

A Study of the Pollutant Load Capacity of the lower Sangatta River based on BOD, COD, and TSS parameters using the QUAL2KW method

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ABSTRACT

Community activities around the Sangatta River continue to grow and expand. The river's primary function as a source of fresh water remains indispensable to local residents, particularly those living along the riverbanks, even though piped water from the regional water utility company (PDAM) is now available. Residents draw water directly from the river for bathing, cooking, and washing. At the same time, they pollute it by discharging untreated domestic wastewater and solid waste, so that the entire burden is placed on the river to restore itself naturally (self-purification) from all of the pollution generated by community activities. This study aims to determine the water quality and pollutant load of the lower Sangatta River using three simulated scenarios, compared against the Class 2 water quality standard in Appendix VI of Government Regulation No. 22 of 2021, and to calculate the pollutant load capacity of the river using the QUAL2Kw model. The parameters tested were biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS). The study area covers a 32.62 km stretch of the lower Sangatta River, divided into four segments with nine sampling points. Based on the pollutant load capacity calculations, the maximum and minimum load capacities were obtained for each segment. The results of the QUAL2Kw application and evaluation indicate that the Sangatta River is already in a polluted condition.

INTRODUCTION

The Sangatta River plays an important ecological role. Besides serving as habitat for various aquatic organisms, rivers such as this one also function as drainage channels for the abundant rainwater in the surrounding land area. The riparian environment is also used by people for settlement and a range of other activities. Moreover, several large plantation companies and coal mining companies operate within this river basin. Population growth in East Kutai Regency is influenced more by the presence of large coal mining companies, together with their contractors and suppliers, and by oil palm plantation companies and their associated enterprises (Maide, 2020).

The water quality of the Sangatta River is strongly affected by diverse human activities in its surroundings, such as mining, plantations, agriculture, settlements, industry, and many others. Community activities around the river continue to grow and expand. The river's primary function as a source of fresh water remains indispensable to local residents, particularly those living along the riverbanks, even though

piped water from the regional water utility company (PDAM) is now available. Residents draw water directly from the river for bathing, cooking, and washing. At the same time, they pollute it by discharging untreated domestic wastewater and solid waste, so that the entire burden is placed on the river to restore itself naturally (self-purification) from all of the pollution generated by community activities (Maide, 2020).

River water quality management includes, among other measures, regular water quality monitoring, the determination of river load capacity, and the enforcement of water quality standards. Calculating pollutant load capacity through modeling can reduce the cost of field observation (Fatmawati, 2013). One calculation method that can be used is the QUAL2Kw model. The QUAL2Kw model is recommended for calculating load capacity by Minister of Environment Regulation No. 1 of 2010 on the Procedures for Water Pollution Control. The model has several advantages, including its ability to simulate a river as a one-dimensional system with steady, non-uniform flow, and to simulate pollutant loads entering and leaving the river from pollution sources (Pelletier, 2006). The objective of this study is to determine the pollutant load capacity of the lower Sangatta River for the BOD, COD, and TSS parameters using the QUAL2Kw model.

METHODOLOGY

Research Location and Time

The research was conducted on the Sangatta River in East Kutai Regency. Sampling locations were selected based on the conditions surrounding the Sangatta River, taking into account ease of access, cost, and research time, all of which were considered to yield points representative of water quality (Pohan et al., 2017). The scope of site selection was based on the division of monitoring point segments, village and subdistrict administrative boundaries, and the pollution sources expected to enter the Sangatta River. The lower Sangatta River reach is 32.62 km long and is divided into four segments. Water samples were collected at the upstream point (0°32'28.77" N, 117°27'39.41" E) and the downstream point (0°27'52.52" N, 117°34'7.55" E). The study was carried out in the second half of 2024. Primary data were collected in three periods, namely the first, second, and third weeks of December 2024, at nine sampling points.

Data Collection

Secondary data collected included maps, river hydraulic conditions, river water quality, point source water quality, and meteorological conditions. Primary data collected included river water quality and river hydraulic conditions. The study area was divided into four segments. This segmentation was based on tributary inflows, the availability of sampling locations, and the outlets of pollution sources. The research stages carried out before running the QUAL2Kw program were as follows:

- a) Determination of segments or reaches
- b) Determination of sampling time and sampling points
- c) Water quality sampling
- d) Collection of primary and secondary data
- e) Application of the QUAL2Kw model
- f) Model validation
- g) Data analysis
- h) Model verification

Data Analysis

Calibration was performed to adjust the model output so that it matched the available field data; calibration in QUAL2Kw serves to build the model. Model validation was conducted to identify and quantify the error in the model values and to evaluate the accuracy of the comparison between model data and available field data. Model validation in this study used the Root Mean Square Percent Error (RMSPE) method.

Once the model had been calibrated and validated, simulations were run using several scenarios to examine the condition of the river and pollution sources under different conditions. The simulation scenarios used in this study are presented in Table 1.

Table 1. Simulation Scenarios for the Lower Sangatta River Using the QUAL2Kw Model

Simulation	Upstream Water Condition	Pollution Source	River Water Condition
1	Existing	Existing	Model
2	Meets Class II water quality standard	Initial condition	Model
3	Meets Class II water quality standard	Trial and error	Class II water quality standard

RESULT AND DISCUSSION

Water Quality Modeling of the Lower Sangatta River

The Scenario 1 simulation provides a picture of the water quality model that best fits the field data. This scenario uses the existing water quality conditions from upstream to downstream, with the data entered into the program. In this scenario, trial and error was performed by adding pollutant loads in the diffuse source worksheet until the model approximated the existing data. The Scenario 1 simulation results are shown in Figure 1, Figure 2, and Figure 3.

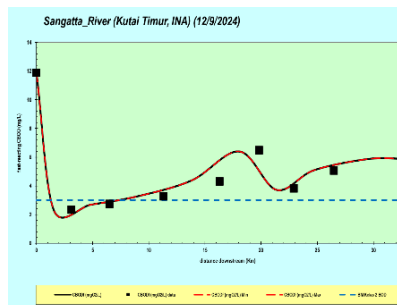


Figure 1. BOD parameter graph

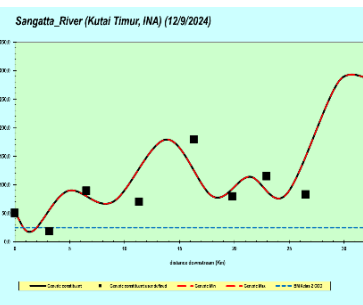


Figure 2. COD parameter graph

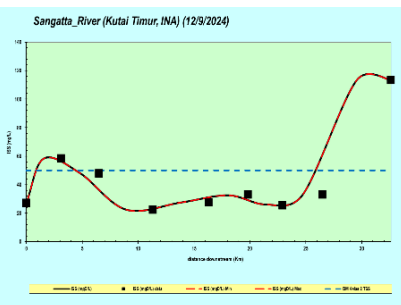


Figure 3. TSS parameter graph

Calculation of the Pollutant Load of the Sangatta River

The pollutant load was calculated by considering two conditions: when the river carries its maximum pollutant load and when it carries its minimum pollutant load. The maximum-load condition occurs in Simulation 3, in which concentrations from point sources and non-point sources were increased and decreased to reproduce the existing condition. The minimum-load condition, by contrast, occurs in Simulation 2, in which pollutant inputs from both point sources and non-point sources were eliminated. The pollutant loads calculated for Simulation 3 and Simulation 2 are presented in Table 2 and Table 3.

Table 2. Maximum Pollutant Load (Scenario 3)

Point	Distance (km)	Segment	Discharge (m ³ /s)	BOD (kg/day)	COD (kg/day)	TSS (kg/day)
ST01	0.00	Segment 1	105.77	1.26	5.34	2.86
ST02	3.12	Segment 1	39.35	0.34	1.44	0.77
ST03	6.51	Segment 1	52.60	0.33	1.41	0.76
ST04	11.32	Segment 2	88.58	0.29	1.16	0.90
ST05	16.31	Segment 2	91.54	0.24	1.95	0.96
ST06	19.82	Segment 3	58.06	0.15	2.48	0.70
ST07	22.93	Segment 3	143.92	0.31	4.98	1.41
ST08	26.48	Segment 4	299.68	0.47	8.86	2.78
ST09	32.62	Segment 4	319.79	0.40	7.46	2.34

The QUAL2Kw simulation results for the lower Sangatta River under the maximum pollutant load (Scenario 3) show considerable variation in pollutant load across the river segments. In Segment 1 (ST01–ST03), the highest pollutant load was recorded at ST01, with a discharge of 105.77 m³/s, a BOD load of 1.26 kg/day, a COD load of 5.34 kg/day, and a TSS load of 2.86 kg/day. These high values indicate organic and inorganic pollutant inputs from the upstream area, probably originating from domestic activities or tributary flows. At ST02, the discharge decreased to 39.35 m³/s, with a BOD load of 0.34 kg/day, a COD load of 1.44 kg/day, and a TSS load of 0.77 kg/day, indicating natural dilution or a reduction in direct pollutant sources. A similar condition occurred at ST03, with a discharge of 52.60 m³/s, a BOD load of 0.33 kg/day, a COD load of 1.41 kg/day, and a TSS load of 0.76 kg/day, indicating that this segment still retains a fairly good self-purification capacity.

Table 3. Maximum Pollutant Load (Scenario 2)

Point	Distance (km)	Segment	Discharge (m ³ /s)	BOD (kg/day)	COD (kg/day)	TSS (kg/day)
ST01	0.00	Segment 1	105.77	0.32	2.64	5.29
ST02	3.12	Segment 1	39.35	0.12	0.98	1.91
ST03	6.51	Segment 1	52.60	0.16	1.31	2.44
ST04	11.32	Segment 2	88.58	0.17	1.00	3.94
ST05	16.31	Segment 2	91.54	0.21	2.29	3.91
ST06	19.82	Segment 3	58.06	0.14	1.36	2.41
ST07	22.93	Segment 3	143.92	0.37	3.40	5.67
ST08	26.48	Segment 4	299.68	0.62	4.75	10.95
ST09	32.62	Segment 4	319.79	0.72	5.65	11.58

The pollutant load calculations for the initial condition (Scenario 2) show pollutant load characteristics that remain relatively low in the upstream section but increase gradually toward the lower reaches of the Sangatta River. In Segment 1 (ST01–ST03), pollutant loads were in the low range. ST01 had a discharge of 105.77 m³/s, with a BOD load of 0.32 kg/day, a COD load of 2.64 kg/day, and a TSS load of 5.29 kg/day. These values reflect an initial pollutant load from upstream domestic activities, which nonetheless remains in the light category. At ST02, the discharge decreased to 39.35 m³/s, with a BOD of 0.12 kg/day, a COD of 0.98 kg/day, and a TSS of 1.91 kg/day, indicating a dilution process or a lack of additional direct pollutant inputs. A similar condition was observed at ST03, with a discharge of 52.60 m³/s, a BOD load of 0.16 kg/day, a COD load of 1.31 kg/day, and a TSS load of 2.44 kg/day, indicating that this segment is still dominated by natural loads, with limited anthropogenic influence.

Calculation of the Pollutant Load Carrying Capacity

Based on the calculated pollutant load carrying capacity above, it can be seen that, for the BOD, COD, and TSS parameters, the water quality of the Sangatta River in several segments has exceeded the minimum carrying capacity. For BOD, the exceeded carrying capacity occurs in Segment 1, Segment 2, and Segment 3, with values of -1.34 kg/day, -0.26 kg/day, and -0.01 kg/day, respectively. For COD, the excess pollutant load occurs in Segment 1, Segment 2, Segment 3, and Segment 4, with values of -3.26 kg/day, -0.16 kg/day, -2.69 kg/day, and -5.93 kg/day, respectively, whereas for TSS there is no excess pollutant load. The calculated pollutant load carrying capacity of the Sangatta River is presented in Table 4.

Table 4. Pollutant Load Carrying Capacity

Point	Distance (km)	Segment	Discharge (m ³ /s)	BOD (kg/day)	COD (kg/day)	TSS (kg/day)
ST01	0.00	Segment 1	105.77	-0.94	-2.70	2.43
ST02	3.12	Segment 1	39.35	-0.22	-0.46	1.14
ST03	6.51	Segment 1	52.60	-0.18	-0.10	1.68
ST04	11.32	Segment 2	88.58	-0.13	-0.16	3.03
ST05	16.31	Segment 2	91.54	-0.03	0.34	2.95
ST06	19.82	Segment 3	58.06	-0.01	-1.12	1.71
ST07	22.93	Segment 3	143.92	0.06	-1.57	4.26
ST08	26.48	Segment 4	299.68	0.15	-4.12	8.17
ST09	32.62	Segment 4	319.79	0.33	-1.81	9.24

The high pollutant loads in several segments arise because almost all of the sampling points are located in densely populated areas. Wastewater generated by domestic activities plays a major role in the pollution of the river water. According to an analysis by Yiping Wu (2012), point sources and non-point sources together contribute 94% of river water pollution, as measured by the BOD and COD parameters.

Management Strategies

Controlling Pollutant Loads at the Source

An inventory is needed of domestic waste sources and economic activities that have the potential to discharge wastewater directly into the river. Once these sources have been identified, management measures can be directed toward enforcing discharge regulations, limiting waste inputs, and prioritizing control at the points that contribute the most. The literature indicates that when discharge supervision is strengthened, control outcomes become more realistic because the load entering the water body can be reduced before it exceeds the river's capacity (Ciawi et al., 2022). In other words, the most effective response is not only to improve the condition of the river but, first of all, to limit the pressure at its source.

Improving Wastewater Treatment

The lower Sangatta River requires a response in the form of strengthened wastewater treatment systems prior to discharge into the water body. Where domestic pollutant sources are dominant, the construction or optimization of communal wastewater treatment plants (IPAL) may be a relevant option (Putri et al., 2022). However, where there are contributions from economic activities or small industries whose waste has different characteristics, the appropriate treatment technology needs to be selected carefully so that load reduction is genuinely effective (Zuhria et al., 2018). Accordingly, wastewater treatment cannot be generalized but must be tailored to the characteristics of the pollutants and the local management capacity.

Protecting Riparian Zones and Reducing Non-Point Source Inputs

In addition to point sources, research also shows that land use conditions around the river affect water quality through surface runoff, sediment, and the input of non-point loads from built-up areas (Pramaningsih et al., 2020). In the Winongo River study, the recommended management strategies included establishing riparian buffer strips or riverbank vegetation, because vegetation can help reduce pressure on water quality and support riparian protection (Marlina & Melyta, 2019). This approach is consistent with the need to control non-point inputs, which are often difficult to trace but can contribute substantially to the decline in water quality.

Spatial Planning Based on Carrying Capacity and Scenario Simulation

This approach is important because river carrying capacity is not uniform: some segments can still accept additional loads, whereas others have already exceeded their capacity (Wifarulah et al., 2021). It also enables the development of more realistic load-reduction scenarios, for example by focusing control efforts first on the most critical segments. Thus, carrying-capacity-based management not only describes the condition of the river but also provides a scientific basis for determining the sequence of control actions.

Strengthening Monitoring and Evaluation

Regular water quality monitoring is an important component of the management response because river quality is dynamic and can change as loads increase, land use changes, and hydrological conditions vary. A study of the Surabaya River showed that DO, BOD, COD, and TSS data can be used to examine the relationships among parameters and to monitor the long-term sustainability of water quality (Razif, 2022). Monitoring should preferably be conducted at representative points in each segment so that changes in water quality can be traced spatially and temporally. If monitoring results show a shift in water quality or a change in pollutant load, the carrying capacity model needs to be updated so that management strategies remain consistent with the actual condition of the river.

CONCLUSION

Based on the BOD, COD, and TSS parameters, the pollutant load carrying capacity (DTBP) of the Sangatta River is in an exceeded condition. For BOD, exceeded DTBP values occur at several stations. For BOD, the exceeded carrying capacity occurs in Segment 1, Segment 2, and Segment 3, with values of -1.34 kg/day, -0.26 kg/day, and -0.01 kg/day, respectively. For COD, the excess pollutant load occurs in Segment 1, Segment 2, Segment 3, and Segment 4, with values of -3.26 kg/day, -0.16 kg/day, -2.69 kg/day, and -5.93 kg/day, respectively, whereas for TSS there is no excess pollutant load. It can therefore be concluded that the existing condition of the Sangatta River water body is already polluted by organic waste.

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