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Water Quality Modelling with Industrial and Domestic Point Source Pollution: a Study Case of Cikakembang River, Majalaya District

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ABSTRACT Rapid industrial development is one of the leading causes of environmental degradation. The textile industries and the domestic activities in Majalaya District produce wastewater directly discharged into the Cikakembang River. As a result, the Cikakembang River's water quality has decreased to the point that the water quality cannot be used for daily needs. This study modeled three main parameters in water quality modelling, namely Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD). Using MATLAB, the three-water quality governing equations originating from the Advection-Dispersion Equation were solved using the Runge Kutte-4 discretization scheme. The numerical modelling was carried out along 2.36 km of the Cikakembang River. All water quality coefficients, such as the DO Saturation (DO_{sat}), the Reaeration Rate (k_a), the Dispersion Coefficient (D), the Deoxygenation Rate (k_d), and the Decomposition Rate (k_c), for the Cikakembang River were estimated using equations developed by existing studies. The estimation of k_a and D coefficients requires hydraulic parameters, which in this study were estimated using the HEC-RAS simulation. Meanwhile, k_d and k_c values were obtained from the calibration and verification process. The Relative Root Mean Square Error (RRMSE) objective function was used to evaluate the results of water quality modelling at three sampling points. In the calibration process, the results of water quality modelling produced RRMSE values for the DO, BOD, and COD parameters of 1.99%, 0.36% and 0.92%, respectively. Meanwhile, for the verification process, the RRMSE values for the DO, BOD, and COD parameters are 1.95%, 1.02% and 1.86%. All water quality parameters produce small RRMSE values in the calibration and verification processes. Hence, the water quality model created has good accuracy and stability.

KEYWORDS Advection-Dispersion Equation; MATLAB; Point-Source Pollution; Water Quality Coefficients; Water Quality Modelling

1 INTRODUCTION

Rapid industrialization in the 21st century is one of the leading causes of recent environmental degradation (Nasrollahi et al., 2020). Industry produces wastewater that can pollute local water bodies so that the available water quality can be below suitable standards for use. However, industrialization can only be stopped partially because this sector supports other parts of human life. At the same time, the exponential increase in population and drastic climate change affect water sustainability in terms of quantity and quality (Tabari, 2020; Liyanage and Yamada, 2017). Due to industrial activities in Africa, Asia, and Latin America, polluted rivers are almost one-third of all rivers; in Europe, 60% of surface water is polluted; while in the USA, polluted rivers are 50% (Worldwide, 2019). Limited quantities of water with safe quality make water increasingly essential for human life (Tang et al., 2022). In several areas that have experienced an extreme water crisis, this forces the use of water of below-standard quality, thereby triggering the emergence of disease. Globally, using polluted water causes the deaths of around 829,000 people yearly due to diarrhea (Lin et al., 2022).

The early step to solving the water quality degradation problems can be done by understanding the existing conditions for the organic parameters, such as Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD) parameters. One way to assess the severity of the quality conditions of a water channel in several locations over a continuous period is to use numerical modelling. In addition, numerical modelling is considered suitable for assessing water quality conditions without discharging actual wastewater into the water system (Menendez et al., 2016). MATLAB is one of many software used to carry out numerical modelling. MATLAB has been widely used in research, engineering, financial analysis, and other fields (Srinivas et al., 2023). The ability provided by MATLAB can solve partial differential equations, including water quality governing equations or, more specifically, the Advection-Dispersion Equation.

The Cikakembang River, located in Majalaya District, is one of many rivers facing water quality degradation. The Majalaya District is a dense textile industry area with 174 industries, with wastewater being dumped directly into the Cikakembang River (Wikiandy et al., 2013). BOD and COD parameters found in industrial wastewater have relatively high concentrations (Wang et al., 2022). In the past few years, BOD and COD parameters in the Cikakembang River have exceeded the water quality standard on 30 and 17 occurrences, respectively (Fitriana et al., 2023). Even in sampling carried out in September 2013, the BOD and COD parameters in the Cikakembang River reached 150 mg L^{-1} and 400 mg L^{-1}, respectively. These two parameters have the impact of reducing DO levels, potentially damaging aquatic ecosystems and making water unfit for use. Apart from industrial wastewater, domestic wastewater in Majalaya District also contributes to reducing the water quality of the Cikakembang River. Domestic wastewater characteristic also has a relatively high concentration of BOD and COD, but it is lower than textile industrial wastewater.

This study focuses on numerical water quality modelling for three organic parameters, DO, BOD, and COD, in the Cikakembang River, Majalaya District. The numerical modelling was carried out using MATLAB software. Modelling is carried out in two conditions, namely, the rainy season and the dry season. The two seasons have different hydraulic parameter conditions, so they also have different water quality parameter conditions. The modelling results can describe the severity of industrial and domestic wastewater discharging along the Cikakembang River. An objective function, which is Relative Root Mean Square Error (RRMSE), was used to measure the accuracy of the model that has been created. This research can be an initial stage in developing a model for non-organic pollutant parameters, such as heavy metals. However, the existence of other pollutant parameters needs to be investigated further. The pollution control program of the Cikakembang River due to textile industry wastewater can also be developed using the developed water quality model.

2 METHODS

2.1 Water Quality Model Setup

This study uses a research flow, as shown in Figure 1. Data on hydraulic parameters, water quality parameters, and channel cross-sectional shape were collected. Flow velocity and depth are the types of data taken in hydraulic parameters. Meanwhile, for water quality parameters, the data type is the concentration of DO, BOD, and COD parameters. Along the study location, bathymetry measurements were carried out at 36 points to obtain the channel cross-sectional shape of the river. After the data collection, hydrodynamic simulations were carried out to obtain hydraulic parameter values at the 36 cross-section points. The following process uses MATLAB software to code the Advection-Dispersion Equation using the Runge-Kutte 4 discretization scheme. The calibration and verification process is carried out by estimating water quality coefficients and concentration of Point Source Pollution. This calibration and verification process continues until the solution produces the smallest RRMSE value. The model was evaluated to determine its capability and accuracy.

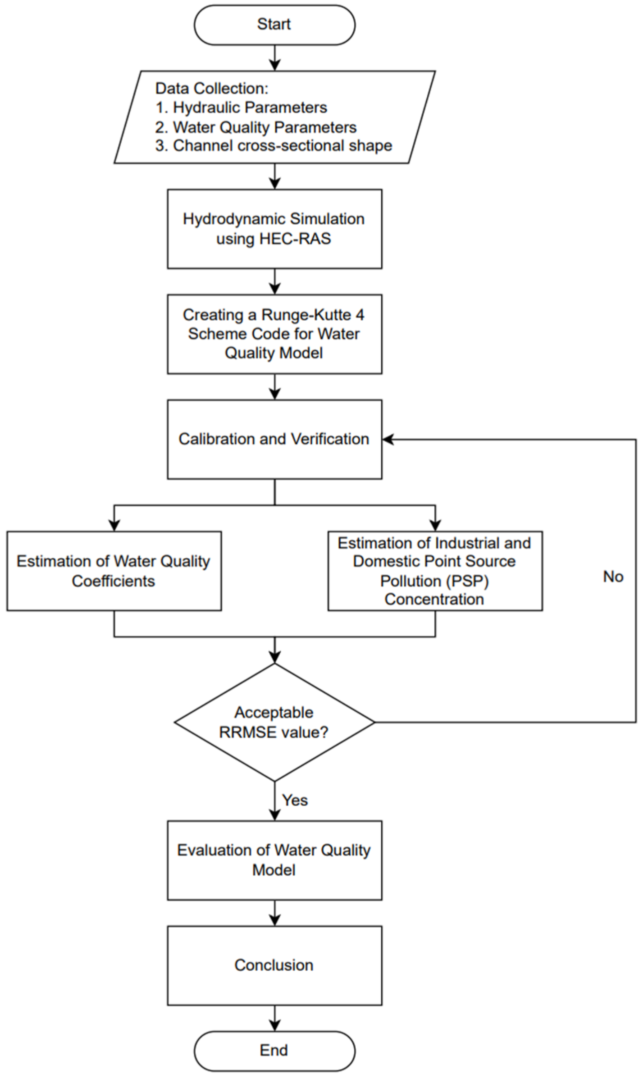


Figure 1 Research flowchart

2.2 Advection-Dispersion Equation (ADE)

The Advection-Dispersion Equation (ADE) is a partial differential equation commonly used to describe pollutant transport (Sun et al., 2020). Equation 1 is a one-dimensional ADE form.

$$\frac{\partial C}{\partial t} = -\frac{\partial v_x C}{\partial x} + D\frac{\partial^2 C}{\partial x^2} \tag{1}$$

where, C is the substance's concentration (mg L^{-1}), v_x is the mean longitudinal velocity (m s^{-1}), and D is the dispersion coefficient (m^2 s^{-1}). Equation 1 can be rewritten as Equation 2.

$$\frac{\partial C}{\partial t} = -(v_x \frac{\partial C}{\partial x} + C\frac{\partial v_x}{\partial x}) + D\frac{\partial^2 C}{\partial x^2} \quad (2)$$

Since the modelling is done in a steady state flow condition, the term $\partial v_x/\partial x$ can be assumed as 0. So, the final form of ADE can be seen in Equation 3.

$$\frac{\partial C}{\partial t} = -v_x \frac{\partial C}{\partial x} + D\frac{\partial^2 C}{\partial x^2} \quad (3)$$

The river recovery system for the organic parameters has two main processes that happen simultaneously: deoxygenation and reaeration. The deoxygenation process occurs to decompose the BOD and the COD parameters by a particular bacterium, which would consume the DO parameter. On the other hand, reaeration is the process of oxygen exchange between the atmosphere and the surface of the water body. The DO value will significantly decrease if the presence of BOD and COD in the water body exceeds the river's recovery ability. This relationship can be modelled through mathematical equations, which can be seen in Equation 4, Equation 5, and Equation 6. As can be seen in Equation 5 and Equation 6, there are differences in the reaeration term *(k_a(DO_{sat} - DO))* in the BOD and COD parameters. The reaeration term in the numerical calculation of BOD and COD does not include the DO parameter in its calculation. Bacteria that decompose these two organic parameters will react to the amount of oxygen entering the water body. Meanwhile, the DO parameter values that are already low in water bodies will not be decomposed again by the bacteria. This is the main reason for the difference in reaeration terms in the DO equation compared to the BOD and COD equations.

$$\frac{\partial DO}{\partial t} = -v_x \frac{\partial DO}{\partial x} + D\frac{\partial^2 DO}{\partial x^2} + k_a(DO_{sat} - DO) - k_d BOD - k_c.COD \quad (4)$$

$$\frac{\partial BOD}{\partial t} = -v_x \frac{\partial BOD}{\partial x} + D\frac{\partial^2 BOD}{\partial x^2} - k_d.BOD - k_a.DOsat \quad (5)$$

$$\frac{\partial COD}{\partial t} = -v_x \frac{\partial COD}{\partial x} + D\frac{\partial^2 COD}{\partial x^2} - k_c.COD - k_a.DOsat \quad (6)$$

where, DO is the Dissolved Oxygen (mg L^{-1}), BOD is the Biological Oxygen Demand (mg L^{-1}), COD is the Chemical Oxygen Demand (mg L^{-1}), v_x is the mean longitudinal flow velocity (m s^{-1}), k_a is the reaeration rate (day^{-1}), DO_{sat} is the saturation value of DO parameter (mg L^{-1}), D is the dispersion coefficient (m^2 s^{-1}), k_d is the deoxygenation rate for BOD parameter (day^{-1}), and k_c is the decomposition rate for COD parameter (day^{-1}).

2.3 Study Location

The Cikakembang River is in the Majalaya Sub-District, Bandung District, West Java Province, Indonesia. There are 16 wastewater disposal points on the Cikakembang River, of which 12 are industrial wastewater entry points and the other four are domestic. Modelling was carried out from the downstream of the Cikakembang River to 2.39 km upstream. The study location segment was selected based on the existence of the textile industry along the Cikakembang River. Figure 2 is a map of study locations for numerical modelling of the Cikakembang River. Figure 3 is a schematic of the entry points for industrial and domestic wastewater along the study location. The wastewater entry location points were obtained from field observations.

2.4 Observation Data

The three water quality parameters observed are DO, BOD, and COD. Collection and testing of Cikakembang River water samples were carried out at three observation points, namely A4, A19, and A23 (see Figure 3). A total of six collections were carried out between January 27th 2022 and October 19th 2022. Three samplings were carried out in the rainy season, while the other three were in the dry season. Data was collected on water quality data and physical parameter data for the Cikakembang River. Based on trend analysis of water quality observation data, the data set for the rainy season was on February 23th 2022, while the dry season was on August 24th 2022. Water quality data for three parameters, namely DO, BOD, and COD, are shown in Table 1. Physical parameter data is shown in Table 2.

2.5 Hydraulic Parameter Data

Hydraulic parameters of the Cikakembang River were generated using HEC-RAS software. HEC-RAS simulation can generate several hydraulic parameters, such as hydraulic depth (H), flow velocity (v_x), and channel's top width (W). These parameters were used to estimate several water quality coefficients: dispersion coefficient (D), reaeration rate (k_a), and decomposition rate for the COD parameter (k_c). Steady flow simulation was used to produce the hydraulic parameter from HEC-RAS. Some variables are needed to simulate the flow: The manning coefficient, the cross-sectional area along the river, the upstream discharge of the Cikakembang River, and the wastewater discharge at each point-source pollution. Manning's coefficient was determined by observation in the field. The channel's material of the upper stream is considered a natural stream; hence, the manning's coefficient value used is 0.04. However, the downstream part from A19 to A36 has been protected using concrete, so the value is 0.015. The upstream discharge of the Cikakembang

Figure 2 The study location

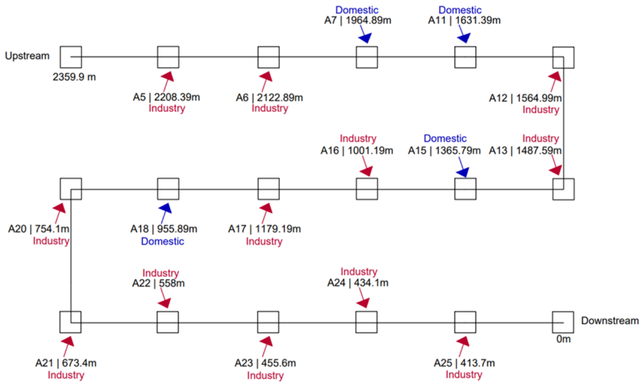


Figure 3 Industrial and domestic inlet wastewater scheme of the Cikakembang River

River was measured at the same time as water sampling. Respectively, the upstream discharge in the rainy and dry seasons are 0.349 m^3 s^{-1} and 0.252 m^3 s^{-1}, respectively. The wastewater discharge values are also estimated and ranged from 0.001 m^3 s^{-1} to 0.053 m^3 s^{-1}. The hydraulic parameters of the Cikakembang River in the rainy and dry seasons are shown in Figure 4.

Table 1. DO, BOD, and COD observed data

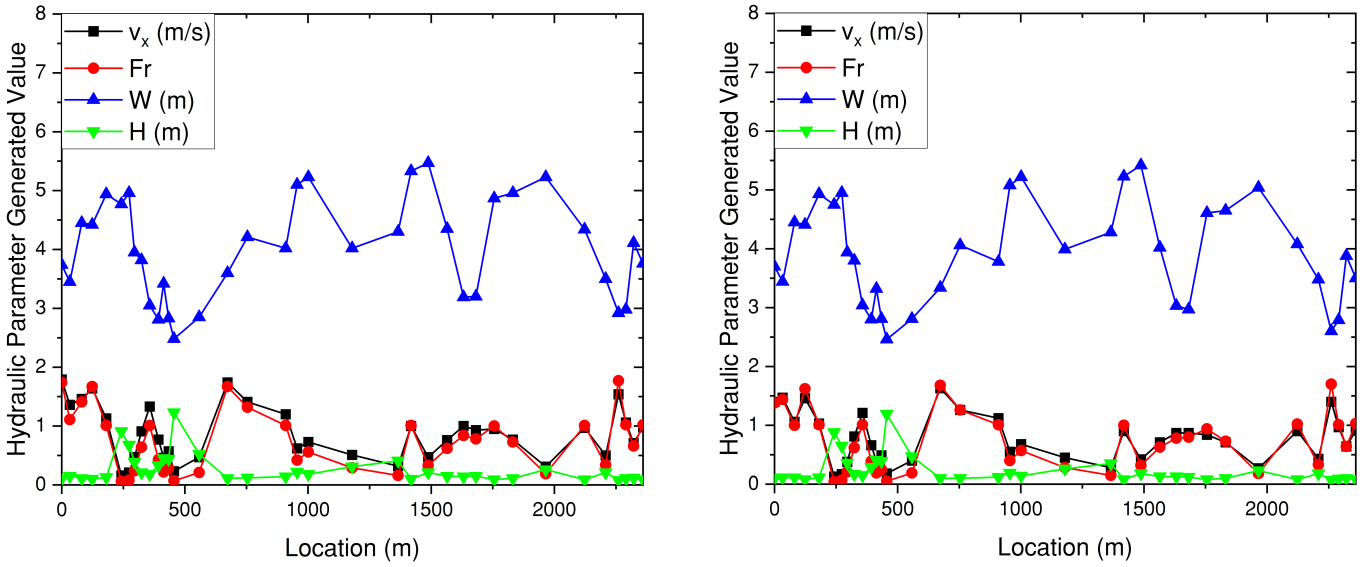
Location from the Downstream (m)	Sampling Points	DO (mg L^{-1})		BOD (mg L^{-1})		COD (mg L^{-1})	
		Rainy Season	Dry Season	Rainy Season	Dry Season	Rainy Season	Dry Season
2260.29	A4	6.10	2.90	23.00	15.00	85.00	81.60
909.49	A19	3.30	2.40	16.00	9.50	63.50	43.70
434.10	A23	3.30	2.40	16.00	10.50	61.70	42.60

Table 2. Observed data for physical parameters

Location from the Downstream (m)	Sampling Points	*pH*		Temperature (°C)	
		Rainy Season	Dry Season	Rainy Season	Dry Season
2260.29	A4	6.82	6.57	29.00	29.00
909.49	A19	6.43	6.79	28.00	30.00
434.10	A23	6.60	6.93	29.00	29.00

2.6 Water Quality Coefficients Used

All water quality coefficients must be estimated or calibrated based on the characteristics of the Cikakembang River. The water quality coefficient consists of reaeration rate (k_a), DO saturation (DO_{sat}), deoxygenation rate for the BOD parameter (k_d), decomposition rate for the COD parameter (k_c), and dispersion coefficient (D). All water quality coefficients are determined and estimated using the equations or optimal ranges in Table 3. The equation selection for each parameter is based on



(a) (b)

Figure 4 Hydraulic parameters of the Cikakembang River in (a) rainy season and (b) dry season

Table 3. Calibrated water quality coefficient values in the rainy season

Parameters	Symbol	Units	Equations	Optimal Ranges	References
Reaeration Rate	k_a	day^{-1}	$if Fr \geqslant 1, k_a = 5.791(v_x^{0.5} H^{-0.25})$	-	(Jha et al., 2001)
			$if Fr < 1, k_a = 0.603286(v_x^{0.4})$	-	(Jha et al., 2004)
Dispersion Coefficient	D	m^2 s^{-1}	$D = 2(\frac{W}{H})^{1.5} H \sqrt{g.H.S_0}$	-	(Iwasa and Aya, 1991) (Zeng and Huai, 2014)
Deoxygenation Rate (BOD)	k_d	day^{-1}	-	0.05 to 0.5	(Schnoor, 1996)
DO Saturation	DO_{sat}	mg L^{-1}	$DO_{sat} = 14.652 - 0.41022T + 0.007991T^2 - 0.000077774T^3$	-	(Benedini and Tsakiris, 2013)
Decomposition Rate (COD)	k_c	day^{-1}	$k_c = K_{cod} + \frac{v_s}{H}$	-	(Benedini and Tsakiris, 2013)

the thesis conducted by Polisar (2023). The thesis modelled the Cikakembang River water quality using HEC-RAS using the same equations in Table 3 and has been evaluated to produce excellent values.

where, v_x is the mean longitudinal velocity m s^{-1}; H is the water depth; T is the average water temperature (°C); K_{cod} is the decay rate for the COD parameter (day^{-1}); v_x is the settling velocity m day^{-1}; W is the channel's top width (m); g is the gravitational force (m s^{-2}); and S_0 is the average channel's slope.

2.7 Point Source Pollution (PSP)

The numerical model includes point-source pollution (PSP) as the primary source of pollution. In this study, non-point source pollution (N-PSP) is neglected because the pollution caused by organic parameters resulting from agriculture and livestock activities is not significant. PSP is calculated using the water mass balance equation, written in Equation 7. This study assumes that domestic wastewater is discharged between 06:00 AM and 08:00 AM and 05:00 PM and 07:00 PM, while industrial wastewater is discharged between 08:00 AM and 05:00 PM. These periods were selected based on the working hours in Indonesia.

$$C_{mix} = \frac{Qriv.C_{riv} + Q_{eff}.C_{eff}}{Q_{riv} + Q_{eff}} \tag{7}$$

where, C_{mix} is the mixed concentration (mg L^{-1}), Q_{riv} is the river's discharge (m^3 s^{-1}), C_{riv} is the concentration of a particular substance in the water body (mg L^{-1}), Q_{eff} is the effluent discharge (m^3 s^{-1}), and C_{eff} is the effluent concentration of a particular substance (mg L^{-1}).

2.8 Discretization using Runge-Kutte 4 Scheme

This study uses an explicit discretization scheme because of its simplicity, efficiency, and ease of computing. One of the explicit discretization schemes is the Runge-Kutte 4, which consists of four constants in its numerical calculation. The Runge-Kutte 4 discretization scheme and its constants can be mathematically written as shown in Equation 8 until Equation 12 respectively (Popescu, 2014).

$$C_i^{t+1} = C_i^t + (\frac{\Delta t}{6})(k_{1\_i}^t + 2k_{2\_i}^t + 2k_{3\_i}^t + k_{4\_i}^t) \tag{8}$$

$$k_{1\_i}^t = D_i(\frac{C_{i+1}^t - 2C_i^t + C_{i-1}^t}{\Delta x^2} - v_x(\frac{C_i^t - C_{i-1}^t}{\Delta x} \tag{9}$$

$$k_{2\_i}^t = D_i(\frac{C_{i+1}^t - 2(C_i^t + 0.5k_{1\_i}^t + C_{i-1}^t}{\Delta x^2} - v_x(\frac{(C_i^t + 0.5k_{1\_i}^t) - C_{i-1}^t}{\Delta x}) \tag{10}$$

$$k_{3\_i}^t = D_i(\frac{C_{i+1}^t - 2(C_i^t + 0.5k_{2\_i}^t + C_{i-1}^t}{\Delta x^2} - v_x(\frac{(C_i^t + 0.5k_{2\_i}^t) - C_{i-1}^t}{\Delta x}) \tag{11}$$

$$k_{4\_i}^t = D_i(\frac{C_{i+1}^t - 2(C_i^t + k_{3\_i}^t + C_{i-1}^t}{\Delta x^2} - v_x(\frac{(C_i^t + k_{3\_i}^t) - C_{i-1}^t}{\Delta x}) \tag{12}$$

Equation 8 – Equation 12 only solves the Advection-Dispersion Equation without any sinks or sources term included. Inputting the reaeration and deoxygenation rate terms of the DO, BOD, and COD parameters must be done in the Runge-Kutte 4 constants, which are $k_{1\_i}^t$, $k_{2\_i}^t$, $k_{3\_i}^t$, and $k_{4\_i}^t$. The term $v_x\Delta t/\Delta x$ in the numerical calculation is commonly known as Courant Number, and it is used to evaluate the model's stability. The Courant Number values are limited below one to ensure the model's stability.

2.9 MATLAB Software

The complexity of numerical model calculations does not allow researchers to calculate numerical modelling manually. Hence, numerical model calculations must be assisted using programming languages, such as MATLAB software. Several water-related issues have been solved by using MATLAB, such as groundwater quality modelling (Yan et al., 2019), water quality prediction using Artificial Neural Network (ANN) (Deng et al., 2021; Yu et al., 2020), and others. This study will not use tools provided by MATLAB, such as Simulink. Instead, computations for solving the ADE using the Runge Kutte-4 discretization scheme were coded out manually in the MATLAB script.

2.10 Objective Functions

The objective function measures the accuracy of modelling results in the calibration and verification process.

Table 4. Boundary conditions of the Cikakembang River

Parameter	Symbol	Units	Rainy Season	Dry Season
Temperature	T_1^t	˚C	28.00	29.00
DO (upstream)	DO_1^{t+1}	mg L-1	6.10	2.90
DO (downstream)	DO_{36}^{t+1}	mg L-1	DO_{35}^{t+1}	
BOD (upstream)	BOD_1^{t+1}	mg L-1	23.00	15.00
BOD (downstream)	BOD_{36}^{t+1}	mg L-1	BOD_{35}^{t+1}	
COD (upstream)	COD_1^{t+1}	mg L-1	85.00	81.60
COD (downstream)	COD_{36}^{t+1}	mg L-1	COD_{35}^{t+1}	

This study uses the Relative Root Mean Square Error (RRMSE) objective function, where this objective function normalizes the Root Mean Square Error (RMSE) value so that the value is dimensionless (Despotovic et al., 2016). The RRMSE equation can be seen in Equation 13.

$$RRMSE = \frac{1}{\Sigma_{i=1}^N} \sqrt{\frac{\Sigma_{i=1}^N (C_0 - C_M)^2}{N}} \tag{13}$$

where, RRMSE is Relative Root Mean Square Error (unitless), C_0 is the mean concentration of the observed parameter (mg L^{-1}), C_0 is the concentration of the observed parameter (mg L^{-1}), C_M is the concentration generated from the numerical model (mg L^{-1}), and N is the total calculated sample.

3 RESULTS

3.1 Boundary Conditions

The boundary conditions in this study use two methods, namely the Dirichlet method and the Neumann method. The Dirichlet method's boundary conditions determine a variable's value based on its observed value. In contrast, the Neumann method's boundary conditions assume no change in gradient over the spatial step. Boundary conditions in the upstream Cikakembang River are determined according to the Dirichlet method, while boundary conditions in the downstream Cikakembang River are determined according to the Neumann method. More complete details regarding the boundary conditions used in water quality modelling can be seen in Table 4.

3.2 Calibration

Two water quality coefficients, such as reaeration rate k_a and dispersion coefficient (D), have a calculated range of values based on their hydraulic parameter. Meanwhile, the other two coefficients, deoxygenation (k_d) and decomposition rate (k_c) are calibrated to produce acceptable values. All water quality coefficient

Table 5. Calibrated water quality coefficient values in the rainy season

Water Quality Coefficients	Units	Values Used
Reaeration Rate (k_a)	day^{-1}	10.25 – 50.34
Deoxygenation Rate (k_d)	day^{-1}	0.23
Decay Rate for COD parameter (K_{cod})	day^{-1}	0.02
Settling Velocity for COD parameter (v_s)	m day^{-1}	0.30
Decomposition Rate (k_c)	day^{-1}	0.26 - 3.77
Dispersion Coefficients (D)	m^2 s^{-1}	2.33 – 7.64

Table 6. The PSP concentration for domestic and industrial wastewater

Parameter	Concentration (mg L^{-1})	
	Domestic	Industry
DO	2.00	1.00
BOD	30.00	45.00
COD	50.00	60.00

values used are represented in Table 5. Haider et al. (2013) evaluated various types of reaeration equations. Based on this study, reaeration values vary widely, ranging from 2 day^{-1} to greater than 50 day^{-1}. In addition, Jha's equation was tested with a model performance (R^2), which resulted in almost close to 1. The calculated values of (k_a) range from 10.25 day^{-1} to 50.34 day^{-1}. The estimated reaeration rate for the Cikakembang River is at a medium to high level regarding Dissolved Oxygen recovery ability. Nogare and Bauer (2022) quantify the dispersion coefficient (D) using 27 developed regression equations in small channels. The research results show that the dispersion coefficient ranges between 0.01 m^2 s^{-1} and 79.26 m^2 s^{-1} in natural and concrete channels. The estimated results of D values obtained using the Iwasa and Aya (1991) equation are in the range between 2.33 m^2 s^{-1} and 7.64 m^2 s^{-1}.The estimated dispersion coefficient value indicates the process of mixing pollutants in the Cikakembang River at low levels.

Also, the PSP concentration used in the calibration process for each parameter was set according to the applicable wastewater regulations. The regulations governing textile industry wastewater are Indonesian Ministerial Regulation No. 16 of 2019, while the regulations governing domestic wastewater are the Ministry of Environment and Forestry of the Republic of Indonesia No. P68 of 2016. The details of PSP concentration for domestic and industrial wastewater are represented in Table 6.

Both in the calibration and verification process, the model runs for one day of the simulation, from 06:00 AM to the next day. The time-step (Δt) is given a value equal to 20 seconds. The selection of the time step value is based on the Courant number value ($v_x(\Delta t/\Delta x)$) so that it is not greater than one. The calibration results are shown in Figure 5, with the calculation of RRMSE represented in Table 7.

3.3 Verification

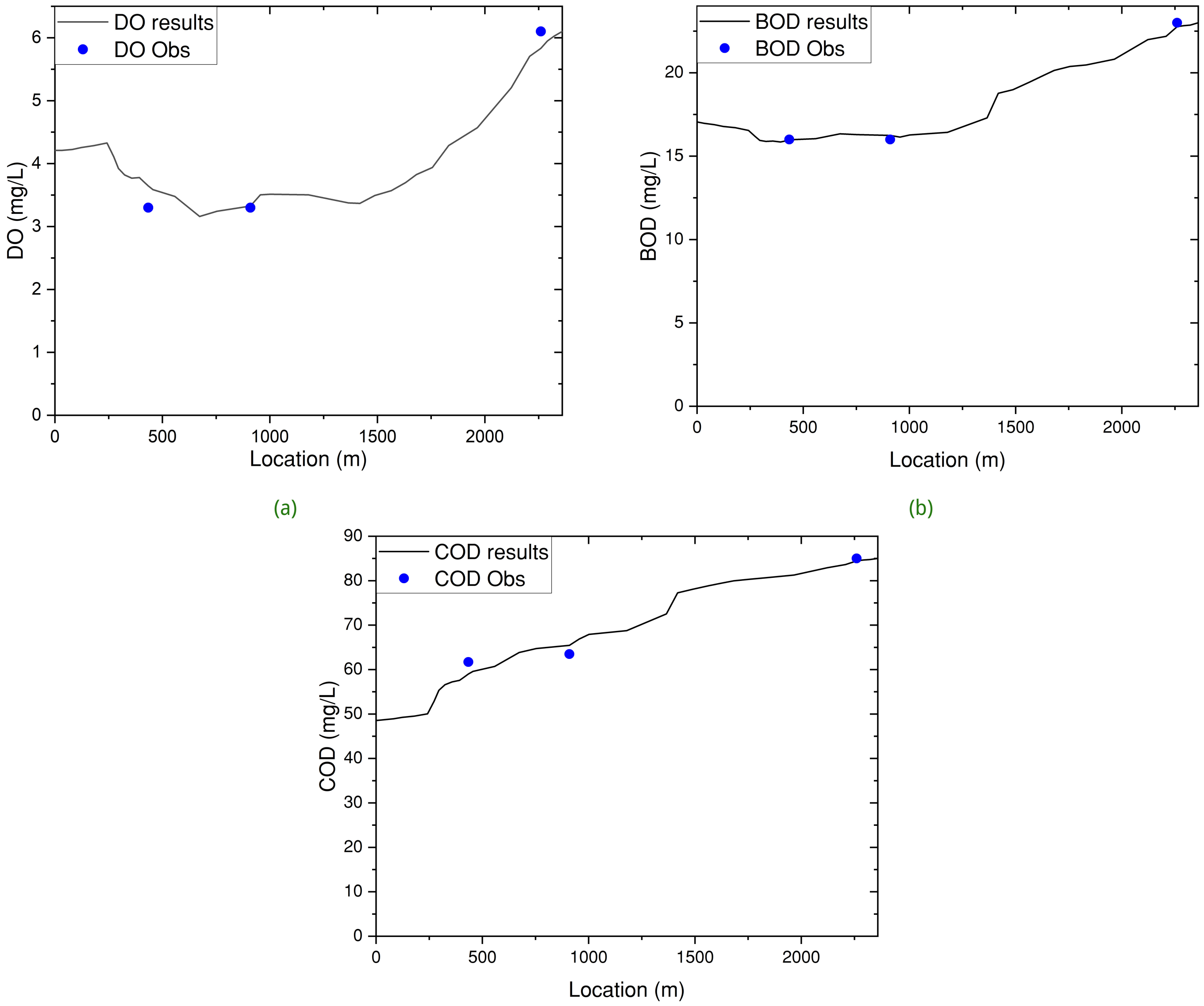
Water quality coefficient values such as reaeration rate k_a and dispersion coefficient (D) change according to the hydraulic parameter values in the dry season. The deoxygenation rate (k_d), decay rate (K_{COD}), and settling velocity (v_s) values are not changed from the calibration process. However, due to changes in water depth values from the rainy to the dry season, the range of COD decomposition coefficient values (k_c) changes. All water quality coefficient values used in the verification process can be seen in Table 8. In this verification process, the PSP concentration values for industrial and domestic waste are the same as those used in the calibration process. Also, a time-step (Δt) value of 20 seconds used is unchanged. The results of the verification process modelling for the three parameters can be seen in Figure 6, with error values listed in Table 9.

4 DISCUSSION

The water quality modelling of the Cikakembang River is created using the Runge-Kutte 4 discretization scheme. The Runge-Kutte 4 is an explicit scheme and can simulate the water quality condition both in spatial and temporal axes. The ease of writing code makes the Runge-Kutte 4 scheme useful for solving ADE problems. However, this scheme does not directly show the Courant Number value ($v_x(\Delta t/\Delta x)$). Special attention is required so the model does not use a Courant number value above one. The Courant Number values in the calibration and verification processes range from 0.03 to 0.83 and 0.03 to 0.89. These two ranges indicate that the model results created are stable.

This study simulates the Cikakembang River water quality conditions in two seasons. The rainy season data set is used for calibration, while the dry season data set is used for verification. Both calibration and verification processes produce good values, where the indication factor used is the RRMSE objective function. In the calibration process, the RRMSE values for the DO, BOD, and COD parameters were 1.99%, 0.36%, and 0.92%. All parameters produce acceptable RRMSE values, which are below 10%. In the verification process, the RRMSE values resulting from the DO, BOD, and COD parameters were 1.95%, 1.02%, and 1.86%. The three water quality modelling parameters produce small error values, so the model's accuracy is excellent. Similar research was conducted by Iqbal et al. (2018), by modelling water quality in several rivers in Asia using the QUAL2Kw model. The study conducted by Iqbal et al. (2018) shows that the accuracy of the QUAL2Kw model is similar to the accuracy of the model developed in this study through the small RMSE values of the DO and BOD parameters.

Although modelling has produced accurate values, the



(a) (b)

(c)

Figure 5 Calibration results of (a) DO, (b) BOD, and (c) COD parameter

Table 7. Evaluation of calibration results using RRMSE objective function

	RRMSE (%)		
	DO	BOD	COD
Value	1.99	0.36	0.92

Table 8. Calibrated water quality coefficient values in the dry season

Water Quality Coefficients	Units	Values Used
Reaeration Rate (k_a)	day^{-1}	10.21 – 46.40
Deoxygenation Rate (k_d)	day^{-1}	0.23
Decay Rate for COD parameter (K_{cod})	day^{-1}	0.02
Settling Velocity for COD parameter (v_s)	m day^{-1}	0.30
Decomposition Rate (k_c)	day^{-1}	0.27 - 4.31
Dispersion Coefficients (D)	m^2 s^{-1}	2.31 – 7.54

uncertainty of the results cannot be neglected. The uncertainty sources that can influence the modelling results are the existence of other organic parameters, the hydraulic parameter values of the Cikakembang River, which can change with time or unsteady flow conditions, or different combinations of PSP concentration and discharge. With the various study limitations that have been mentioned, further research is needed to test how significant the impact of the uncertainty factors that have been mentioned is. Testing the effects of uncertainty factors on the model can also significantly increase model accuracy.

The existence of industrial and domestic PSPs dramatically influences the water quality of the Cikakembang River. During industrial working hours (08:00 AM – 05:00 PM), the DO, BOD, and COD parameters in the Cikakembang River are very bad. These three parameters exceed drinking water quality standards. The modelling results show that the industrial effluent in the

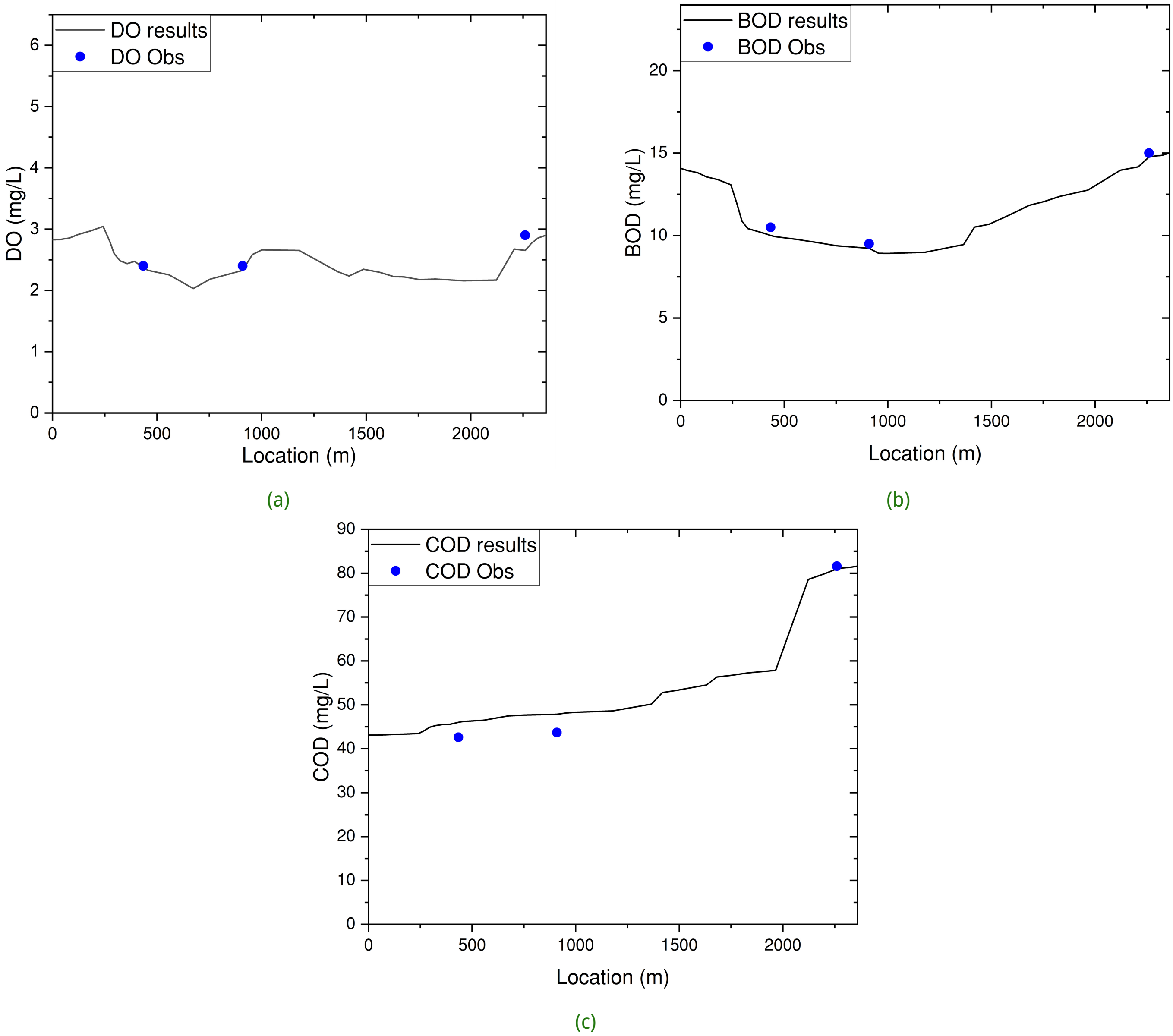


Figure 6 Verification results of (a) DO, (b) BOD, and (c) COD parameter

Table 9. Evaluation of verification results using RRMSE objective function

	RRMSE (%)		
	DO	BOD	COD
Value	1.95	1.02	1.86

Majalaya District was not treated sufficiently before being discharged into the Cikakembang River. Observing the ongoing pollution despite the regulation of industrial effluent concentrations, the stakeholders need to reevaluate the applicable wastewater standard regulations.

Future research can focus more on the numerical modelling of heavy metal parameters with non-biodegradable characteristics. The textile industry generally produces industrial waste containing heavy metals, such as Zinc, Iron, Chromium, and Copper (Khalish et al., 2022; Dey and Islam, 2015). Investigating which heavy metal parameters are polluting the Cikakembang River is necessary. In addition, future research can also focus on developing pollution control programs that can accelerate the recovery of the Cikakembang River. Various simulations could be conducted using the developed model to achieve the pollutant-carrying capacity of the Cikakembang River. New policies can be established to prevent pollutant concentrations from exceeding applicable river water quality standards.

5 CONCLUSION

Numerical modelling of Cikakembang River water quality for organic parameters in both seasons has been successfully carried out. The results obtained also indicate a reasonably good level of model accuracy. The maximum RRMSE value produced by the DO parameter in the calibration process is 2.27%. The COD parameter produced a sufficiently small error value in the verification process, namely 1.86%. This study only models three water quality parameters: DO, BOD, and COD. Adding other organic waste parameters can increase the model's accuracy, especially the DO parameter. The textile industry commonly produces heavy metal waste, which can also pollute the environment. Until this paper was written, few programs were available to model heavy metal parameters in rivers. This study can be a basis for future research on modelling water quality parameters for heavy metals in the Cikakembang River. Apart from that, the development of pollution control in the Cikakembang River can also be carried out based on the results of this study.

DISCLAIMER

The authors declare no conflict of interest.

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