Journal of Natural Resources and Environmental Management
http://dx.doi.org/10.29244/jpsl.14.3.641

RESEARCH ARTICLE

OPEN ACCESS

Check for updates

Analysis of the Pollution Load Capacity of Batang Merao Watershed in Jambi Province

Syiskha Eka Patri[a], I Putu Santikayasa[b], Suria Darma Tarigan[c]

[a] Study Program of Natural Resources and Environmental Management, Postgraduate School of IPB University, IPB Baranangsiang Campus, Bogor, 16143, Indonesia
[b] Department of Geophysics and Meteorology, Faculty of Mathematics and Natural Sciences, IPB University, IPB Darmaga Campus, Bogor, 16680, Indonesia
[c] Department of Soil Science and Land Resources, Faculty of Agriculture, IPB University, IPB Darmaga Campus, Bogor, 16680, Indonesia

Article History
Received
16 November 2023
Revised 20 February 2024
Accepted
24 February 2024

Keywords
Batang Merao, QUAL2Kw, Total Maximum Daily Loads

ABSTRACT

The Batang Merao Watershed, has been experiencing a decline in water quality due to human activities involving waste utilization and disposal. Therefore, an analysis is necessary to determine the Total Maximum Daily Loads (TMDLs). This study aims to calculate the TMDL of the Batang Merao Watershed and the current as well as the five-year future pollution load capacity using the QUAL2Kw water quality model based on the regulations outlined in the Minister of Environment and Forestry's Regulation No. 01 of 2010. The calibration results of the model using the Nash Sutcliffe Efficiency (NSE) for TSS, BOD_5, and COD parameters were 0.766, 0.574, and 0.633, respectively, indicating that water quality modeling can be used to predict river pollution loads. The modeling results indicate that the Total Maximum Daily Loads (TMDLs) for the Batang Merao Watershed are 95,057 kg day^{-1} for TSS parameters, 5,739 kg day^{-1} for BOD_5 parameters, and 46,774 kg day^{-1} for COD parameter. Meanwhile, the current pollution loads are 147,962 kg day^{-1} for TSS, 10,086 kg day^{-1} for BOD_5, and 60,369 kg day^{-1} for COD. In the estimated condition, in the year 2028, the pollution loads will amount to 163,023 kg day^{-1} for TSS parameters, 11,432 kg day^{-1} for BOD_5 parameter, and 69,211 kg day^{-1} for COD parameter.

Introduction

Batang Merao River Watershed spans two administrative regions: Kerinci Regency and Sungai Penuh City in Jambi Province. The Batang Merao Watershed plays a vital role for the residents of Kerinci Regency and Sungai Penuh City. It serves as a water source for agricultural irrigation, provides additional livelihoods for fishing communities, and is utilized for daily activities, such as bathing, washing, and sanitation. Additionally, it serves as a raw water source for drinking water regional companies and supports alternative energy sources, such as Micro-Hydro Power Plants [1]. People living along the riverbanks rely on the Batang Merao River for household waste disposal. Furthermore, agricultural activities along riverbanks involve livestock such as cattle, goats, and ducks. The increasing population growth along the Batang Merao River has exacerbated these issues. The degradation of the Batang Merao Watershed is on the rise, and in addition to changes in land cover, poor watershed management is also a significant factor contributing to declining watershed quality [2]. Activities such as the disposal of waste into the river, runoff from agricultural fields, and sand mining operations in the upstream regions of Sub-DAS Siulak and Batang Merao have led to water quality that is unfit for consumption. Laboratory tests have revealed elevated levels of chloride (Cl) and iron (Fe) that exceed river water quality standards [3]. Rivers are natural water resources that must be preserved and protected from pollution sources, including pollutants and liquid waste originating from industrial, domestic, agricultural, and other sources [4].

Corresponding Author: Syiskha Eka Patri syiskha.ekapatrisyiskha@apps.ipb.ac.id Study Program of Natural Resources and Environmental Management, Postgraduate School of IPB University, IPB Baranangsiang Campus, Bogor, Indonesia.

Based on the results of the Environmental Management Performance Information Document for Sungai Penuh City in 2022, both upstream and downstream of the Batang Merao River have concentrations of parameters such as BOD_5 (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), TSS (Total Suspended Solids), and fats and oils that exceed the water quality standards outlined in Government Regulation No. 82 of 2001, Class II. The Water Quality Index/*Indeks Kualitas Air* (IKA) from 2015 to 2021 tended to increase. In 2015, the IKA value was 30; in 2021, it increased to 51.35. To develop programs for water quality management and pollution control, it is essential to have a good understanding of the various human activities that influence rivers [5].

Jambi Province has not yet established the Total Maximum Daily Load (TMDL) for the Batang Merao Watershed. However, based on the water quality monitoring results in the 2022 Regional Environment Management Performance Information Document/*Dokumen Informasi Kinerja Pengelolaan Lingkungan Hidup Daerah* (DIKPLHD), the Batang Merao Watershed is experiencing light pollution. This indicates that the pollution entering the river exceeded the river's TMDL. Therefore, according to the Ministry of Environment and Forestry's Regulation No. 01 of 2010 regarding Procedures for Controlling Water Pollution, local governments must determine water quality. Determining wastewater quality standards begins by determining TMDL to understand the river's pollution load capacity. Determining the TMDL and pollution load capacity for both the existing condition and the next five years requires a substantial amount of financial resources and a significant amount of time to generate accurate data [6]. Therefore, water quality modeling approaches are necessary to minimize these issues.

The QUAL2Kw model is a commonly used one-dimensional water quality simulation model designed to simulate variations in river water quality and is capable of calculating the rate of changes and dispersion due to pollution loads [7]. In Indonesia, numerous studies have been conducted to assess pollution modeling, particularly using QUAL2Kw, on rivers with hydrological characteristics similar to those of the Batang Merao River. One such example is modeling the Karang Mumus River in Samarinda City using QUAL2Kw, which can provide calculations for pollution load capacity. This enables the formulation of strategies to manage the Karang Mumus River [8]. The QUAL2Kw model on the Tukad Bandung River, one of the major rivers flowing Denpasar, allows for the simulation of the pollution load. This simulation provided alternative management options derived from simulated scenarios [9]. The simulation results from the QUAL2Kw model can calculate the excess pollution load of BOD_5 and COD parameters in the Bukit Batu River in Bengkalis Regency [6].

Water quality modeling can assess pollution loads under various scenarios, thereby helping to determine effective water resource management policy strategies [6,8–10]. Water quality is critical for water resource management [11]. Based on the issues mentioned above, the decline in the water quality of the Batang Merao River indicates that the watershed has experienced pollution, which, in turn, impacts the sustainability of water resources within the Batang Merao Watershed. Given the complexity of the Batang Merao River issues and the existing studies on the decline in water quality and quantity in the Batang Merao Watershed, it is necessary to research and identify the dominant factors contributing to the decline in river water quality. This study should also aim to obtain the TMDL through QUAL2Kw model simulations and formulate watershed management policy strategies. The goal is to ensure that the Batang Merao River can be utilized in accordance with its intended purposes and remains sustainable.

Methods

Study Area

The research was conducted from May to July 2023 at 13 sampling points, as shown in Table 1, spanning 46.74 km from the upstream to the downstream of the Batang Merao Watershed. Among these points, eight sampling locations were used as data for the model simulation, and five sampling points were employed for model calibration. River water sampling activities were carried out from morning to afternoon using the grab sampling method, following the guidelines outlined in the Indonesian National Standard (SNI 8995–2021) regarding the Sampling Method for Physical and Chemical Testing of Water. This research was conducted in the Batang Merao Watershed, located in the administrative regions of Kerinci Regency and Sungai Penuh City in Jambi Province. The research area map is shown in Figure 1.

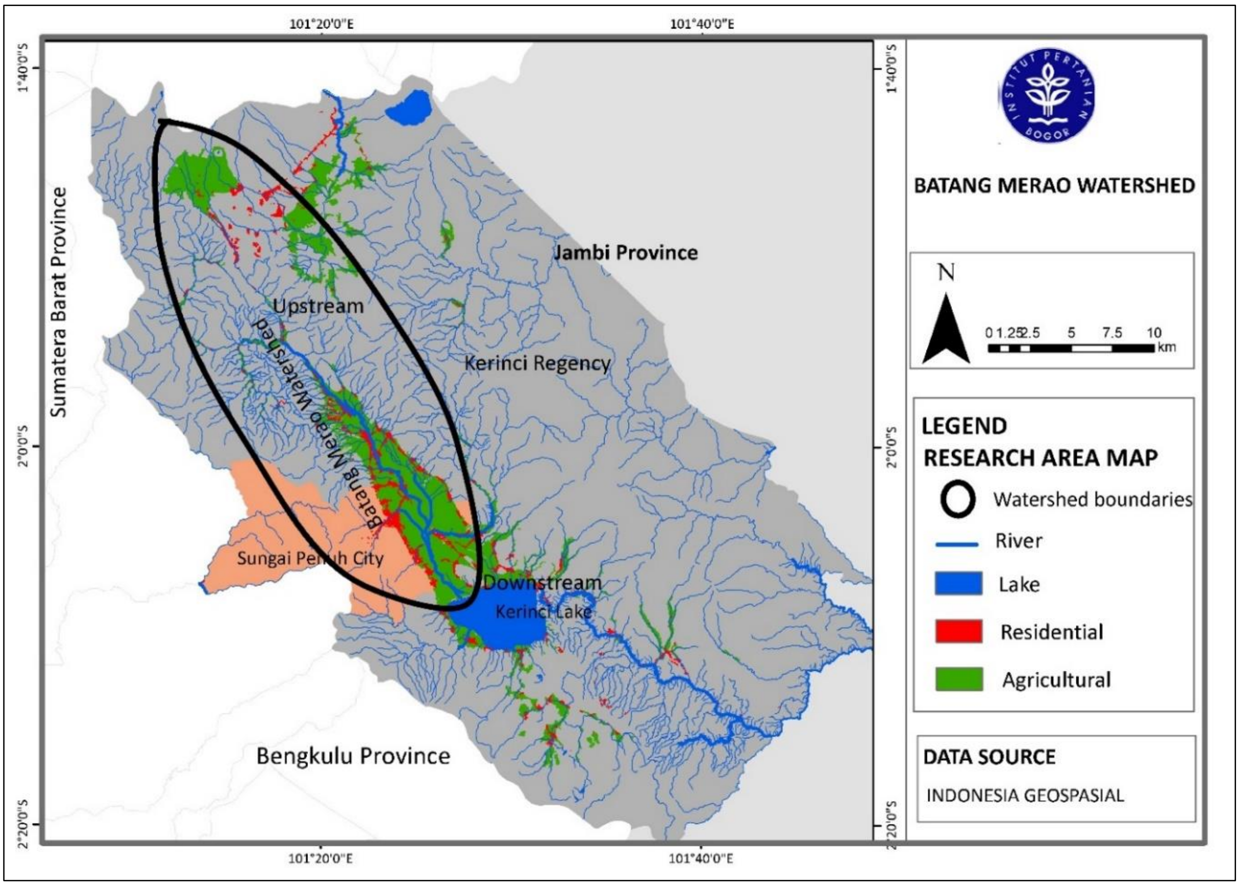


Figure 1. Study area.

Table 1. Sampling points.

No.	Sampling points	Coordinate point
1	Upstream	S 01051'18" E 101016'06.7"
2	Segment 1 (Agricultural)	S 01053'09" E 101017'46"
3	Segment 1 (Residential)	S 01054'22" E 101017'56"
4	Segment 2 (Residential)	S 01056'45" E 101020'05"
5	Segment 2 (Agricultural)	S 01057'17.9" E 101020'34.6"
6	Segment 3 (Residential)	S 01058'02.9" E 101021'18.6"
7	Segment 3 (Agricultural)	S 01058'17.9" E 101021'41.3"
8	Segment 4 (Agricultural)	S 02000'37.1" E 101023'00.1"
9	Segment 4 (Residential)	S 02001'02.1" E 101023'04.1"
10	Segment 5 (Residential)	S 02002'36.6" E 101024'41.0"
11	Segment 6 (Residential)	S 02^{0}06'02.7" E 101025'53.7"
12	Segment 6 (Agricultural)	S 02007'41.7" E 101027'05.7"
13	Downstream	S 02008'07.1"E 101027'24.2"

Data Collection Method

Descriptive and experimental research was conducted, and the data collected included both primary and secondary data. Primary data collection involved in-situ parameters measured at the sampling locations, including temperature and pH. Additionally, GPS coordinates were recorded, and river water velocity was measured using a current meter. Other collected data included river depth and width measurements, cloud cover, and shade. The length of each river segment and area of agricultural land were determined using ArcGIS 10.8 software. Water samples from the river were collected and subjected to water quality testing for parameters such as TSS (Total Suspended Solids), BOD_5 (Biochemical Oxygen Demand), and COD (Chemical Oxygen Demand) at the Environmental Laboratory of the Jambi Provincial Environmental Agency. Secondary data, such as wind speed and shade, were obtained from online.bmkg.go.id (accessed on 3 July 2024), while population data were sourced from bps.go.id (accessed on 3 July 2024).

Data Analysis Method

The water quality of the Batang Merao Watershed was analyzed in the laboratory for the following parameters: TSS, analyzed based on SNI 6989.3:2019; BOD_5, analyzed based on SNI 6989.72:2009; and COD, analyzed based on SNI 6989.73:2019. The laboratory test results, along with other supporting data, were input into the QUAL2Kw application with three different modeling scenarios, as shown in Table 2.

Table 2. QUAL2Kw models.

No.	Model	Upstream	Point source	Diffuse source	Purpose
1	Water quality standard	Water quality standard Class II PP 22 Year 2021	Trial and error	Trial and error	Determine TMDL of Batang Merao Watershed
2	Existing conditions	Existing conditions	Existing conditions	Trial and error	Determine the current pollution load capacity
3	Next 5 years	Existing conditions	Existing conditions	Population growth rate	Determine the pollution load capacity for the year 2028

Water quality modeling based on standards results in the TMDL, which is used as a reference in determining the river's pollution load capacity. TMDL is the ability of water in the body to accept pollutants but does not cause the water to be polluted; if the river's pollution load exceeds its TMDL, it means the river lacks pollution load capacity, indicating pollution. Conversely, the river was considered unpolluted if the pollution load was less than the TMDL. Existing water quality modeling describes the current conditions of a river. When the pollution load capacity is known, it can be used to determine whether the river is polluted. Meanwhile, water quality modeling for five years ahead estimates the river's condition in the year 2028, assuming population growth based on the population growth rate in 2022 based on secondary data from Kerinci Regency in figures 2023 and Sungai Penuh City in figures 2023, with point sources, climate, and river discharge remaining in their current state. The population growth projection uses the following arithmetic formula for Malthus [12]:

$$Pn = P0(1 + rt) \quad (1)$$

where Pn is population at the end of the year, P0 is population at the beginning of the year, r is population growth rate, t is difference between the end and beginning years.

After estimating the population in 2028, the clean water usage rate was calculated using Formula 2 for Preston [13]:

$$Q_{\text{clean water}} = \text{Population (inhabitants) x Clean water requirement } (120 \text{ L person}^{-1} \text{ day}^{-2}) \quad (2)$$

Clean water flow is needed to calculate the domestic wastewater flow using Formula 3, according for Fair [14]:

$$Q_{\text{domestic wastewater}} = 80\% \text{ x } Q_{\text{clean water}} \quad (3)$$

After inputting all data into the QUAL2Kw application, concentration models for each segment are yielded. A model calibration was performed before calculating the pollution load using the concentration data obtained from the model. Model calibration using the Nash-Sutcliffe efficiency (NSE) provides results with relatively small errors and has been proven effective in simulating water quality data for efficient river water quality restoration planning [15,16]. The Nash-Sutcliffe efficiency test aims to verify the model's accuracy using the criteria presented in Table 3 by Nash and Sutcliffe [17].

$$NSE = 1 - \frac{\sum_{i=1}^{n}(x-y)^2}{\sum_{i=1}^{n}(x-\bar{x})^2} \quad (4)$$

where NSE is Nash-Sutcliffe coefficient, n is number of data points, y is value from the model result, x is value from the observed data, and $\bar{x}$ is mean value of the observed data.

Table 3. Nash-Sutcliffe Efficiency (NSE) value criteria.

NSE value	Interpretation
0.75< NSE < 1	Very good
0.65 < NSE < 0.75	Good
0.5 < NSE < 0.65	Satisfactory
NSE $\leq$ 0.5	Unsatisfactory

If the NSE value is more significant than 0.5, the modeled concentration data can be used as a reference for pollution load calculations. The pollution load calculation was based on the formula provided by Novotny and Olem [18]:

$$BP = Q \times C \times f \quad (5)$$

where BP is pollution load (kg day^{-1}), Q is discharge (m^3 s^{-1}), C is pollutant concentration (mg L^{-1}), and F is correction factor (86.4 kg L s mg^{-1} m^{-3} day^{-1}).

The pollution load obtained from water quality modeling based on standards is referred to as the TMDL. The pollution load capacity for existing conditions and five years ahead can be calculated using the following formula:

$$\text{Pollution Load Capacity (kg day}^{-1}\text{)} = \text{TMDL} - \text{Calculated pollution load} \quad (6)$$

Results and Discussion

River Segmentation

The initial step in calculating the TMDL was to divide the river into six segments, as shown in Figure 2. River segmentation is based on administrative district boundaries, pollution source locations, and the length of each river segment. The river segmentation map provides the length of each river segment as indicated in Table 4. These data are essential for inputting into the QUAL2Kw application. The pollution load capacity for each river segment was determined in the TMDL calculation. Therefore, this information is crucial for establishing policy recommendations for river management based on the pollution-load capacity of each segment.

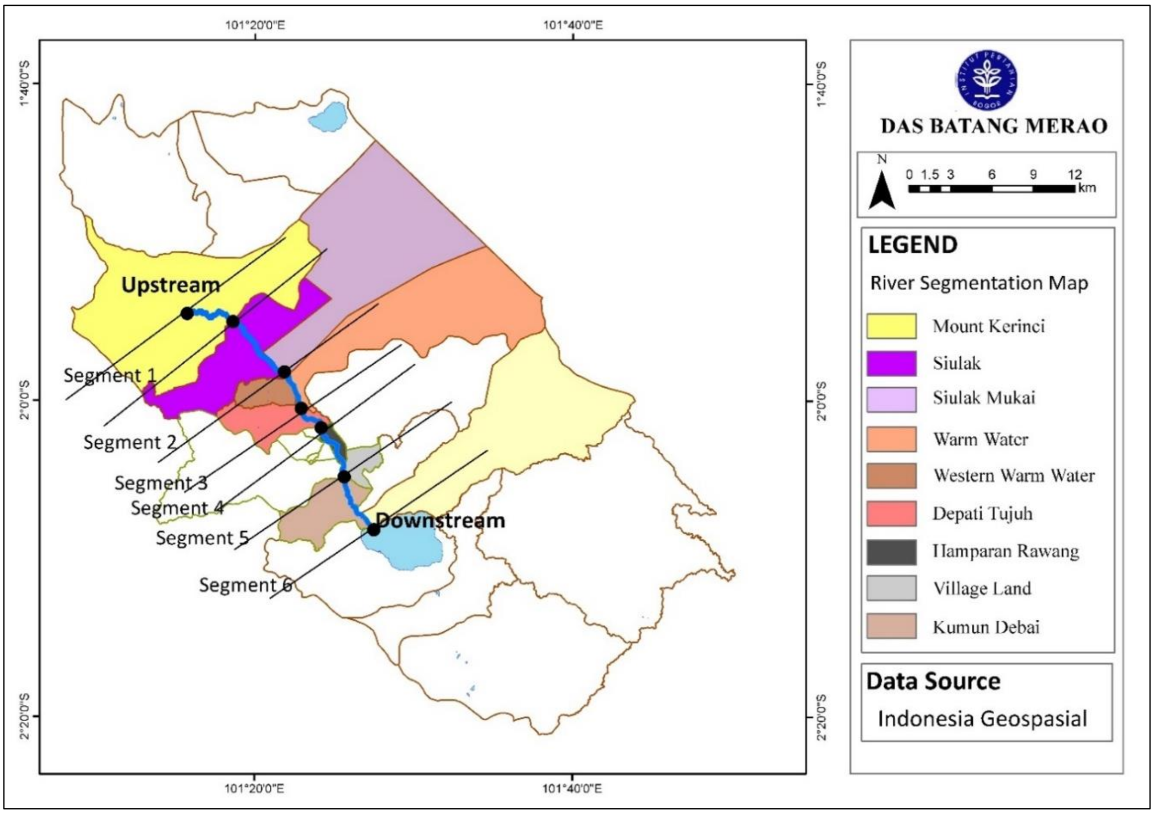


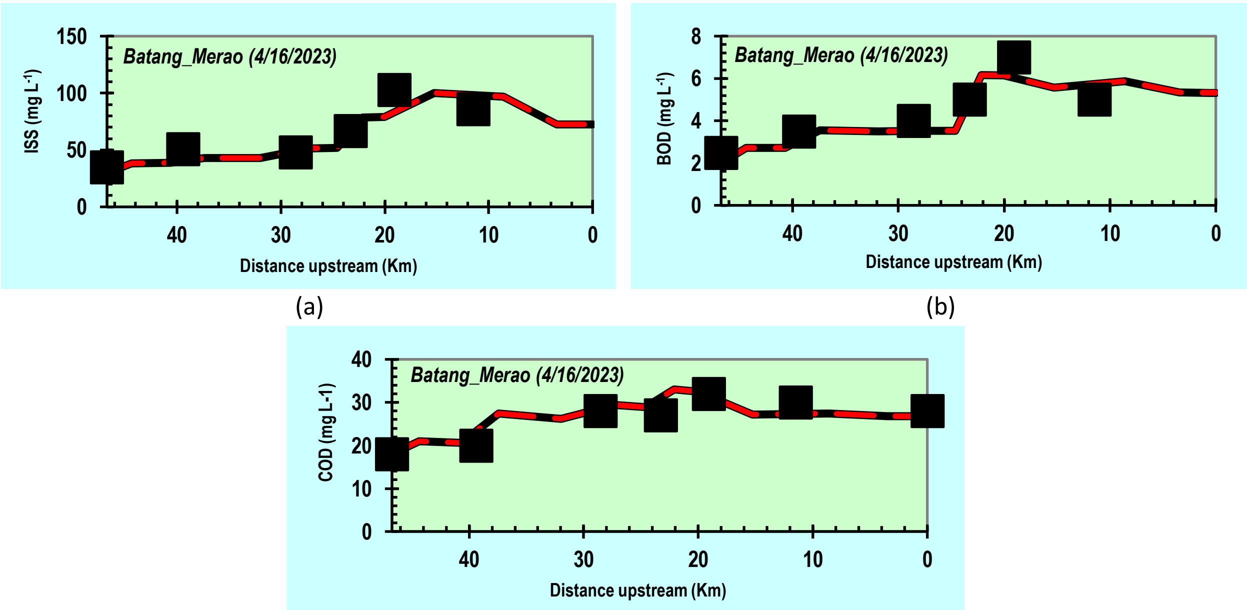
Figure 2. River segmentation map.

Table 4. River segment identification.

Segment	District	Segment length (km)
1	Mount Kerinci	7.36
2	Siulak and Siulak Mukai	10.84
3	Warm Water and Western Warm Water	5.29
4	Depati IV	4.19
5	Hamparan Rawang and Village Land	7.58
6	Kumun Debai and Kerinci Lake	11.48
	Total	46.74

Model Calibration

Calibration of the TMDL calculation model using QUAL2Kw was tested by determining the NSE based on the current water quality test values. The water quality concentration values entered into the QUAL2Kw application were for sampling points 1, 2, 4, 6, 9, 10, 11, and 13, while the other points were used for model verification. The calibration results of the model using the NSE for TSS, BOD_5, and COD parameters were 0.766, 0.574, and 0.633, respectively, indicating that water quality modeling can be used to predict river pollution loads. The proximity of the observed values to the model results indicates that the TSS, BOD_5, and COD concentrations from the water quality model can be used in TMDL calculations. Figure 3 shows the QUAL2Kw output graph, where the x-axis represents the sampling points from upstream to downstream, and the y-axis represents the pollutant concentration. The black squares represent the observed data, whereas the red lines represent the model data. Figure 3 shows that the observed and model data are similar in terms of concentration values, and there is a trend of increasing concentration values from upstream to downstream.



(c)

Figure 3. QUAL2Kw output graph–comparison of observed data with model data (a) TSS (b) BOD, (c) COD.

Pollution Load Capacity

The calculation of the TMDL for the Batang Merao Watershed is based on key river water quality parameters, which include TSS, BOD_5, and COD. The water quality standards for the TMDL calculations in the Batang Merao Watershed are based on Class II water quality standards according to Government Regulation No. 22 of 2021 on the Implementation of Environmental Protection and Management, Annex VI, National Water Quality Standards. The key parameters used in the model were Class II standards: 3 mg L^{-1} for BOD_5, 25 mg L^{-1} for COD, and 50 mg L^{-1} for TSS. The calculation of TMDL for the Batang Merao Watershed was performed using the QUAL2Kw application, and it involved trial and error adjustments to the water quality test concentration for point sources and diffuse sources until the concentration distribution of TSS, BOD_5, and COD parameters at each sampling point was below Class II water quality standards according to government regulations [19]. The calculation results are listed in Table 5.

In Table 5, the concentration of each segment is presented as the output of QUAL2Kw application. The obtained concentration values met the water quality standards and were used to calculate the Total Maximum Daily Load (TMDL). The calculated TMDL for the Batang Merao Watershed can serve as a reference for determining the current and future pollution load capacity. The pollution load capacity for each segment can serve as a guideline for government authorities to monitor the water quality of the Batang Merao Watershed. The government can formulate different policies for each segment based on the values obtained for TSS, BOD_5, and COD. The TMDL obtained through modeling represents the maximum allowable pollution load that the Batang Merao Watershed can withstand. If the river only receives pollution loads, as presented in Table 5, it can undergo optimal self-purification, ensuring the river's water quality is well preserved.

Table 5. Presents the results of TMDL calculations for the Batang Merao Watershed.

Segment	TSS		BOD_5		COD	
	Concentration (mg L^{-1})	TMDL (kg day^{-1})	Concentration (mg L^{-1})	TMDL (kg day^{-1})	Concentration (mg L^{-1})	TMDL (kg day^{-1})
1	34.22	11,828	2.35	813	19.32	6,677
2	48.02	20,372	2.56	1,088	22.68	9,619
3	45.47	13,710	2.54	766	22.01	6,636
4	44.94	19,063	2.56	1,086	21.29	9,031
5	43.48	11,044	2.88	732	21.72	5,518
6	43.90	19,040	2.89	1,254	21.43	9,293
Total		95,057		5,739		46,774

The Existing Pollution Load Capacity

Water quality modeling to calculate the pollution load capacity under existing conditions represents the water quality that best matches the current situation. Repeated trials and errors were conducted to determine the diffuse source concentrations, to produce a combination of pollutant source concentrations that best aligned with the observed concentration distribution. The pollution load capacities for each parameter are presented in Table 6.

Table 6. Existing pollution load capacity.

Segment	Pollution load (kg day^{-1})			Pollution load capacity (kg day^{-1})		
	TSS	BOD_5	COD	TSS	BOD_5	COD
1	13,288	943	7,247	–1,460	–130	–571
2	18,211	1,510	11,639	–2,161	–423	–2,020
3	15,543	1,066	8,874	–1,832	–300	–2,238
4	33,598	2,612	13,791	–14,533	–1,526	–4,760
5	25,409	1,414	6,913	–14,365	–681	–1,395
6	41,915	2,542	11,904	–22,875	–1,288	–2,611
Total	147,962	10,086	60,369	–52,905	–4,347	–13,594

In the existing model, which represents the current conditions of the Batang Merao Watershed, nearly all segments exceeded the TLDM. The TLDM, based on the national water quality standards outlined in Regulation No. 22 of 2022 Regarding the Implementation of Environmental Protection and Management is smaller in Table 5 than the pollution loads in Table 6. Therefore, the pollution load capacity of the Batang Merao Watershed has surpassed the required water quality standards. The negative sign (–) in Table 6 indicates a deficiency in the pollution load capacity, meaning that the pollution loads are higher than the TLDM for the Batang Merao Watershed. The calculations for the TSS parameter revealed that the highest pollution load came from Segment 6, amounting to 41.915 kg day^{-1}.

Segment 6 was located downstream, and pollution loads from all along the river accumulated in this segment. The accumulation of pollution loads from residential, agricultural, and livestock activities carried by the water flow renders Segment 6 unable to achieve optimal self-purification, leading to high pollution loads in this segment. This is in line with research by Badrzadeh et al. [20], which suggests that residential and agricultural activities contribute to pollutant loads that degrade river quality. This results in an increasing deficit in Segment 6's pollution load capacity. The calculations for the pollution load of the BOD_5 and COD parameters were highest in Segment 4, the shortest segment. The length of the segment affects the dilution of pollutants carried by the water flow. A shorter segment resulted in less dilution, leading to higher concentrations of BOD_5 and COD.

Pollution Load Capacity for the Next 5 Years

The water quality model to determine the capacity for the next five years is conducted by calculating domestic wastewater discharge based on the population growth rate and involves trial and error with diffuse source concentrations. The results of these calculations are presented in Table 7, where the negative sign (-) indicates a deficiency in the pollution load capacity, meaning that the pollution loads exceed the TLDM for the Batang Merao Watershed. In Table 7, which represents an estimation of pollution loads in 2028, we observe an increased deficit in pollution load capacity compared to the existing conditions. In the water quality model for the next five years, which predicts river pollution loads in the absence of effective management and with an increasing population growth rate, it is anticipated that the pollution loads in 2028 will rise. Consequently, the pollution load capacity falls significantly short of achieving river water quality that meets the standards. This aligns with the research by Xu et al. [21], which highlights the cumulative effects of pollution over time in the absence of restoration and management, exacerbating water quality deterioration.

Table 7. Pollution load capacity for the next 5 years.

Segment	Pollution load (kg day^{-1})			Pollution load capacity (kg day^{-1})		
	TSS	BOD_5	COD	TSS	BOD_5	COD
1	15,303	1,109	8,115	–3,475	–296	–1,438
2	21,364	1,638	13,867	–992	–550	–4,247
3	19,106	1,493	10,219	–5,395	–728	–3,583
4	37,014	2,949	15,534	–17,950	–1,863	–6,503
5	26,550	1,526	7,968	–15,507	–793	–2,450
6	43,685	2,717	13,509	–24,646	–1,463	–4,216
Total	163,023	11,432	69,211	–67,966	–5,693	–22,437

Segment 6 represents the highest pollution load for TSS, as all upstream wastewater accumulates in Segment 6 which is the downstream area. On the other hand, for the BOD_5 and COD parameters, the highest pollution load was found in Segment 4, which was the shortest segment at 4.19 km in length. Additionally, tranquil and straight flow patterns reduce air reaeration in river water. This diminished reaeration process causes suboptimal self-purification in Segment 4, leading to high BOD_5 and COD pollution loads. It is important to note that COD concentration is a key parameter for assessing wastewater biodegradability and evaluating the mass and energy balances in the overall processes [22]. The increase in population without proper wastewater treatment leads to an increase in domestic wastewater, resulting in higher concentrations of BOD_5 and COD.

This is consistent with the theory that domestic wastewater contains both solid and liquid household waste, often containing bacteria and organic materials, leading to elevated BOD_5 levels [23]. It is predicted that by 2028, in line with the growing population, pollution loads will continue to increase, causing the Batang Merao Watershed to further exceed its pollution load capacity. This aligns with research by [21,24], which suggests that a rising population leads to increased pollution that degrades water quality. After obtaining the TLDM for the Batang Merao Watershed and calculating the pollution load capacity for both the existing and 5 years future conditions, it can be concluded that without proper river management, river water quality will decline, and pollution loads will increase. Firmansyah et al. [25] explain that in Indonesia, in 2018, there were 25 heavily polluted rivers, and by 2019, this number had increased to 38. The pollution load capacity of rivers needs to be determined to serve as a guideline for river management efforts.

Management policies for the Batang Merao Watershed in the Jambi Province are expected to restore the pollution that has occurred and ensuring the quality and intended use of the watershed. Currently, freshwater sources are contaminated by various sources, including industrial, urban, biomedical, and other anthropogenic activities [26,27]. Pollution has severe adverse effects on the environment and communities [28,29]. The proximity of settlements to rivers, often located along riverbanks, should prompt the government to initiate a large-scale policy to educate people on regulations prohibiting the construction of houses along riverbanks. This would enable the government to plant vegetation along rivers and create green belts that prevent landslides.

Vegetation along riverbanks can also act as a filter, preventing pollutants from entering the river and mitigating pollution loads. For short-term policies, it is crucial to construct communal wastewater treatment plants to manage domestic wastewater from the settlements. The design and management of these communal treatment plants should involve expert teams to ensure their optimal functioning. Regular maintenance and monitoring are essential to ensure that all domestic wastewater is correctly accommodated, preventing further river discharge. Community participation in managing communal treatment plants can also have economic benefits, such as utilizing the final sludge as a component in concrete brick production, which is in line with research by Amsayazhi and Mohan [30].

The issue of sludge disposal can be significantly reduced if sludge, whether raw, digested, dried, or incinerated, can be economically utilized on a large scale [31]. Proper domestic wastewater management is a key solution for controlling river pollution. As suggested by Bilgili et al. [32], as domestic wastewater directly dumped into the environment increases, recycling practices such as composting food scraps become essential. Household waste management is a critical practice that should be integrated from waste generation to disposal [33]. The considerable increase in the contamination load and diversity of urban, agricultural, and industrial contaminants has necessitated the need to understand the process of changes and predict the quality of water resources. In this regard, simulations are considered as important tools [34].

Conclusion

The pollution load for both the existing conditions and the next five years exceeded the TLDM for the Batang Merao Watershed based on Regulation No. 22 of 2021. This resulted in a pollution load capacity deficiency for the TSS, BOD_5, and COD parameters. Short-term and long-term policy strategies are required to manage the Batang Merao Watershed to ensure the river's water quality can be used as intended. Short-term strategies can involve the construction of communal wastewater treatment plants, planting vegetation along riverbanks to create green belts, enhancing community participation, and implementing regulations that contribute to water quality restoration. Long-term efforts should be made to relocate settlements from riverbanks to areas suitable for residential development.

Author Contributions

SEP: Acquisition of data, Analysis, interpretation of data and revision; **IPS**: Conception and design of the study, Drafting the manuscript, and Critical review; **SDT**: Conception and design of the study, Drafting the manuscript, and Critical review.

Conflicts of Interest

There are no conflicts to declare.

References

1. Ningsih, S.R.; Putra, E.G.E.; Goembira, F. Analisis ketersediaan, kebutuhan dan kualitas air pada DAS Batang Merao. *J. Ilmu Lingkung.* **2020**, *18*, 545–555, doi:10.14710/jil.18.3.545-555.
2. Mulyawan, R.; Wahjunie, E.D.; Ichwandi, I.; Tarigan, S.D. Kajian peran stakeholder pada implementasi kebijakan pengelolaan DAS terpadu, studi kasus DAS Krueng Aceh. *J. Ilmu Lingkung.* **2022**, *20*, 198–209, doi:10.14710/jil.20.2.198-209.
3. Wandira, N.A.; Deliana, A.; Junedi, H. Kualitas Sub DAS Siulak dan Batang Merao Daerah Mukai Tinggi dan sekitarnya, Kecamatan Siulak Mukai, Kabupaten Kerinci, Provinsi Jambi. In Proceedings of the Seminar Teknologi Kebumian dan Kelautan (SEMITAN II) Institut Teknologi Adhi Tama Surabaya (ITATS), Indonesia, 12 Juli 2020; Surabaya, 2020; pp. 507–515.
4. Budiman, A. Pemodelan kualitas air dengan parameter BOD dan DO pada Sungai Ciliwung. *Indones. J. Urban Environ. Technol.* **2016**, *5*, 97, doi:10.25105/urbanenvirotech.v5i3.679.
5. Lestari, A.D.N.; Sugiharto, E.; Siswanta, D. Aplikasi model QUAL2Kw untuk menentukan strategi penanggulangan pemcemaran air Sungai Gajahwong yang disebabkan oleh bahan organik. *J. Mns. dan Lingkung.* **2013**, *20*, 284–293.
6. Saily, R.; Setiawan, B. Determination of Carrying and Load Capacity Using QUAL2Kw Modeling Simulation. In Proceedings of the 5th International Seminar on Sustainable Urban Development, Jakarta, Indonesia, 5 August 2020; Volume 737.
7. Ombaki, R.; Kerongo, J. Formulated mathematical model for delayed particle flow in cascaded subsurface water reservoirs with validation on river flow. *J. Appl. Math.* **2022**, *2022*, 1–11.
8. Betti, S.H.; Nurhayati, E. Water Modelling of Karang Mumus River using QUAL2Kw application. In Proceedings of the 2nd Conference of Sustainability and Resilience of Coastal Management, 29–30 November 2021; Volume 1095.
9. Ciawi, Y.; Padilla, P.M.D.; Yekti, M.I. Tukad Badung pollution control strategy using QUAL2Kw and AHP. In Proceedings of the 4th International Conference on Civil and Environmental Engineering, Badung, Indonesia, 3–5 August 2022; Volume 1117.

10. Pangestu, R.; Riani, E.; Effendi, H. Estimasi beban pencemaran point source dan limbah domestik Di Sungai Kalibaru Timur Provinsi DKI Jakarta, Indonesia. *J. Pengelolaan Sumberd. Alam dan Lingkung.* **2017**, *7*, 219–226, doi:10.29244/jpsl.7.3.219-226.
11. Khonok, A.; Tabrizi, M.S.; Babazadeh, H.; Saremi, A.; Ghaleni, M.M. Sensitivity analysis of water quality parameters related to flow changes in regulated rivers. *Int. J. Environ. Sci. Technol.* **2022**, *19*, 3001–3014.
12. Malthus, T. An essay on the principle of population, as it affects the future improvement of society with remarks on the speculations of Mr Godwin, M. Condorcet, and other writers. In *Environment and Ecology in the Long Nineteenth-Century*, 1st ed.; Frost, M., Eds.; Routledge: Oxfordshire, England, UK, 2022; pp. 81–85, ISBN 978-0-4293-5565-3.
13. Preston, S.H.; Heuveline, P.; Gullot, M. *Demography: Measuring and Modeling Population Processes*; Blackwell Publising: New York, NY, USA, 1988.
14. Fair, G.M.; Geyer, J.C.; Okun, D.A. *Water and Wastewater Engineering*; Wiley: New York, NY, USA, 1968.
15. Sharma, D.; Kansal, A.; Pelletier, G. Water quality modeling for urban reach of Yamuna River, India (1999–2009), using QUAL2Kw. *Appl. Water Sci.* **2017**, *7*, 1535–1559, doi:10.1007/s13201-015-0311-1.
16. Raeisi, N.; Moradi, S.; Scholz, M. Surface water resources assessment and planning with the QUAL2KW model: A case study of the Maroon and Jarahi Basin (Iran). *Water* **2022**, *14*, 1–18.
17. Nash, J.E.; Sutcliffe, J.V. River flow forecasting through conceptual models - Part I - A discussion of principles. *J. Hydrol.* **1970**, *10*, 282–290.
18. Novotny, V.; Olem, H. *Water Quality: Prevention, Identification and Management of Diffuse Pollution*; Van Nostrand Reinhold: New York, NY, USA, 1993.
19. Sekretariat Negara Republik Indonesia. Peraturan Pemerintah Republik Indonesia Nomor 22 Tahun 2021 Tentang Penyelenggaraan Perlindungan Dan Pengelolaan Lingkungan Hidup. Available online: https://jdih.menlhk.go.id/new2/home/portfolioDetails/22/2021/7 (accessed on 3 July 2024)
20. Badrzadeh, N.; Samani, J.M.V.; Mazaheri, M.; Kuriqi, A. Evaluation of management practices on agricultural nonpoint source pollution discharges into the rivers under climate change effects. *Sci. Total Environ.* **2022**, *838*, 1–11, doi:10.1016/j.scitotenv.2022.156643.
21. Xu, H.; Gao, Q.; Yuan, B. Analysis and identification of pollution sources of comprehensive river water quality: Evidence from two river basins in China. *Ecol. Indic.* **2022**, *135*, 1–13.
22. Cazaudehore, G.; Schraauwers, B.; Peyrelasse, C.; Lagnet, C.; Monlau, F. Determination of chemical oxygen demand of agricultural wastes by combining acid hydrolysis and commercial COD kit analysis. *J. Environ. Manage.* **2019**, *250*, 1–5, doi:10.1016/j.jenvman.2019.109464.
23. Djoharam, V.; Riani, E.; Yani, M. Analisis kualitas air dan daya tampung beban pencemaran Sungai Pesanggrahan di wilayah Provinsi DKI Jakarta. *J. Pengelolaan Sumberd. Alam dan Lingkung.* **2018**, *8*, 127–133, doi:10.29244/ jpsl.8.1.127-133.
24. Wang, F.; Zhang, P.; Yan, W.; Jia, M.; Su, X.; Wang, J.; Tian, S. Riverine organic pollution source and yield from the whole Changjiang River network: Effects of urbanization under changing hydrology. *J. Hydrol.* **2023**, *620*, 1–9, doi:10.1016/j.jhydrol.2023.129544.
25. Firmansyah, Y.W.; Setiani, O.; Darundiati, Y.H. Kondisi sungai di Indonesia ditinjau dari daya tampung beban pencemaran: Studi literatur. *J. Serambi Eng.* **2021**, *6*, 1879–1890, doi:10.32672/jse.v6i2.2889.
26. Ghosh, S.; Das, A.P. Bioleaching of manganese from mining waste residues using *Acinetobacter* sp. *Geol. Ecol. Landscapes* **2017**, *1*, 77–83, doi:10.1080/24749508.2017.1332847.
27. Das, A.P.; Ghosh, S. Role of microorganisms in extenuation of mining and industrial wastes. *Geomicrobiol. J.* **2022**, *39*, 173–175, doi:10.1080/01490451.2022.2038953.
28. Bal, B.; Nayak, S.; Das, A.P. *Recent Advances in Molecular Techniques for the Diagnosis of Foodborne Diseases*; Elsevier: Amsterdam, Netherlands, 2017; ISBN 978-0-1281-1943-3.
29. Sadasivuni, K.K.; Rattan, S.; Waseem, S.; Brahme, S.K.; Kondawar, S.B.; Ghosh, S.; Das, A.P.; Chakraborty, P.K.; Adhikari, J.; Saha, P.; et al. Silver nanoparticles and its polymer nanocomposites—synthesis, optimization, biomedical usage, and its various applications; In *Polymer Nanocomposites in Biomedical Engineering*; Sadasivuni, K.K., Ponnamma, D., Rajan, M., Al-Maadeed, M.A.S.A., Eds.; Springer Nature: Cham, Switzerland, 2019; ISBN 978-3-0300-4741-2.

30. Amsayazhi, P.; Mohan, K.S.R. Use of sludge waste as ingredient in making of brick. *Int. J. Eng. Technol.* **2018**, *7*, 419–422, doi:10.14419/ijet.v7i3.12.16120.

31. Liang, C.; Le, X.; Fang, W.; Zhao, J.; Fang, L.; Hou, S. The utilization of recycled sewage sludge ash as a supplementary cementitious material in mortar: A review. *Sustain.* **2022**, *14*, 1–20, doi:10.3390/su14084432.

32. Bilgili, L.; Çetinkaya, A.Y.; Sarı, M. Analysis of the effects of domestic waste disposal methods on mucilage with life cycle assessment. *Mar. Pollut. Bull.* **2022**, *180*, 1–9, doi:10.1016/j.marpolbul.2022.113813.

33. Hussain, I.; Elomri, A.; Kerbache, L. Domestic waste management with Io-enabled applications: A case study of the Al Rayyan, Qatar Region. *IFAC-PapersOnLine* **2022**, *55*, 830–835, doi:10.1016/j.ifacol.2022.09.515.

34. Ghorbani, Z.; Amanipoor, H.; Battaleb-Looie, S. Water quality simulation of Dez River in Iran using QUAL2KW model. *Geocarto Int.* **2022**, *37*, 1126–1138, doi:10.1080/10106049.2020.1762763.