

Modeling Water Quality and Pollution Load Capacity of the Musi River Using QUAL2Kw

Nur Faizaturrohmah¹, Rafles Ami Poza¹, Rifka Noor Azizah¹, Erlina Kurnianingtyas², Isoralla², Muhammad Ulin Nuha³, Arif Rohman³, Aulia Try Atmojo³, Daffa Adli Nauval Purnomo⁴, Dion Awfa*¹

¹Departement of Environmental Engineering, Faculty of Infrastructure and Regional Technology, Institut Teknologi Sumatera, Lampung Selatan, Indonesia

²Departement of Integrated Water Management Engineering, Faculty of Infrastructure and Regional Technology, Institut Teknologi Sumatera, Lampung Selatan, Indonesia

³Departement of Geomatics Engineering, Faculty of Infrastructure and Regional Technology, Institut Teknologi Sumatera, Lampung Selatan, Indonesia

⁴Departement of Landscape Architecturer, Faculty of Infrastructure and Regional Technology, Institut Teknologi Sumatera, Lampung Selatan, Indonesia

e-mail: *¹dion.awfa@tl.itera.ac.id

Abstract

The aim of this study was to analyze the water quality and determine the pollution load capacity of the Musi River in Palembang City, Indonesia, using the QUAL2Kw model. The method involved collecting water quality data (TSS, NH₃, COD, and pH), calibrating and validating the model using hydraulic and water quality parameters, and pollution load capacity. Field observations were conducted along a 7.93 km river segment divided into two reaches with six sampling points representing the main river and tributary inputs. The results showed that the QUAL2Kw model performed well, with strong agreement between observed and simulated data. TSS and NH₃ concentrations generally increased from upstream to downstream, reflecting anthropogenic influences from tributary inflows, domestic wastewater, agricultural runoff, and surrounding land-use activities. TSS remained within the river's assimilative capacity in both reaches, while NH₃ exceeded the allowable load in Reach 1. COD was the most critical parameter because its concentration exceeded the Class II water quality standard and showed negative pollutant load capacity in both reaches. These findings emphasize the need to reduce organic pollutant discharges from domestic and industrial sources to improve Musi River water quality.

Keywords : River Quality, Pollutant Load Capacity, Musi River, QUAL2Kw

INTRODUCTION

River water quality is an increasingly important environmental issue, because of anthropogenic activities such as urbanization, industry and agriculture, which greatly increase pollutant loads. Rivers have a limited capacity to receive and assimilate pollutants, called the pollutant load capacity. When this threshold is exceeded, water quality will be severely compromised and may affect ecosystems and human health (García-avila et al., 2025; Juwana et al., 2024). Determining the pollutant load capacity is important for water quality management because it closely relates to the river's ability to maintain conditions in accordance with established quality standards (Fitriana et al., 2025; Patel & Jariwala, 2024). Therefore, analyzing water quality and pollutant load capacity is a fundamental consideration in planning sustainable water resource management.

Various models and technologies have been developed to analyze river water quality and the capacity of rivers to accommodate pollutant loads, including statistical models, water-quality indices, and dynamic mathematical models. These models simulate existing conditions and predict changes in water quality resulting from variations in pollutant loads from different sources. Research often uses water-quality modelling approaches, such as QUAL2Kw, because they integrate physical, chemical, and biological parameters within river systems (Darji & Lodha, 2025; Fitriana et al., 2025). Furthermore, the QUAL2Kw model supports scenario-based decision-making, leading to more effective and efficient management strategies.

The QUAL2Kw model is a one-dimensional water quality model commonly used to assess

pollutant load capacity in rivers, as it can dynamically simulate various water quality parameters, including DO, BOD, COD, nutrients, and temperature (Ciawi et al., 2022; Raeisi et al., 2022). This model was developed using a steady-flow approach but can be automatically calibrated using an optimization algorithm for a more accurate and representative simulation of field conditions (Hu et al., 2018; Salem et al., 2025). Studies of QUAL2Kw showed it is effective for pollutant load capacity and evaluation of water quality management scenarios in rivers (Haryono et al., 2024; Melka & Aragaw, 2026). Given these benefits, the application of the QUAL2Kw model in river systems under pollution stress is of great importance for conducting pollutant capacity studies and developing effective management strategies. A high level of activity characterizes one such river.

The Musi River, one of the biggest rivers in Indonesia, is heavily polluted by domestic, industrial and water transportation activities. Several previous studies found that the water quality of the Musi River is affected by pollution, with increasing levels of TSS, NH₃, COD, and pH along the river's flow to the estuary (Rahutami et al., 2022; Rendana et al., 2022). Meanwhile, other studies also indicate that water quality management in the Musi River needs a data-driven modelling approach to accurately determine the pollutant load capacity (Lestari et al., 2019; Putra, 2017). Therefore, analyzing quality models, such as QUAL2Kw, is important for supporting the sustainable management of the Musi River.

Despite the availability of previous studies on the Musi River, there remains a lack of recent and integrated assessments that combine updated field observations, model calibration validation, and detailed pollution load capacity analysis. Most existing studies have emphasized general water quality assessment, while limited attention has been given to the use of QUAL2Kw for evaluating reach-based assimilative capacity under recent hydrological and pollution conditions. This gap is particularly important for the urban section of the Musi River in Palembang City, where domestic, industrial, agricultural, and river-transport activities continuously contribute to pollutant inputs. Therefore, this study applies the QUAL2Kw model using 2025 field data to simulate water quality and quantify the pollution load capacity for TSS, NH₃, COD, and pH. The findings are expected to support evidence based river pollution control and sustainable water-quality management in the Musi River.

RESEARCH METHODOLOGY

Study Area

The study area is located on the Musi River in Palembang City, South Sumatra Province, Indonesia. The study area is 7.93 km long across the Palembang city area and has a width ranging from 247 to 1090 m. The Musi River flows through areas dominated by settlements and agricultural land, indicating significant anthropogenic pressure on the river system (Figure 1). The Musi River is also an important resource for domestic, economic and transportation activities and is thus highly vulnerable to environmental degradation due to population growth and changing land use.

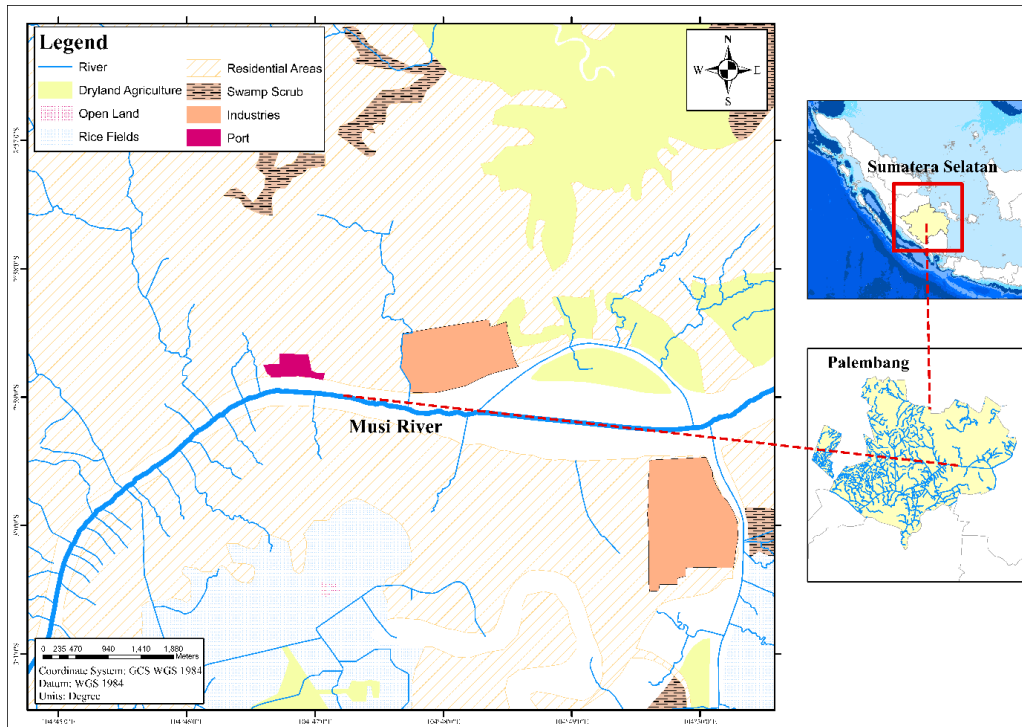


Figure 1 Land cover map of the sampling site

This research was conducted in October 2025 with a sampling route of 7.93 km from Ampera Bridge to the Plaju Oil and Gas Industrial area. The present study area was divided into 2 river sections, with 6 sampling points: 3 on the main river body and 3 on tributaries, as shown in Figure 2. Sampling locations were purposively selected based on tributary inflows and outflows and on land-use characteristics around the study area to represent the diversity of pollutant sources entering the river system. Water quality parameters analyzed: Total Suspended Solids (TSS), pH, ammonia (NH₃) and Chemical Oxygen Demand (COD), which were selected because they reflect physical, chemical and organic pollution pressures in the water.

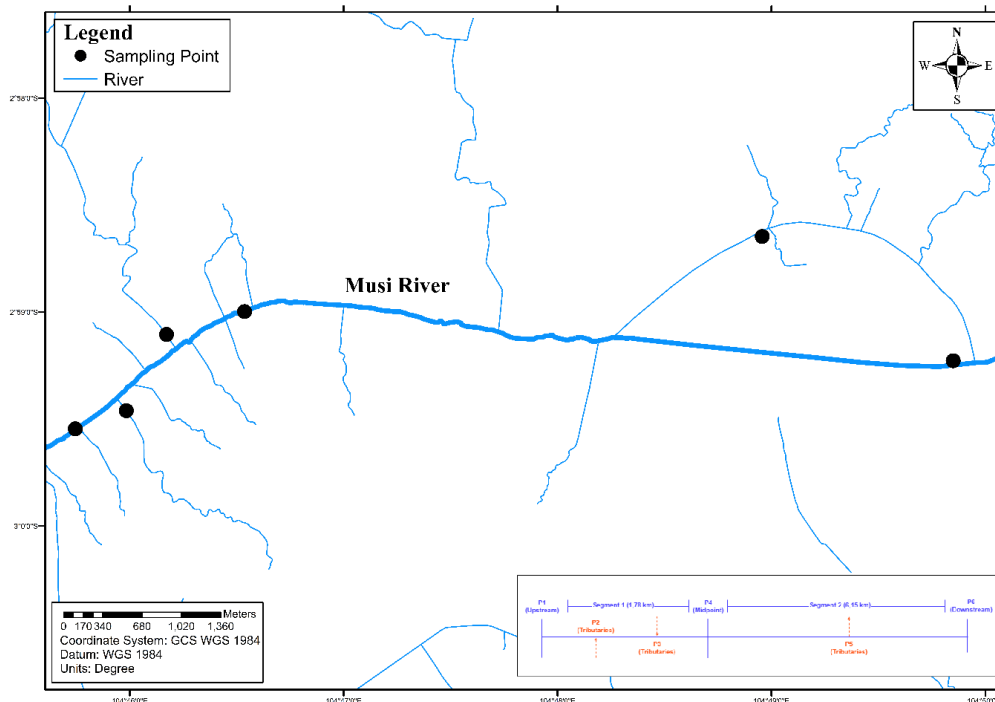


Figure 2 Map of Sampling Locations and Sections

Description of the QUAL2Kw Model

QUAL2Kw is an enhanced version of the QUAL2E model and is designed as a onedimensional steady-state water quality model. The solution is based on the differential advection-dispersion equation in each part using an implicit scheme (Soares et al., 2023). Before application, the QUAL2Kw model requires several systematic steps from data collection to interpretation of the simulation results, as illustrated in Figure 3.

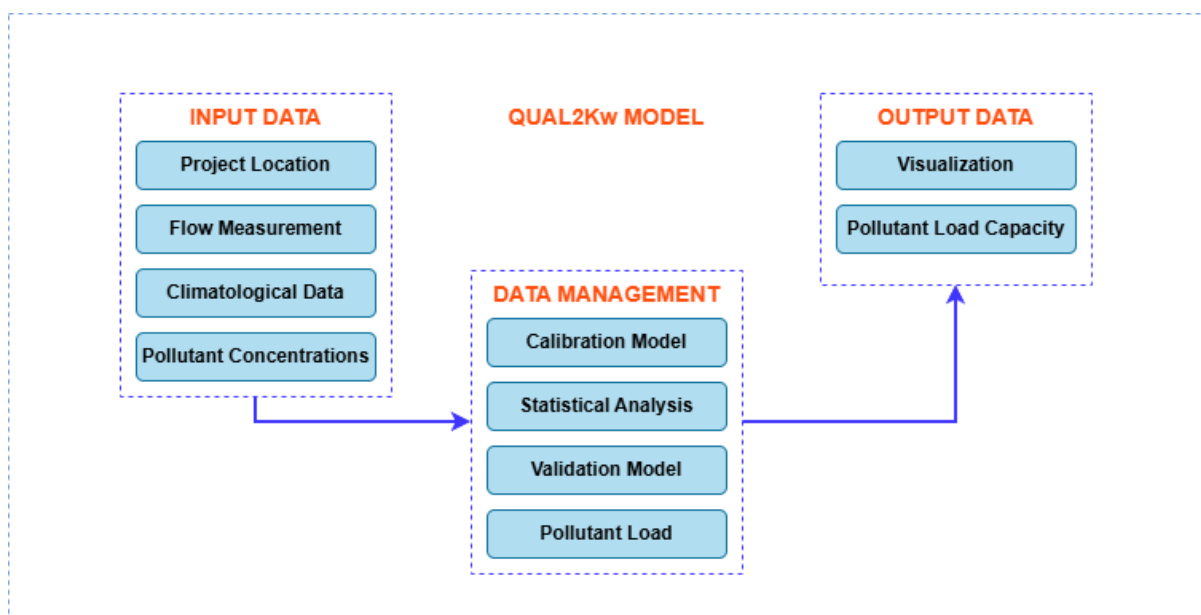


Figure 3 Steps in using the QUAL2Kw model

The relationships adopted in the QUAL2Kw model are flow, mass balance and temperature. Assuming perfect mixing along the river, they are given in equation (1).

$$Q_i = Q_{i-1} + Q_{in,i} - Q_{ab,i} \quad (1)$$

Where Q_i is the outflow from each i , Q_{i-1} is the outflow from each $i-1$, $Q_{in,i}$ is the inflow from point sources and non-point sources for each i , and $Q_{ab,i}$ is the outflow from all point sources and non-point sources for each i . Figure 4 is a schematic diagram of the flow balance.

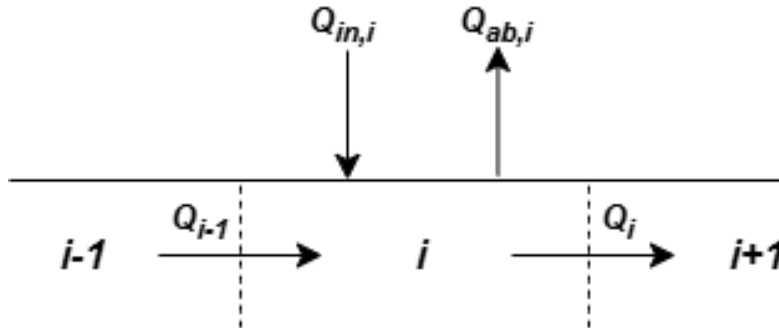


Figure 4 Flow Balance at QUAL2Kw

In the development of water-quality models, QUAL2Kw adheres to one of the fundamental principles, the law of conservation of mass. The authors usually use the Fischer equation, which is embedded in the QUAL2K model. The main Equation solved by the QUAL2Kw model is a one-dimensional advection-dispersion equation for all parameters except marine algae, as shown in equation (2).

$$\frac{dc_i}{dt} = \frac{Q_{i-1}}{V_i} c_{i-1} - \frac{Q_i}{V_i} c_i - \frac{Q_{ab,i}}{V_i} c_i + \frac{E_{i-1}}{V_i} (c_{i-1} - c_i) + \frac{E_i}{V_i} (c_{i+1} - c_i) + \frac{W_i}{V_i} + S_i \quad (2)$$

where Q_i is the outflow from reach i (m^3/day), Q_{i-1} is the outflow from the upstream reach $i-1$ (m^3/day), V_i is the volume of reach i (m^3), C_i is the concentration of the selected water-quality parameter in reach i (g/m^3), E_i is the bulk dispersion coefficient between reach i and reach $i+1$ (m^3/day), W_i is the external pollutant load entering reach i (g/day), and S_i represents internal sources and sinks of pollutants within reach i ($g/m^3/day$). Figure 5 is a schematic diagram of the mass balance relationships in QUAL2Kw.

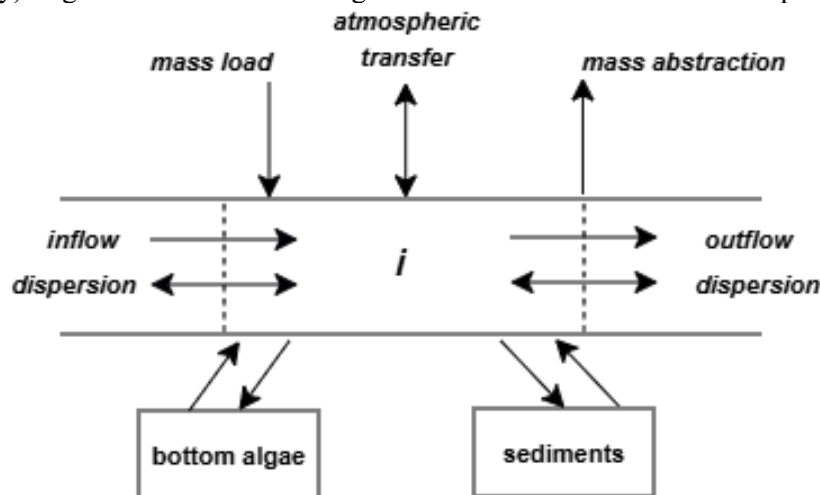


Figure 5 Mass Balance Relationship at QUAL2Kw

Calibration Model

Before water quality modelling and pollutant load capacity analysis using QUAL2Kw to represent the hydraulic characteristics and pollutant dynamics in the Musi River, an initial calibration stage (baseline) was carried out. This stage aims to match the simulation results as closely as possible to the real field conditions, even though it is possible that deviations from the observation data are possible. In this study, the model was calibrated using Manning's roughness coefficient and selected water-quality kinetic coefficients, including reaeration rate, ISS settling velocity, NH_3 nitrification rate, and generic

decay rate. The calibration was performed through a trial-and-error approach, in which the coefficient values were adjusted within the ranges reported in previous studies, as presented in Tables 1 and 2.

Table 1 Manning's Roughness Coefficient Used for Hydraulic Calibration

Hydarulic Component	Manning's "n"
River Channel	0.033

(Agency, 2019)

The range of coefficient values in this study was determined by compiling data from previous researchers based on a theoretical approach.

Table 2 Coefficient Value of Calibration

Coefficient Name	Unit	Value Range
Reaeration*	day ⁻¹	0.0 – 100
ISS Settling Velocity**	m/day	0.001 – 1.99
NH ₃ Nitrification Rate**	day ⁻¹	0.88 – 7.89
Generic Decay Rate*	day ⁻¹	0.05 – 1.0

*(Yusuf, 2016)**(Hu et al., 2018)

Validation Model

The model validation was conducted to determine whether the constructed river model was suitable for real river conditions. Three validity tests were used in this study to determine the error value and the reasons for the error in the results. The validity tests used in this study were Root Mean Square Error (RMSE), Coefficient of Determination (R²), and Mean Absolute Error (MAE), as shown in equations (3), (4), and (5). Models with high R² values and low RMSE and MAE values are suitable for decision-making in river water quality management (Al-Dalimy & Al-Zubaidi, 2023). You can use the following equations:

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (O_i - E_i)^2}{N}} \quad (3)$$

$$R^2 = \frac{[\sum_{i=1}^N (O_i - \bar{O})(E_i - \bar{E})]^2}{\sum_{i=1}^N (O_i - \bar{O})^2 - \sum_{i=1}^N (E_i - \bar{E})^2} \quad (4)$$

$$MAE = \frac{\sum_{i=1}^N |O_i - E_i|}{N} \quad (5)$$

Where, O_i is the value in the existing data, \bar{O} is the mean of the existing data, E_i is the value in the predicted data, \bar{E} is the mean of the predicted data, and N is the total number of data points.

Pollutant Load Capacity

The water quality of the Musi River is modelled first before computing the pollutant load capacity. The modelling was carried out using two simulation scenarios, as shown in Table 3.

Table 3 Simulation scenarios for the QUAL2Kw model

Simulation	Simulation Scenario			Purpose
	Upstream	Source of Pollution	Downstream	
1	Existing	Existing	Existing	Actual Pollutant Load
2	Quality Standard Class II	Trial and Error	Quality Standard Class II	Maximum Pollutant Load

Pollutant load concentration is the concentration of pollutant elements in water. The real pollutant load is the pollutant concentration value under the present conditions. The maximum pollutant load is the maximum concentration of pollutants that meets the applicable quality standards (Mujib et al., 2022;

Wiratmojo et al., 2023). Research on the calculation burden of pollutants. This is shown in the following equations (6) and (7).

$$APL = Q \times C \times k \quad (6)$$

$$MPL = Q \times C_m \times k \quad (7)$$

Where, Q is the river discharge (m^3/s), C is the pollutant concentration (mg/L), C_m is the pollutant concentration in accordance with the applicable quality standard (mg/L), and k is the conversion factor (86,4).

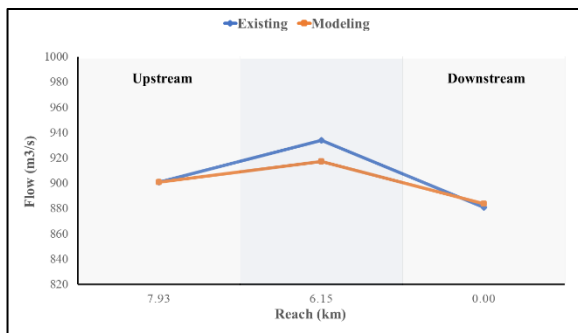
Pollution load capacity is the ability of a water body to receive pollutant inputs without violating applicable water quality standards. In relation to the calculations, the power capacity burden of river pollutants is calculated as the difference between the maximum and current pollutant loads (Poedjiastoeti et al., 2015). The value of the difference between the current burden of pollution and the maximum allowable pollution load is greater than his potential to pollute the receiving water body, as shown in equation (8) below.

$$PLC = MPL - APL \quad (8)$$

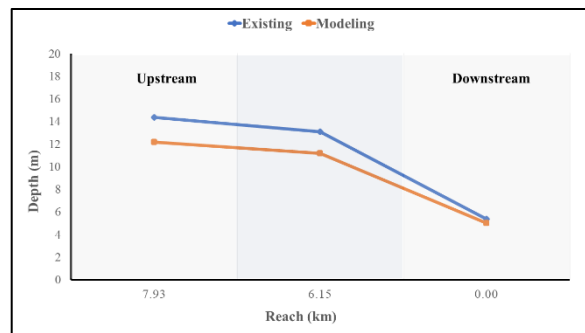
Where, PLC is the pollutant load capacity (kg/day), MPL is the maximum pollutant load (kg/day), and APL is the actual pollutant load (kg/day).

RESULTS AND DISCUSSION

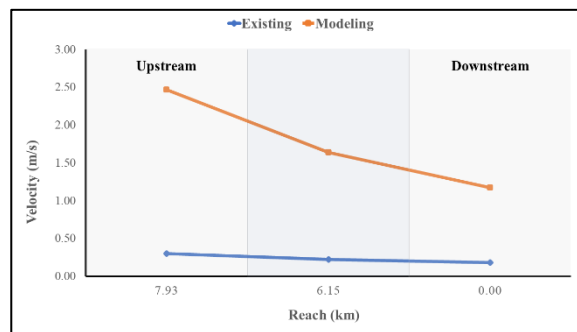
Calibration Model



RMSE: 9.78 | MAE: 6.49 | R²: 0.97



RMSE: 1.67 | MAE: 1.47 | R²: 1



RMSE: 1.59 | MAE: 1.52 | R²: 0.99

Figure 6 Calibration Model Graph at the QUAL2Kw

Model calibration was conducted to evaluate the ability of QUAL2Kw to reproduce the hydraulic characteristics of the Musi River before simulating water quality and pollutant load capacity. The calibration performance was assessed using RMSE, MAE, and R². In hydrological and water-quality modelling, R² values greater than 0.60 are generally considered satisfactory for watershed-scale flow simulations, while values approaching 1.00 indicate a very strong agreement between observed and simulated data. However, RMSE and MAE do not have universal fixed thresholds because they are scale dependent and must be interpreted according to the unit, range of observed data, and modelling objective. Therefore, lower RMSE and MAE values indicate better model performance, especially when the simulated trend remains consistent with field observations.

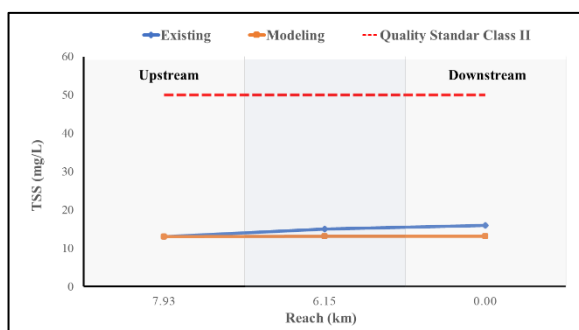
Based on the calibration results, the discharge model showed strong agreement with observed data, as indicated by $R^2 = 0.97$, which exceeds the commonly accepted threshold for satisfactory model performance. The RMSE and MAE values for discharge were 9.78 and 6.49, respectively, indicating that although the model captured the longitudinal discharge pattern, some deviations still occurred in the magnitude of simulated discharge. These deviations may be related to daily flow variability, uncertainty in tributary inflow estimation, simplification of river cross sections, and field measurement errors (Samborska-goik & Pogrzeba, 2024; Savvidis et al., 2025). This condition is common in river water quality modelling because hydraulic input uncertainty directly affects pollutant transport and dilution processes.

The depth calibration produced the best statistical performance, with (RMSE = 1.67, MAE = 1.47, and $R^2 = 1.00$). This indicates that the model was able to represent the longitudinal variation in river depth with a very high level of agreement. The close match between observed and simulated depth suggests that the river geometry and discharge depth relationship used in the model were sufficiently representative of field conditions. Since depth affects water volume, residence time, and dispersion processes, reliable depth calibration strengthens the basis for subsequent water-quality simulations (Ahnouch et al., 2025; Mazioti et al., 2024).

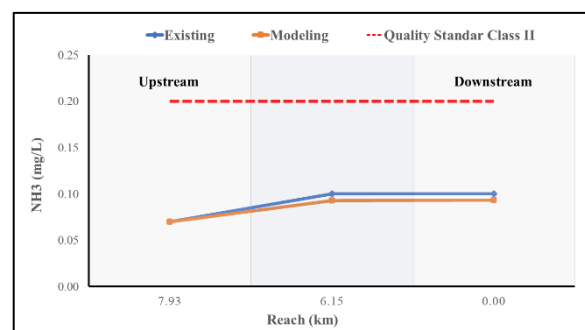
The velocity calibration also showed a high coefficient of determination, with (RMSE = 1.59, MAE = 1.52, and $R^2 = 0.99$). The high R^2 value indicates that the model successfully reproduces the spatial trend of flow velocity from upstream to downstream. Nevertheless, the relatively higher RMSE and MAE values suggest that some uncertainty remains in estimating the absolute magnitude of velocity. This may be due to local variations in channel roughness, riverbed slope, sediment conditions, vegetation cover, and human activities along the river (Darmian & Schmalz, 2024, 2025). Therefore, the velocity calibration can be considered acceptable for representing the hydraulic trend, but the magnitude should be interpreted cautiously.

Compared with previous QUAL2K/QUAL2Kw applications, the calibration performance obtained in this study is within the range reported for reliable river water-quality simulations. Al-Dalimy and Al-Zubaidi (2023) applied QUAL2K to the Hilla River and reported that low RMSE and MAE values indicated good agreement between observed and simulated water-quality parameters. Raesi et al. (2022) also demonstrated that QUAL2Kw could reliably simulate river water quality in the Maroon and Jarahi Basin, with high model accuracy during validation. Compared with these studies, the R^2 values obtained in the present study, ranging from 0.97 to 1.00, indicate excellent trend agreement, while the RMSE and MAE values reflect remaining uncertainty in the magnitude of hydraulic variables. Overall, the calibrated model is considered acceptable for further simulation of water quality and pollutant load capacity in the Musi River.

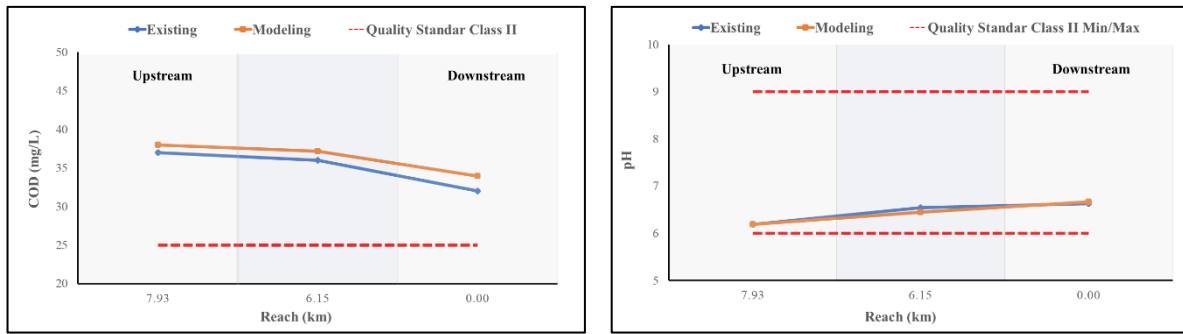
River Water Quality Simulation Results



RMSE: 1.93 | MAE: 1.55 | R^2 : 0.93



RMSE: 0.01 | MAE: 0.01 | R^2 : 1



RMSE: 1.2 | MAE: 1.03 | R²: 0.98

RMSE: 0.06 | MAE: 0.05 | R²: 0.91

Figure 7 Grafik Quality River at the QUAL2Kw

To strengthen the interpretation of the QUAL2Kw simulation results, the observed concentrations of each water-quality parameter were compared with the Class II river water quality standards stipulated in Government Regulation Number 22 of 2021. This comparison provides a clearer basis for evaluating whether the existing water quality conditions of the Musi River still comply with the applicable regulatory threshold. The comparison also supports the interpretation of the spatial pattern shown in Figure 7, particularly for identifying parameters that remain within the permissible limits and those indicating potential pollution pressure.

Table 4 Comparison of Observed Water Quality Concentrations with Class II River Water Quality Standards

Parameter	Unit	Upstream	Midpoint	Downstream	Class II Standars
TSS	mg/L	13	15	16	50
NH ₃	mg/L	0.07	0.1	0.1	0.2
COD	mg/L	38	36	32	25
pH	-	6.19	6.55	6.63	6-9

As shown in Table 4, the observed concentrations of TSS and NH₃ generally remain below the Class II water quality standards, indicating that suspended solids and ammonia pollution are still within the permissible limits during the observation period. The pH values also remain within the acceptable range, suggesting that the river still maintains a relatively stable acid–base condition. In contrast, COD exceeds the Class II standard at the observed points, indicating a higher organic pollution pressure in the study area. Therefore, COD becomes the main parameter of concern in the Musi River, while TSS, NH₃, and pH provide supporting evidence of the spatial influence of anthropogenic activities along the river section.

Based on the comparison between observed concentrations and Class II water quality standards, each parameter was further interpreted to identify its spatial pattern, model performance, and possible pollution sources along the Musi River. The TSS parameter indicates that the current concentration tends to increase from upstream to downstream, consistent with the trend shown in Simulation 1. The TSS parameter indicates that the current TSS concentration increases from upstream to downstream, consistent with Simulation 1. However, the results of the relatively stable QUAL2Kw model do not fully reflect this. This difference indicates uncertainty between the observational data and the model, as evidenced by the validation metrics (RMSE 1,93; MAE 1,55; R² 0,93). This can be influenced by sampling and laboratory analysis errors that can cause measurement bias (Jaywant & Arif, 2024). In addition, the rise in TSS in the Musi River is linked to anthropogenic activities, mainly soil erosion, surface runoff, and the discharge of domestic, industrial, and agricultural waste, which add suspended particles to the water body (Ogbonna et al., 2023; Rodríguez-Martínez et al., 2021). This condition is consistent with the characteristics of the study area in Figure 1, which is dominated by settlements and agricultural land, both of which greatly increase TSS loads from runoff and erosion.

Simulation 1 shows a relatively consistent upstream-to-downstream increase pattern in the NH₃ parameter between existing data and the QUAL2Kw model results, with excellent model performance

(RMSE 0,01; MAE 0,01; R² 1). This indicates that the model captures ammonia dynamics correctly. The increase in NH₃ concentration indicates anthropogenic activities such as domestic waste disposal, organic matter decomposition, and agricultural runoff treated with nitrogen fertilizers. Moreover, environmental conditions such as temperature, pH and dissolved oxygen are also associated with nitrogen conversion to ammonia in water bodies (Fahmi et al., 2023; Yue et al., 2017). This is in accordance with the conditions of the study area shown in Figure 1, which is dominated by settlements and agricultural activities that contribute to increased nitrogen loads in the Musi River.

The COD parameter shows a small decreasing trend from upstream to downstream, and the model results are in good agreement with the available data (RMSE 1,02; MAE 1,03; R² 0,98). This indicates that the model is very good at simulating the distribution pattern of organic matter, although there are still deviations. The relatively high COD values indicate the presence of organic pollutant loads from domestic waste (i.e., garbage dumped into the river), industry, and agricultural runoff (Purwono et al., 2019; Rendana et al., 2022). The COD values along the river are also influenced by biological degradation processes and natural dilution (Al-Ali & Al-Dabbas, 2022). There may be a small discrepancy between the model and observations due to uncertainty in pollutant load estimates and variability in biochemical processes in the field. This condition indicates the pressure of human activities around the watershed on the water quality of the Musi River.

The pH parameters exhibit relatively stable conditions from upstream to downstream with excellent agreement between the existing data and the model (RMSE 0,06; MAE 0,05; R² 0,91). This indicates that the QUAL2Kw model can simulate the water acidity conditions well. The pH is neutral, indicating that the buffer capacity of the aquatic system remains high enough to resist chemical changes. Small variations in pH can be affected by photosynthetic activity, the respiration of aquatic organisms, and the influx of domestic and agricultural waste. Also, geochemical factors, such as the interaction of water with sedimentary material, control water pH (Burescu et al., 2025; Dewangan et al., 2023). This condition shows that, despite anthropogenic pressures, the Musi River system can still maintain a basic chemical balance.

Pollutant Load Capacity

The analysis of the Musi River's pollutant load capacity was conducted using QUAL2Kw model simulation results to assess the Musi River's ability to receive pollutant loads. The analysis included calculating the actual pollutant load, the maximum pollutant load according to class II river quality standards, and the difference between the two as an indicator of the river's assimilative capacity. For each segment (reach), this analysis considered discharge variability and the distribution of key water quality parameters (TSS, NH₃, and COD), providing a complete picture of existing conditions and pollution pressure in the river system. The results of the above calculations are shown in the table below for interpreting the pollutant load capacity in each section of the river.

Table 5 Results of Calculations for Actual Pollutant Load, Maximum Pollutant Load, and Pollutant Load Capacity for Each Reach of the Musi River

Reach	Distance (km)	Input Flow (m ³ /s)	Actual Pollutant Load (kg/day)		
			TSS	NH ₃	COD
1	7.93 – 6.15	16.2	32,192.64	1,538.96	53,187.84
2	6.15 - 0	0.07	96.76	0.60	229.82
Reach	Distance (km)	Input Flow (m ³ /s)	Maximum Pollutant Load (kg/day)		
			TSS	NH ₃	COD
1	7.93 – 6.15	16.2	69,984	279.93	34,992
2	6.15 - 0	0.07	302.4	1.20	151.2
Reach	Pollutant Load Capacity (kg/day)				

	Distance (km)	Input Flow (m ³ /s)	TSS	NH ₃	COD
1	7,93 – 6,15	16,2	37,791.36	-1,259.02	-18,195.84
2	6,15 - 0	0,07	205.63	0.60	-78.62

The pollutant load capacity results indicate that the Musi River still has remaining assimilative capacity for TSS in both reaches, as shown by positive PLC values of 37,791.36 kg/day in Reach 1 and 205.63 kg/day in Reach 2. This condition shows that the actual TSS loads remain lower than the maximum allowable loads under the Class II water quality standard. In contrast, COD shows negative pollutant load capacity values in both reaches, namely -18,195.84 kg/day in Reach 1 and -78.62 kg/day in Reach 2. These negative values occur because the existing COD concentrations have already exceeded the Class II standard, causing the actual COD loads to be higher than the maximum allowable loads. The high COD load reflects strong organic pollution pressure, which may originate from domestic wastewater, industrial effluents, urban runoff, and the input of biodegradable and refractory organic matter into the river system. Recent studies also show that COD and organic pollution in river systems are strongly associated with domestic sewage, agricultural activities, industrial discharge, and landscape disturbance in urban and peri-urban watersheds (Lu et al., 2025; Mei et al., 2025).

For NH₃, the pollutant load capacity shows different conditions between the two reaches. Reach 2 still has a positive NH₃ capacity of 0.60 kg/day, indicating that the actual load remains below the maximum allowable load. However, Reach 1 shows a negative NH₃ capacity of -1,259.02 kg/day because the actual NH₃ load reaches 1,538.96 kg/day, far exceeding the maximum allowable load of 279.93 kg/day. This condition is strongly influenced by the tributary entering Reach 1, which has a very high NH₃ concentration and increases the nitrogen load in the main river. Several factors may contribute to the elevated NH₃ concentration in the tributary, including untreated domestic wastewater, decomposition of organic matter, livestock and household waste inputs, fertilizer runoff from agricultural areas, low dilution capacity, and limited nitrification under certain dissolved oxygen, pH, and temperature conditions. Ammonium pollution is also known to be highly influenced by land to water delivery through surface runoff and lateral flow, particularly in watersheds with sewage discharge, livestock activity, and fertilizer application (Lu et al., 2025). Therefore, COD and NH₃, particularly in Reach 1, should be considered priority parameters for pollution control in the Musi River.

CONCLUSIONS AND RECOMMENDATIONS

Based on the analysis and simulation results, the QUAL2Kw model successfully represented the hydraulic conditions and water quality dynamics of the Musi River. The calibration and validation results showed strong agreement between observed and simulated data, indicating that the model was reliable for evaluating water quality distribution and pollutant load capacity in the study area. The simulation results showed that TSS and NH₃ concentrations generally increased from upstream to downstream, reflecting the influence of anthropogenic activities, tributary inputs, domestic wastewater, agricultural runoff, and surrounding land-use activities. Although the observed concentrations of TSS and NH₃ remained below the Class II river water quality standards during the observation period, the pollutant load capacity analysis indicated that NH₃ in Reach 1 had exceeded the allowable load due to the high ammonia input from tributary flow. Meanwhile, pH remained within the acceptable range, indicating that the river still maintained relatively stable acid–base conditions.

In contrast, COD was identified as the most critical parameter because its existing concentration exceeded the Class II water quality standard and its pollutant load capacity showed negative values in both river reaches. This condition indicates that the actual organic pollutant load has exceeded the river’s assimilative capacity, reflecting significant organic pollution pressure in the Musi River. Therefore, water quality management should prioritize the reduction of organic pollutant discharges, particularly from domestic wastewater, industrial activities, urban runoff, and other non-point pollution sources. Improvement of wastewater treatment efficiency, stricter control of pollutant discharge, tributary-based pollution management, and regular water quality monitoring are needed to reduce pollutant loads and support sustainable water quality management in the Musi River. Future studies should include seasonal

variations, longer monitoring periods, and management scenario simulations to improve the accuracy of pollution control strategies using the QUAL2Kw model.

ACKNOWLEDGEMENTS

Funding for this research was provided by the BIMA Grant for Early-Career Lecturers' Research 2025 (1483dx/IT9.2.1/PT.01.03/2025).

REFERENCES

- Agency, J. I. C. (JICA). (2019). The Project for Assessing and Integrating Climate Change Impacts into the Water Resources Management Plans for Brantas and Musi River Basins (Water Resources Management Plan). In *Final Report Supporting Report B* (pp. B2-10).
- Ahnouch, L. B., Buschman, F., Boisgontier, H., Bio, A., Vieira, L. R., Antunes, S. C., Kett, G. F., Sousapinto, I., & Iglesias, I. (2025). Representing Small Shallow Water Estuary Hydrodynamics to Uncover Litter Transport Patterns. *Water*, 17(2698), 1–25. <https://doi.org/https://doi.org/10.3390/w17182698>
- Al-Ali, I. A., & Al-Dabbas, M. A. (2022). Assessment of some organic and inorganic pollution Indices / Euphrates River / Iraq. *International Journal of Health Sciences*, 6(April), 12395–12417. <https://doi.org/https://doi.org/10.53730/ijhs.v6nS3.9484>
- Al-Dalimy, S. Z., & Al-Zubaidi, H. A. M. (2023). Application of QUAL2K Model for Simulating Water Quality in Hilla River, Iraq. *Journal of Ecological Engineering*, 24(6), 272–280. <https://doi.org/10.12911/22998993/162873>
- Burescu, F., Chereji, B., & Gavrilas, S. (2025). The Impact of Anthropogenic Activities on the Catchment's Water Quality Parameters. *Water*, 17(1791), 1–24. <https://doi.org/https://doi.org/10.3390/w17121791>
- Ciawi, Y., Padilla, P. M. D., & Yekti, M. I. (2022). The strategy of Tukad Badung pollution control using QUAL2Kw and AHP. *4th International Conference on Civil and Environmental Engineering*, 1117(1), 1–12. <https://doi.org/10.1088/1755-1315/1117/1/012071>
- Darji, J., & Lodha, P. (2025). QUAL2Kw – A Water Quality Modeling Tool for Rivers and Streams: A Review. *International Journal on Science and Technology (IJSAT)*, 16(3), 1–17. <https://doi.org/10.71097/ijst.v16.i3.7594>
- Darmian, M. D., & Schmalz, B. (2024). Ecological Informatics River quality management : Integrating uncertainty , failure probability , and assimilation capacity. *Ecological Informatics*, 83(June), 102829. <https://doi.org/10.1016/j.ecoinf.2024.102829>
- Darmian, M. D., & Schmalz, B. (2025). Ecotoxicology and Environmental Safety Uncertainty analysis in river quality management considering failure probability : controllable and uncontrollable input pollutants. *Ecotoxicology and Environmental Safety*, 289(January), 117698. <https://doi.org/10.1016/j.ecoenv.2025.117698>
- Dewangan, S. K., Toppo, D. N., & Kujur, A. (2023). Investigating the Impact of pH Levels on Water Quality : An Experimental Approach. *International Journal For Research in Applied Science and Engineering Technology*, 11(September), 756–759. <https://doi.org/https://doi.org/10.22214/ijraset.2023.55733>
- Fahmi, M. ., Rohman, A., Ahsan, S. ., Firmansyah, F., Perdananugraha, G. ., & Rusyidi, A. . (2023). Evaluation of ammonium issues in Indonesian groundwater : Potential sources and removal methods Evaluation of ammonium issues in Indonesian groundwater : Potential sources and removal methods. *6th International Symposium on Green Technology for Value Chains 2022*, 1–9. <https://doi.org/10.1088/1755-1315/1201/1/012108>
- Fitriana, F., Yudianto, D., & Seo, Y. C. (2025). Comparative analysis of water quality models for the Cibarani Irrigation Channel using WASP and QUAL2Kw. *Sustinere: Journal of Environment and Sustainability*, 9(2), 162–172. <https://doi.org/10.22515/sustinere.jes.v9i2.487>
- García-avila, F., Sinche-morales, A., Sagal-bustamante, F., Criollo-illescas, F., & Valdiviezo-gonzales, L. (2025). Exploring the Potential of Mathematical Self-Purification Models Used for Evaluating Water Quality in Rivers. *Earth*, 6(131), 1–36. <https://doi.org/10.3390/earth6040131>
- Haryono, I., Agustina, H., & Soesilo, T. E. B. (2024). Biophysics indicators as the sustainable strategy

- for river pollution control : Case study in Jangkok River , Mataram. *Journal of Sustainability, Society, and Eco-Welfare (JSSEW)*, 2(1), 29–48. <https://doi.org/https://doi.org/10.61511/jssew.v2i1.2024.943>
- Hu, J., Sun, L., Li, C. H., Wang, X., Jia, X. L., & Cai, Y. P. (2018). Water quality risk assessment for the laoguanhe river of China using a stochastic simulation method. *Journal of Environmental Informatics*, 31(2), 123–136. <https://doi.org/10.3808/jei.201800387>
- Jaywant, S. A., & Arif, K. M. (2024). Remote Sensing Techniques for Water Quality Monitoring : A Review. *Sensors*, 24(8041), 1–31. <https://doi.org/10.3390/s24248041>
- Juwana, I., Sodri, A., Muttill, N., Hikmat, R. R., Indira, A. L., & Sutadian, A. D. (2024). Potential Pollution Loads of the Cikembar Sub-Watershed to the Cicatih River, West Java, Indonesia. *Water*, 16(256), 1–23. <https://doi.org/10.3390/w16020256>
- Lestari, H., Haribowo, R., & Yuliani, E. (2019). Determination of Pollution Load Capacity Using QUAL2Kw Program on The Musi River Palembang. *Civil and Environmental Science*, 002(02), 105–116. <https://doi.org/10.21776/ub.civense.2019.00202.4>
- Lu, J., Fu, Y., Zhang, L., & Huang, W. (2025). Model-based dynamic estimation of water environmental capacity using grid-level simulation and functional zoning : a case study of the Ganjiang River estuary. *Frontiers in Environmental Science*, December, 1–17. <https://doi.org/10.3389/fenvs.2025.1676840>
- Mazioti, A. A., Kolovoyiannis, V., Krasakopoulou, E., Tragou, E., Zervakis, V., Assimakopoulou, G., Athiniotis, A., Paraskevopoulou, V., Pavlidou, A., & Zeri, C. (2024). Implementation of a Far-Field Water Quality Model for the Simulation of Trace Elements in an Eastern Mediterranean Coastal Embayment Receiving High Anthropogenic Pressure. *Journal of Marine Science and Engineering*, 12(797), 1–25. <https://doi.org/10.3390/jmse12050797>
- Mei, K., Shi, H., Wu, Y., Dahlgren, R. A., & Ji, X. (2025). Impact of landscape patterns on river water quality: Spatial-scale effects across an agricultural-urban interface. *Ecological Indicators*, 170(September 2024), 113019. <https://doi.org/10.1016/j.ecolind.2024.113019>
- Melka, E. G., & Aragaw, T. T. (2026). Industrial effluent impact on Wabe River : a QUAL2Kw water quality simulation. *Environ Monit Assess*, 198(406), 1–25. <https://doi.org/10.1007/s10661-026-15230-3>
- Mujib, M. A., Ikhsan, F. A., Apriyanto, B., Astutik, S., & Khasanah, A. N. (2022). Evaluasi Daya Tampung Beban Pencemaran Air Sungai Menggunakan Pendekatan Metode Neraca Massa. *Jurnal Kesehatan Lingkungan Indonesia*, 21(2), 152–161. <https://doi.org/10.14710/jkli.21.2.152-161>
- Ogbonna, C. G., Ahuchaogu, E. U., Nwachi, C. C., Okeoma, I. O., & Emeana, R. C. (2023). Total Suspended Solids Loading Of Stormwater From Different Land Use Areas In An Urban Watershed Introduction . Most cities in Sub-Saharan Africa , Nigeria inclusive , have witnessed rapid urbanization with the attendant complexities in land-use developme. *Journal of Innovations and Sustainability*, 7(2), 09. <https://doi.org/10.51599/is.2023.07.02.09>
- Patel, H. B., & Jariwala, N. D. (2024). Determining Assimilative Capacity Of River Tapi Using QUAL2Kw Model. *Water Conservation and Management*, 8(2), 217–226. <https://doi.org/10.26480/wcm.02.2024.217.226>
- Poedjiastoeti, H., Indrawati, R., & Tengah, J. (2015). Simulation of Pollution Load Capacity using QUAL2Kw in Babon River. *2nd Integrated Solution to Overcome the Climate Change Impact on Coastal Areand Integrated Solution to Overcome the Climate Change Impact on Coastal Area, C-V-261*, 1–12.
- Purwono, P., Ristiawan, A., Ulya, A. U., Matin, H. A. A., & Ramadhan, B. S. (2019). Physical-chemical quality analysis of Serayu River water, Banjarnegara, Indonesia in different seasons. *Sustinere: Journal of Environment and Sustainability*, 3(1), 39–47. <https://doi.org/10.22515/sustinere.jes.v3i1.83>
- Putra, F. Y. E. (2017). *Studi Penentuan Daya Tampung Beban Pencemaran Hilir Sungai Musi Ruas Ptba-Kilang Pertamina Kota Palembang Dengan Menggunakan Aplikasi Qual2kw* [Universitas Brawijaya]. <http://repository.ub.ac.id/id/eprint/7761/>
- Raeisi, N., Moradi, S., & Scholz, M. (2022). Surface Water Resources Assessment and Planning with the QUAL2KW Model: A Case Study of the Maroon and Jarahi Basin (Iran). *Water (Switzerland)*,

14(5). <https://doi.org/10.3390/w14050705>

- Rahutami, S., Said, M., Ibrahim, E., & Herpandi. (2022). Actual Status Assessment and Prediction of the Musi River Water Quality, Palembang, South Sumatra, Indonesia. *Journal of Ecological Engineering*, 23(10), 68–79. <https://doi.org/10.12911/22998993/152284>
- Rendana, M., Yandriani, Y., Pitayati, P. A., Izzudin, M., & Lestari, M. (2022). Assessment of Water Quality Status and Pollution Index in Musi River, South Sumatera, Indonesia. *Indonesian Journal of Environmental Management and Sustainability*, 6(4), 114–118. <https://doi.org/10.26554/ijems.2022.6.4.114-118>
- Rodríguez-Martínez, G., I. Galaviz-Villa, S. Partida-Sedas, C.A. Sosa-Villalobos, R. de G. Bernal-Ramírez, V. Alcántara-Méndez, & A. García-Saldaña. (2021). Water Erosion , its Relationship to Total Suspended Solids and Water Quality in the Lower Basin of the Usumacinta River , Tabasco , Mexico. *Nature Environment and Pollution Technology*, 20(3), 1097–1106.
- Salem, M. S., Hassan, N. M. H., Aly, M. M., Soliman, Y., Peters, R. W., & Mostafa, M. K. (2025). Integrating Deep Learning and Process-Based Modeling for Water Quality Prediction in Canals : CNN-LSTM and QUAL2K Analysis of Ismailia Canal. *Sustainability*, 17(7743), 1–20. <https://doi.org/10.3390/su17177743>
- Samborska-goik, K., & Pogrzeba, M. (2024). A Critical Review of the Modelling Tools for the Reactive Transport of Organic Contaminants. *Applied Science*, 14(3675), 1–65. <https://doi.org/https://doi.org/10.3390/app14093675>
- Savvidis, Y., Papadimitriou, C. A., Apostolidou, S., & Galinou-Mitsoudi, S. (2025). Microplastics from the Post-Flood Agricultural Soils of Thessaly (Greece) Entering the NW Aegean Sea : A Preliminary Modeling Study for Their Transport in the Marine Environment. *Water*, 17(1666), 1–25. <https://doi.org/10.3390/w17111666>
- Soares, S., Vasco, J., & Scalize, P. (2023). Water Quality Simulation in the Bois River, Goiás, Central Brazil. *Sustainability (Switzerland)*, 15(4), 1–21. <https://doi.org/10.3390/su15043828>
- Wiratmojo, M. A., Tri Budi Prayogo, & Emma Yuliani. (2023). Daya Tampung Beban Pencemaran Nitrat dan Fosfat Sungai Brantas Ruas Sengkaling-Tlogomas, Kota Malang. *Jurnal Teknologi Dan Rekayasa Sumber Daya Air*, 3(2), 205–216. <https://doi.org/10.21776/ub.jtresda.2023.003.2.018>
- Yue, F., Li, S., Liu, C., Zhao, Z., & Ding, H. (2017). Tracing nitrate sources with dual isotopes and long term monitoring of nitrogen species in the Yellow. *Scientific Reports*, 7(8537), 1–11. <https://doi.org/10.1038/s41598-017-08756-7>
- Yusuf, I. A. (2016). Penentuan Parameter Kinetik Model Kualitas Air Untuk Sungai : Studi Kasus Di Zona Hulu Sungai Citarum Determination Of Kinetic Parameters For River Water Quality Model : A Case Study In The Upper Zone Of Citarum River. *Jurnal Teknik Hidraulik*, 7(1), 31–46.