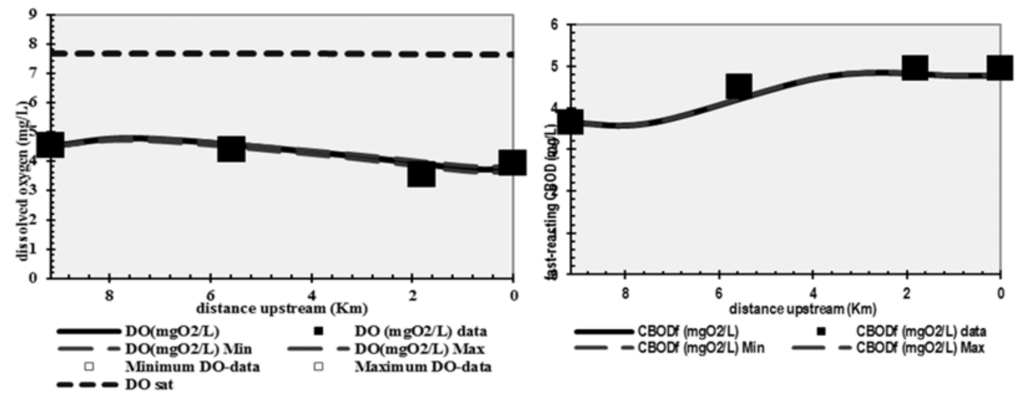
3.1. Calibration and validation

The model calibration results for the water quality data at four locations are shown in Fig. 3. The model calibration results are in conformed to the measured data, because model data has been made as similar to the input data (black box). The calibrated parameter values in the model are presented in Table 3. The relative mean error between the simulated and observed values for DO, BOD, and COD are 8,46%; 5,21%; and 6,82% respectively. All is below 20% error value, thus can be accepted.

Based on water quality model (see Fig.3), DO value tended to lower from upstream to downstream, while BOD and COD value tended to increase. This is because in each river segment there were more pollution entering, whether it was point source or non-point sources. Those wastewater added high organic and inorganic materials which resulted in low DO. Moreover, downstream flow had higher decomposition of organic material and oxidation of inorganic material rate that depleted DO vastly. Decomposition can make lower dissolved oxygen rate [12].

Table 3. Root Mean Squared Percent Errors (RSME) for predicted vs. measured water quality parameters

Length (km)	DO Data (mg/L)	DO Model (mg/L)	RMSPE DO	BOD Data (mg/L)	BOD Model (mg/L)	RMSPE BOD	COD Data (mg/L)	COD Model (mg/L)	RMSPE COD
9.15	4.5	4.5	8.46%	3.64	3.64	5.21%	18	18	6.82%
5.55	4.35	4.69		4.5	3.69		20	16.76	
1.8	3.5	4.15		4.94	4.86		22	21.04	
0	3.9	3.61		4.94	4.88		22	20.52	



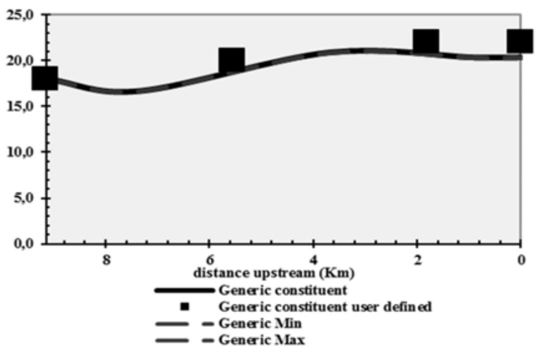


Figure 3. Calibration of water quality parameters in Kali Surabaya river

3.2. Simulation results

Simulation 1 was actual condition simulation where it used actual debit data and river water quality based on sampling result. Climatology data and pollution sources data (whether it be point sources or diffuse sources) using existing data from related institution. This simulation was aimed to calculate the existing pollution load entering Kali Surabaya River. Pollution load is the amount of polluted elements contained in the water body or waste water body. The first simulation are shown in Table 4.

Domestic wastewater contributed the most as pollution source of Kali Surabaya River compared to other pollution source (see Table 4). The percentage of pollution source from domestic waste in each segments were 40.94%; 68.26%; and 54.20% respectively.

Simulation 2 was a simulation without pollution source. and simulation 3 was simulation made to meet Class I water quality standard. To calculate the pollution load capacity of each segment, the water quality in headwater was set to Class I water quality standard and the pollutants discharged into the river were considered. Input data of pollution loads for dissolved oxygen, biological oxygen demand, and chemical oxygen demand were adjusted by trial and error until the water quality simulation results met the water quality objectives for simulation 3. While in simulation 2 input data of pollution loads were removed. Simulation 2 and 3 can be seen in Fig. 4. The pollution loads in simulation 3 is greater than that of the simulation 2.

Table 4. Pollution load of Kali Surabaya River.

Segment	Pollution Source	Pollution Load (kg/day)		Proportion (%)	
		BOD	COD	BOD	COD
Cangkir - Bambe	Industry	2200.06	12623.48	17.72%	22.48%
	General Facility	3716.57	15187.82	29.93%	27.04%
	Domestic	5210.63	22994.23	41.97%	40.94%
	Agriculture	1289.24	5353.43	10.38%	9.53%
TOTAL BP		**12416.51**	**56158.96**	**100%**	**100%**
Bambe - Karangpilang	Industry	44.57	248.84	0.19%	0.25%
	General Facility	6185.54	24369.00	26.68%	24.57%
	Domestic	15302.42	67707.37	66.01%	68.26%
	Agriculture	1648.45	6863.09	7.11%	6.92%
TOTAL BP		**23180.98**	**99188.31**	**100%**	**100%**
Karangpilang - Sepanjang	Industry	120.53	1807.11	0.68%	2.43%
	General Facility	8394.34	32227.86	47.27%	43.37%
	Domestic	9244.43	40281.85	52.05%	54.20%
	Agriculture	0.00	0.00	0.00%	0.00%
TOTAL BP		**17759.30**	**74316.82**	**100%**	**100%**

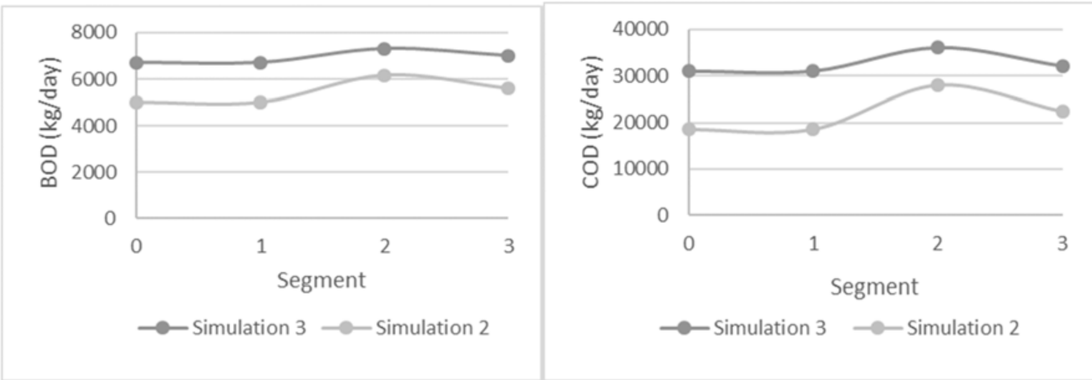


Figure 4. Pollution load capacity model

3.3. Pollution load capacity calculation

Pollution load capacity calculation used the result from worksheet output, as in worksheet source summary, hydraulics summary, and WQ output in the QUAL2Kw program. Those worksheet contained data result of the models in the form of debit and quality of river water and pollution source in each segments. Calculation was obtained through the difference value in pollution load between simulation 3 and 2 (see Fig. 4). The result can be seen in Table 5.

Table 5. Pollution load capacity of Kali Surabaya River

Segment	Location (km)	BOD (kg/day)	COD (kg/day)
1	9.15 - 5.5	1681.57	12396.65
2	5.5 - 1.8	1138.15	8150.84
3	1.8 - 0.0	1398.78	9681.43

In PP RI No. 82 Tahun 2001 regulation, water pollution load capacity is the capability of water in certain water source to receive pollution load without causing the water body to be polluted. In fact, pollution load entering the river (Table 4) has exceeded the capacity of the river (Table 5). This show that Kali Surabaya River is not suitable as water resource of drinking water because it has polluted and exceeded Class I of water quality standard.

Appropriate strategy is needed to reduce pollution entering the river and improve water quality of the river. If river water quality is not maintained, it cause an increase in operational cost to treat Kali Surabaya River as water resources for drinking water. In addition, regulations and monitoring related to the discharge of wastewater into Kali Surabaya River needs to be improved.

4. Conclusions

The one dimensional river water quality model QUAL2Kw was calibrated and validated for Kali Surabaya River using data collected in 2018. QUAL2Kw model represented the field data quite well where the relative mean errors between the simulated and observed data for DO, BOD, and COD were 8.46%; 5.21%; and 6.82% respectively. The model was applied to simulate various water quality by considering pollution loads modification.

The major source of pollutants in Kali Surabaya River was dominated by domestic wastewater. The pollution load entering each river segments for parameter BOD were 12.416 kg/day, 23.180 kg/day, and 17.759 kg/day respectively. The pollution load capacity for BOD were 1.681 kg/day, 1.138 kg/day, and 1.398 kg/day respectively. For COD parameter, the pollution load entering each river segments were 56.158 kg/day, 99.188 kg/day, and 74.316 kg/day while the capacity for COD were 12.396 kg/day, 8.150

kg/day, and 9.681 kg/day. Appropriate strategy to reduce pollution load is needed to improve river water quality so that it doesn't exceed its capacity.

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