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Analysis of the Quality and Pollution Load Carrying Capacity of Point Source Pollutants due to Tofu Industry Waste in Garuda River, Sragen Using QUAL2Kw Modeling

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ABSTRACT

The Garuda River is one of the tributaries of Bengawan Solo in Sragen Regency which is suspected of experiencing a decline in water quality. This study aims to determine the quality and pollution load carrying capacity (PLCC) of the Garuda River to the source of pollutants, especially those caused by tofu industrial liquid waste. The research method used in this study is a quantitative method to analyze the status of river water quality using the pollution index (PI) method and the calculation of river PLCC using the QUAL2Kw model with 3 modeling scenarios. The analysis showed that the Garuda River was proven not to meet the class III quality standards because several parameters such as temperature, TSS, nitrite (NO_2-N), and total Coliform were above the set quality standards. Based on the calculation of the pollution index, it was found that the Garuda River was proven to be polluted with a lightly polluted quality status with a pollution score ranging from 1.49 to 2.91. Based on QUAL2Kw modeling, it was found that the PLCC of Garuda River for TSS parameters was 233.28–259.20 kg/day, BOD was 12.96–15.55 kg/day, and COD was 51.84–103.68 kg/day. One of the control efforts that can be carried out is reducing the pollutant burden on each source of pollution, especially point source pollutants from tofu industrial liquid waste.

Keywords: Garuda River, pollution index, PLCC, QUAL2Kw, quality status.

INTRODUCTION

Water is one of the natural resources that has an important role in the sustainability of all living things on earth, including humans. The United Nations Agency declares that water is one of the human rights, which means that every human being on this earth has the same basic right to the use of water resources. In Indonesia, the use of water has been carried out since ancient times. When armed with local knowledge, customs, and culture passed down from generation to generation, most people use water sources in the surrounding environment to meet their living needs (Hidayati, 2016). This is what then gives rise to human dependence on water. Without water, various life processes will be disrupted, causing economic losses, and can even lead to death (Lestari et al., 2021). The Ministry of Environment and Forestry in a publication entitled Indonesia's Environmental Status in 2020 stated that the available water resources in Indonesian territory reached 3.9 trillion m^3/year, but only 17.69% could be utilized. This figure then brought Indonesia into the top 10 countries rich in water. Wahyuningsih et al. (2019), mentioned that the most widely used water source by humans to meet their daily needs is rivers. This is in line with data published by the Ministry of Environment and Forestry in 2020 which states that surface water sources in Indonesia are dominated by rivers with a total of more than 5.590 rivers. However, along with the times, many rivers have experienced various problems in terms of quality, quantity, and continuity. Problems related to water resources in Indonesia are illustrated in Government Regulation No. 19 of 2020 concerning the National Medium-Term Development Plan for 2020–2024 which states that water availability in several regions of Indonesia, especially on the island of Java, is in critical condition with water quality at a moderate-heavy pollution level.

The Garuda River is one of the tributaries of the Bengawan Solo River in Sragen Regency which is suspected of experiencing a decline in water quality. One of the reasons for the decline in water quality in the river is due to the pollution of waste produced by tofu industry activities, especially in Teguhan Village, Sragen Wetan Village, Sragen District. Based on data obtained from the local RW Chairman, there are a total of 57 tofu industries spread across 3 RT in Teguhan Village, Sragen Wetan Village, where the liquid waste produced from the production process is all discharged into the river body without going through treatment first. This is known from the existence of a pipeline that flows turbid white tofu industrial liquid waste into the river water body. The Sragen Environmental Agency has built a communal wastewater treatment plant (WWTP) facility for industrial wastewater treatment in the area. However, in reality, industry players whose notability is small-scale household industry players do not take advantage of these facilities. One of the driving factors is the amount of maintenance costs needed to carry out maintenance and management (Rachmawati et al., 2023). One of these behaviors then causes changes in the physical condition of the river in the form of high turbidity which can even be assessed with the naked eye. This river water is still used as a source of agricultural irrigation and to support fisheries cultivation.

In Appendix XVIII of the Regulation of the Minister of Environment and Forestry number 5 of 2014 concerning the quality standards of soybean processing (tofu), it is stated that the permissible quality standards are BOD of 150 mg/L, COD of 300 mg/L, TSS of 200 mg/L, and pH 6–9. Meanwhile, liquid waste from the tofu industry has a BOD content of 6000–8000 mg/L, COD of 7500–14000 mg/L, and a fairly low pH of 5–6, which if discharged into the river directly without going through the processing process first can result in disruption of river biological life, reduce water quality, and even cause pollution on the groundwater surface (Pangestu et al., 2021). Although rivers can self-purify due to pollutants entering them, in quantities that exceed the capacity of the river will be difficult to restore its original condition.

Based on the background of the problems found in the Garuda River, this study was conducted to determine the quality and PLCC of the Garuda River against pollutant sources, especially those caused by the tofu industry. The measurement of water quality will be used to calculate the class or level of water pollution of the Garuda River using the pollutant index method while the PLCC calculation is carried out using a numerical modeling method that is calculated through a Microsoft Excel-based program, namely QUAL-2Kw. The determination of water quality status and PLCC is expected to be useful as an evaluator and mitigation material to overcome the problem of river water quality degradation by the entry of various pollutant loads into a water body.

MATERIALS AND METHODS

Location and time of research

Administratively, the research was carried out within the scope of the village area that is passed by the Garuda River, namely in Sragen Wetan Village, Sragen District, Sragen Regency, Central Java (Figure 1). Water measurement and sampling activities will be carried out at 5 location points along the river flow that are suspected of being polluted due to tofu industrial liquid waste located in Teguhan Village, Sragen Wetan Village. The coordinate point of the measurement location can be seen in Table 1. Furthermore, the measurement of parameters, namely, TSS, BOD, COD, DO, total nitrogen, and total Coliform will be carried out at the Environmental Laboratory of Perum Jasa Tirta I (PJT I) Surakarta. The research was carried out in January 2024.

Types of research and data collection techniques

In this study, the research method used is a combination of qualitative and quantitative descriptive analysis methods. The data used in this study includes primary data such as sampling point data, river water and wastewater quality data, interview data, and also documentation and secondary data including data related to river climatology and meteorology data. The primary data collection technique used is through direct data collection in the field and interviews with related parties.

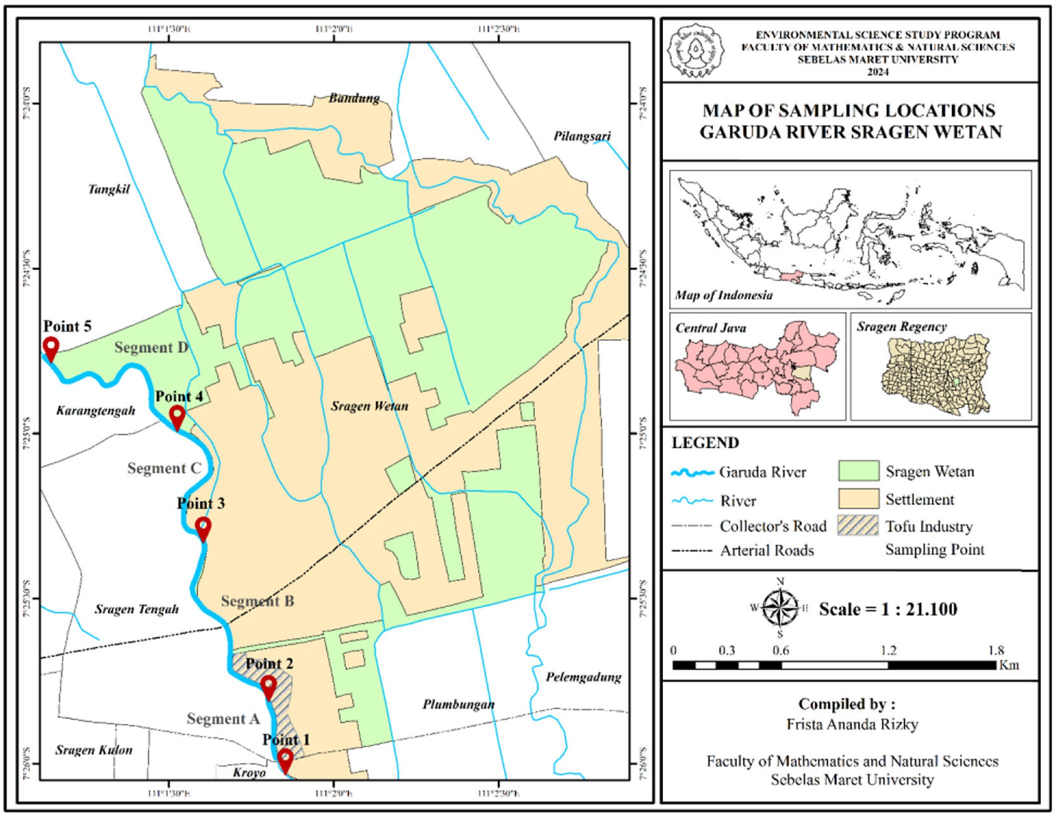

Figure 1. Research location

Table 1. Measurement location coordinate point (GPS essentials)

Sampling points	Coordinate points		Location information
	S	E	
1	07°26.017'	111°01.849'	Administrative boundaries
2	07°26.817'	111°01.819'	Polluting area: Tofu industrial area
3	07°25.445'	111°01.598'	Utilization Point: Krapyak Dam
4	07°25.208'	111°01.547'	Residential areas

Data analysis

Analysis of river water quality status

The data from the measurement results of water quality parameters that have been obtained from field measurements and laboratory tests are then analyzed and calculated using the pollution index method. The pollution index method is fairly simple in calculating the level of pollution relative to the water quality standards that have been determined following its designation. The use of this method in determining the status of river water quality is carried out by referring to the Decree of the Minister of Environment Number 115 of 2003 concerning the determination of water quality status, which states that one of the methods that can be used to determine the level of pollution relative to several water quality parameters is the PI method. The calculation of PI value can be done using the following formula:

$$PIj = \sqrt{\frac{\left(\frac{Ci}{Lij}\right)M^2 + \left(\frac{Ci}{Lij}\right)R^2}{2}} \quad (1)$$

where: *PIj* – pollution index for its designation (j), *Ci* – concentration of water quality parameters (i), *Lij* – listed in the water quality standards (j), *M* – maximum, *R* – average.

Based on the results of the Pollution Index calculation that has been obtained, then an assessment of the quality status of river water quality can be carried out with 4 assessment categories following Table 2.

Table 2. Pollution index category (Decree of the Minister of Environment Number 115 of 2003)

Pollution index score	Quality status
0 ≤ PI ≤ 1.0	Good
1.1 < PI ≤ 5.0	Lightly polluted
5.1 < PI ≤ 10	Moderately polluted
PI > 10	Heavily polluted

Source: Decree of the Minister of Environment Number 115 of 2003.

Analysis of pollution load carrying capacity

The pollution load carrying capacity (PLCC) was calculated using a numerical modeling method that was calculated through a Microsoft Excel-based program, QUAL2Kw. The stages in the simulation using the QUAL2Kw model, according to Ilfan et al. (2022), include the program installation stage, model formation and calibration, model validation, and modeling simulation. After calibrating the model, the next step is to validate the model to determine the suitability of the resulting model with the input water quality data. The results of this model validation will later be used to find out whether the model is accepted or rejected to run a simulation scenario that is useful for formulating recommendations to prevent and overcome water pollution that occurs due to the presence of contaminants or pollutant loads (Antunes et al., 2018). Kamal et al. (2020) stated that model validation could be tested using the Relative Percentage Difference (RPD) calculation method with the following equation:

$$RPD = \frac{Csim - Cobs}{Cobs} \cdot 100\% \quad (2)$$

where: RPD – relative percentage difference, C_{sim} – simulation model concentration (mg/l), C_{obs} – observation concentration (mg/l).

Based on the results of the calculation of the RPD value that has been obtained, then an assessment can be carried out whether the model can be accepted or rejected. Kamal et al. (2020) stated that modeling is acceptable if the RPD value is ≤ 25%. After model calibration and validation, modeling simulations can be carried out through several modeling scenarios. In this study, simulation scenarios were used for modeling the water quality of the Garuda River.

Each simulation scenario carried out in water quality modeling will produce a pollutant concentration which is then used in the calculation to obtain the pollutant load indigo following Government Regulation Number 82 of 2001 concerning water quality management and water pollution control. The calculation can be done through the following equation:

$$BP = Q \cdot c \cdot f \quad (3)$$

where: BP – pollution load (kg/day), Q – waste discharge (m^3/second), c – pollutant concentration (mg/l), f – conversion factor from m^3/s x mg/l to kg/hr (86.4).

Furthermore, the pollution load carrying capacity (PLCC) can be calculated by the following formula:

$$PLCC = PL_{aqs} - PL_m \quad (4)$$

where: $PLCC$ – pollution load carrying capacity (kg/day), PL – pollution load (kg/day), PL_{aqs} – PL according to quality standards, PL_m – PL measured.

RESULT AND DISCUSSION

Garuda river water quality analysis

Assessment of water quality is obtained by comparing the measurement results that have been obtained with the applicable water quality standards. The Garuda River is used for agricultural and fishery irrigation as well as a source of raw water for Karanganyar Regency and Sragen Regency. Based on Government Regulation of the Republic of Indonesia Number 22 of 2021 concerning the Implementation of Environmental Protection and Management, water used in freshwater fish farming, livestock, water for irrigating plants, and/

Table 3. Water quality modeling simulation scenarios

Scenario	Upstream condition	River quality data	Sources of pollution	River water quality
1	Existing	Existing	Existing	Model
2	Existing	Existing	Meet wastewater QS	Model
3	Existing	Meet QS class III	–	Model

Note: QS – quality standards.

or other designations that require the same water quality as the use is included in the designation class III. Therefore, to find out how the condition of water quality in the Garuda River can be done by comparing the results of water quality measurements with class III water quality standards. The results of water quality measurements at five points in the Garuda River flow, precisely in Sragen Wetan Village, can be seen in Table 4.

Temperature

The results of temperature measurements at 5 points of the research location in the Garuda River were 27.6 °C, 28.27 °C, 29.23 °C, 29.17 °C, and 29.50 °C. Based on the results of these measurements, it can be seen that the water temperature in the Garuda River tends to increase at each point. When compared to Government Regulation of the Republic of Indonesia Number 22 of 2021 which states that the river water temperature has a quality standard of deviation 3 from the normal temperature, which ranges from 22–28 °C, the result is obtained that the temperature at point 1 is still within the normal limit and under the quality standards that have been set while the other 4 points exceed the quality standards that have been set. One of these can be influenced by several external factors, including the habit of the community in throwing waste into the river. The Garuda River, located in a densely populated residential area and a fairly large level of tofu industry activity, especially in the area around point 2, namely Teguhan Village, is one of the triggers for the increase in water temperature in the river. This is to the statement of Pagoray et al. (2021) which stated that one of the factors that cause the temperature of water to be high is the discharge of excessive amounts of tofu liquid waste into water bodies which then has an impact on the survival and metabolism of aquatic organisms in it.

Turbidity

The results of measuring the turbidity value in the Garuda River at points 1 to 5 are 131 NTU, 134 NTU, 104 NTU, 105 NTU, and 88.60 NTU, respectively. Based on these results, it was found that the turbidity value tended to increase at point 2 and relatively decreased at the next points. One of the reasons for this is the position of point 2 which is adjacent to the location of the tofu industry where most industry players dispose of the liquid waste they produce directly into the river without going through the processing process first. The waste that is disposed of is liquid waste left over from production activities with a relatively cloudy white color that is still mixed with whitish waste which is the rest of soybean mills. This, of course, has an impact on the high value of turbidity in the river and can even be seen with the naked eye. In addition, the presence of tofu liquid waste that enters the river also causes an unpleasant odor. Furthermore, the decrease in turbidity value at points 3 to 4 is influenced by several factors including river hydrological factors such as depth and flow velocity. The depth and speed of water flow are factors that affect the stirring

Table 4. Results of water quality measurement in the Garuda River

Parameters	Unit	Measurement location					Quality standards (Grade III)
		1	2	3	4	5	
Temperature	°C	27.60	28.27	29.23	29.17	29.50	Deviation 3
Turbidity	NTU	131	134	104	105	88.60	–
TSS	mg/L	129.50	116.50	99	111	93.50	100
pH	-	7.39	7.38	7.33	7.23	7.21	6–9
DO	mg/L	6.66	6.18	6.07	6.22	6.51	Minimum 3
BOD	mg/L	5.46	5.04	5.20	4.86	4.80	6
COD	mg/L	22.55	22.24	26.11	21.98	21.47	40
Nitrate (NO_3-N)	mg/L	1.88	1.92	2.17	2.28	2.37	20
Nitrite (NO_2-N)	mg/L	0.07	0.01	0.24	0.21	0.22	0.06
Total Kjeldahl N	mg/L	0.0789	0.0785	0.0785	0.0695	0.0742	–
Ammonia	mg/L	0.2285	0.2168	0.2093	0.2197	0.2191	0.5
Total nitrogen	mg/L	2.26	2.22	2.699	2.785	2.886	25
Total Coliform	MPN/100 ml	5,400	16,000	3,500	16,000	22,000	10,000

Source: PJT I lab analysis and author analysis results (2024).

of water masses and the sedimentation process, where increasing depth with a small flow speed causes the stirring of water masses to be low and the sedimentation process to increase (Nurlinda et al., 2019). This statement is by the existing conditions that occur in the Garuda River, where points 1 and 2 with deeper depth and slower flow speed than other points produce a greater concentration of turbidity than other points. Meanwhile, points 3, 4, and 5 with relatively shallower depths with relatively faster flow speeds produce smaller turbidity values.

Total suspended solid (TSS)

The results of measuring the concentration of TSS in the Garuda River at points 1 to 5 consecutively were 129.5 mg/l, 116.5 mg/l, 99 mg/l, 111 mg/l, and 93.5 mg/l. Based on these results, it was found that the concentration of TSS at 5 points of the Garuda River with a value close to or even exceeding 100 mg/l indicates a tendency to decrease the concentration downstream. From these results, it can be concluded that the TSS parameters at 3 measurement locations have exceeded the quality standards for class III water quality because they have exceeded 100 mg/l (PP RI No. 22 of 2021). The high TSS value at the 5 measurement points can be caused by domestic waste, industrial waste, and water runoff that enters the river water body. Similar to the turbidity value, the magnitude of the concentration of TSS in the Garuda River is also influenced by different hydrological conditions at each point. This then causes fluctuations in TSS concentrations at all 5 measurement points. The difference in river topographic conditions has an impact on the speed of stirring water masses and the sedimentation process. The measurement results for the TSS parameter follow the results of research conducted by Simbolon et al. (2020) which stated that the further downstream the TSS concentration becomes lower due to the influence of lower detachment and greater river water flow speed.

Degree of acidity (pH)

The results of measuring the pH value of the Garuda River showed results ranging from 7.21 to 7.39. From these results, it can be seen that the pH value at the 5 points shows that the pH value still meets the set quality standards, which is still in the range of values 6 to 9 (PP RI No. 22 of 2021). The pH value shows the same trend for each location and meets the water quality standard which indicates that the source of pollutants that enter the water body has been mixed and diluted by river water so that the value still meets the water quality standard value (Rahman and Fajriati, 2021). With a pH value that still meets these quality standards, bacteria can grow well which will accelerate the decomposition process.

Dissolver oxygen (DO)

The results of measuring the concentration of DO in the Garuda River at points 1 to 5 consecutively were 6.66 mg/l, 6.18 mg/l, 6.07 mg/l, 6.22 mg/l, and 6.51 mg/l. Based on these results, it was found that the concentration of DO at 5 points of the Garuda River still meets the quality standard for class III water quality, which is 3 mg/l and above (PP RI No. 22 of 2021). DO in point 1 has the highest concentration of DO than other points, so it can be concluded that point 1 has better water conditions than other points. However, at points 2 and 3, it was found that the concentration of DO in water tended to decrease which then increased again at points 4 and 5. One of these is due to the input of tofu industrial liquid waste around point 2. Tofu wastewater has a pH that tends to be acidic which can cause a decrease in DO concentration in a body of water (Hidayati et al., 2021).

Biochemical oxygen demand (BOD)

The results of measuring BOD levels in the Garuda River at points 1 to 5 consecutively were 5.46 mg/l; 5.04 mg/l; 5.20 mg/l; 4.86 mg/l; and 4.8 mg/l. Based on these results, it was found that the concentration of BOD at 5 points of the Garuda River still meets the quality standard for class III water quality, which is 6 mg/l (PP RI No. 22 of 2021). The measurement results showed that the concentration of BOD at 5 points of the measurement location fluctuated quite a bit and was almost close to the quality standard. One of these can be influenced by residential activities around the Garuda River. In addition, the discharge of liquid waste from the tofu industry also causes the water condition of the Garuda River to become cloudy and dirty so the concentration of BOD is high. Tofu waste has a very high BOD content so if it is directly discharged into water bodies, it can trigger an increase in microorganisms that have the potential to reduce dissolved oxygen levels in water (Amalia et al., 2022). This, of course, can interfere with the survival of aquatic organisms in it and severe conditions can cause the death of aquatic organisms and can disrupt the balance of the ecosystem. However, based on the measurement results, it was found that the concentration of BOD that still met the quality standards showed a positive correlation with the DO parameter where when this study was carried out the Garuda River still had sufficient dissolved oxygen content so that microorganisms could decipher the pollutant load that entered it properly.

Chemical oxygen demand (COD)

The results of measuring COD concentrations in the Garuda River at points 1 to 5 consecutively were 22.55 mg/l, 22.24 mg/l, 26.11 mg/l, 21.98 mg/l, and 21.47 mg/l. Based on these results, it was found that the COD concentration at the 5 measurement points still met the quality standards for class III water quality, which was 40 mg/l (PP RI No. 22 of 2021). When compared to the other 4 points, point 3 shows the highest concentration of COD parameters. The high measurement results show the high content of chemicals that pollute the waters due to activities carried out by the community. Waste from the use of chemicals such as soap and detergent that directly or indirectly enters water bodies can contribute to pollutants that can have an impact on high concentrations of COD. In addition, waste from livestock activities and tofu industry waste around point 3 is also the main source of organic materials that trigger an increase in COD concentrations at that point (Sumantri and Rahmani, 2020). High concentrations of COD can of course affect the survival of aquatic organisms living in them. Similar to the results of the BOD parameter measurement, the results of the COD parameter measurement also showed a positive correlation with the DO parameter where when this study was carried out the Garuda River still had sufficient dissolved oxygen content so that microorganisms could decipher the pollutant load that entered it properly.

Nitrate (NO_3^-)

The results of measuring the concentration of Nitrate in the Garuda River at points 1 to 5 consecutively were 1.88 mg/l, 1.92 mg/l, 2.17 mg/l, 2.28 mg/l, and 2.37 mg/l. Based on these results, it was found that the nitrate concentration at 5 points was still relatively low with an increasing tendency at each point but was still below the quality standard for class III water quality, which was 20 mg/l (PP RI No. 22 of 2021). The results show that the Garuda River is classified as mesotrophic waters with moderate nutrient levels. Although the nitrate content in the Garuda River is still quite low, this amount does not meet the concentration in its natural condition, which is more than 0.1 mg/l. One of these is due to the existence of nitrogen fertilizer waste, organic waste derived from human feces, domestic waste, livestock waste, and also due to tofu industrial liquid waste around the research site.

Nitrite (NO_2^-)

The results of the measurement of nitrite concentration in the Garuda River at points 1 to 5 consecutively were 0.07 mg/l, 0.01 mg/l, 0.24 mg/l, 0.21 mg/l, and 0.22 mg/l. Nitrite concentrations ranged from 0.01 to 0.24 mg/l. Based on the distribution of nitrite concentrations at the 5 measurement points, it was found that the water of the Garuda River was no longer in its natural condition because it had exceeded the concentration of 0.001 mg/l. When compared to the quality standards, the nitrate concentration at points 1, 3, 4, and 5 has exceeded the class III water quality standard of 0.06 mg/l while point 2 still meets the quality standard (PP RI No. 22 of 2021). Based on the measurement results, it was found that there was a decrease in nitrite concentration at point 2, then an increase at point 3, and tended to decrease at the next measurement point. The decrease in nitrite concentrations at points 2, 4, and 5 is influenced by self-purification ability which is influenced by hydraulic conditions and the type of pollutant source (Novita et al., 2020). Then it was found that there was a considerable increase in nitrite concentration at point 3 caused by the input of domestic waste and waste from industrial activities (Mahyudin et al., 2015). In the context of this study, the industry that is suspected of causing the high nitrite content is the tofu industry which is around point 2 to point 3, so the concentration accumulates at point 3. Tofu industrial liquid waste contains organic substances such as proteins, fats, and other suspended solids that through the decomposition process will produce chemical compounds such as nitrates, nitrites, and ammonia with a fairly high concentration (Perkasa, 2014).

Total Kjeldahl nitrogen (TKN)

The results of TKN measurements in the Garuda River at points 1 to 5 consecutively are

0.0789 mg/l, 0.0785 mg/l, 0.0785 mg/l, 0.0695 mg/l, and 0.0742 mg/l. Based on these results, it was found that the concentration of TKN in the Garuda River tends to be quite volatile with the highest concentration found at point 1 and the lowest at point 4. The high concentration of TKN in water indicates that there is a greater indication of water quality problems. Generally, the higher the total nitrogen concentration in water, the increase in algae growth which then has an impact on the higher turbidity value and lack of dissolved oxygen concentration due to sunlight being difficult to enter water bodies. This condition can then be used as a natural indicator in determining water quality where if there is a sudden spike in concentration marked by an increasing number of algae plants on the water surface, it can be suspected that there is a problem in waste management around the location of the waters.

Ammonia (NH_3)

The results of measuring the concentration of ammonia in the Garuda River at points 1 to 5 consecutively were 0.2285 mg/l, 0.2168 mg/l, 0.2093 mg/l, 0.2197 mg/l, and 0.2191 mg/l. Based on the results of these measurements, it was found that the concentration of ammonia at 5 measurement points of the Garuda River still met the quality standards for class III water quality, which was 0.5 mg/l (PP RI No. 22 of 2021). The existence of ammonia content at the 5 measurement points can be caused by the presence of domestic waste, industrial waste, agricultural waste, and livestock waste that enter water bodies. In addition, the concentration of ammonia in the Garuda River is also influenced by the difference in temperature and pH conditions at each measurement point (Isma and Isma, 2019).

Total nitrogen

The results of the Total Nitrogen measurement in the Garuda River at points 1 to 5 consecutively are 2.260 mg/l; 2.220 mg/l; 2.699 mg/l; 2.785 mg/l; and 2.886 mg/l. It was found that the concentration of the Garuda River ranged from 2.220 mg/l to 2.886 mg/l. Based on the distribution of TN concentrations at the 5 measurement points of the Garuda River, it was found that the water of the Garuda River still meets the quality standard for class III water quality, which is 25 mg/l (PP RI No. 22 of 2021).

Total coliform

Total coliform is one of the biological parameters in water quality that can be used as an indicator of the presence or absence of pollution due to fecal contamination and other waste that can cause health problems in humans (Kadarsih and Caesar, 2017). The results of the Total coliform measurements in the Garuda River at points 1 to 5 were 5,400 MPN/100 ml, 16,000 MPN/100 ml, 3,500 MPN/100 ml, 16,000 MPN/100 ml, and 22,000 MPN/100 ml. Based on the results of these measurements, it was found that the total coliform at 3 measurement points of the Garuda River has exceeded the quality standard for class III water quality, which is 10,000 MP/100 ml, while the other 2 points, namely points 1 and 3, are still below the set quality standard (PP RI No. 22 of 2021).

Analysis of the quality status of garuda river water quality

Referring to the Decree of the Minister of Environment Number 115 of 2003 concerning the Determination of Water Quality Status, the determination of water quality status can be carried out using several methods, one of which is the Pollution Index method. The calculation of the PI of Garuda River water is based on the results of water quality measurements carried out in January 2024. The results of the calculation of the water quality status of the Garuda River using the Pollutant Index method are expected to be useful as elevator materials and mitigation to overcome the problem of pollution or degradation of river water quality due to the large amount of pollutant load that enters it. The results of the calculation of the water quality IP of the Garuda River in the measurement period can be seen in Table 5 and Figure 2. Based on the results of the calculations in Table 5 and Figure 2 above, it can be seen that the Garuda River flowing in Sragen Wetan Village starting from point 1 to point 5 is proven to be polluted with a lightly polluted quality status with a pollution value or score ranging from 1.49 to 2.91. Based on the graph of the IP calculation results as presented in Figure 2, the result is that there is a tendency to increase at each measurement point, which means that downstream the water quality decreases or worsens. The improvement and/or decrease in water quality status can be influenced by anthropogenic activities of land use, the type of vegetation around the river flow, and also the source of pollutants that enter it (Kudubun et al., 2020).

Table 5. Calculation of water pollution index value in Garuda River

Measurement location	Ci/Lij		PI Score	Percentage increase	Quality status
	Max	Average			
Point 1	2.57	0.68	1.88	0%	Lightly polluted
Point 2	2.02	0.60	1.49	-39%	Lightly polluted
Point 3	4.04	0.81	2.91	142%	Lightly polluted
Point 4	3.76	0.94	2.74	-17%	Lightly polluted
Point 5	3.84	0.99	2.81	7%	Lightly polluted

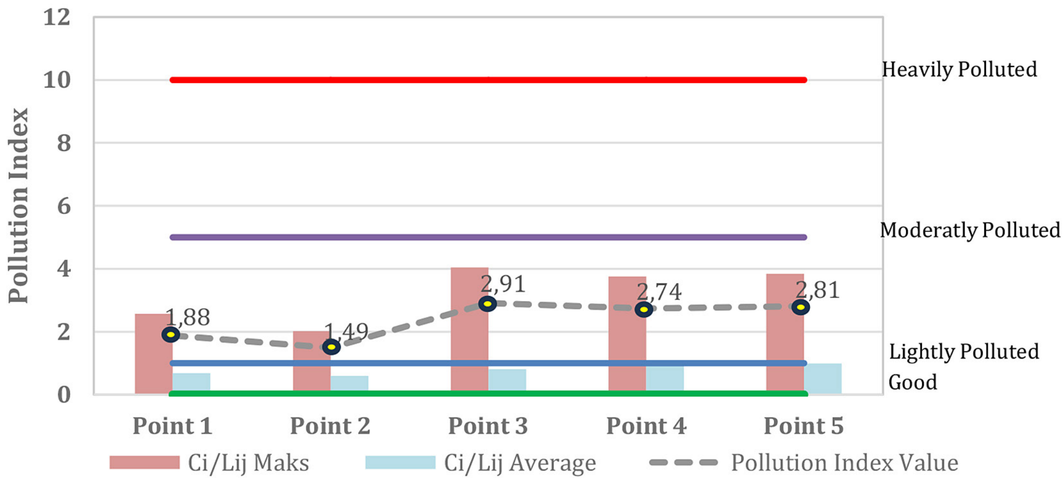

Figure 2. Garuda River pollution index value

Analysis of pollutant load and carrying capacity of garuda river pollution load

The amount of pollution burden and pollution capacity of the Garuda River were obtained through numerical modeling that was calculated through a Microsoft Excel-based program, namely QUAL2Kw. The determination of DBTP values is carried out for all parameters contained in the water quality standards at water sources that have been determined. However, in this study, the DBTP calculation was carried out by focusing only on a few key parameters that are characteristic of the pollutant load in the Garuda River, especially those that come from tofu industry point source waste, namely COD, BOD, and TSS parameters. The determination of these key parameters is based on the significance of a parameter to the level of river pollution (Rahmawati and Siwiendrayanti, 2023). Based on the analysis of water quality and the calculation of the Pollutant Index that has been carried out previously, it was found that the existence of the tofu industry in Teguhan Village has a considerable influence on the decline in the water quality of the Garuda River. Regulations related to tofu industrial waste are regulated in the Regulation of the Minister of Environment and Forestry number 5 of 2014 concerning the quality standards for soybean processing (tofu), precisely in Attachment XVIII which states that the permissible quality standards for tofu industrial wastewater are BOD of 150 mg/L, COD of 200 mg/L, TSS of 300 mg/L, and pH 7. These conditions then underlie the selection of COD, BOD, and TSS parameters as key parameters to determine the Garuda River DTBP against pollutant sources originating from tofu industrial waste.

Quality of pollutant sources

In this study, the source of pollution that is the focus of the study is the source of point source pollution which comes from the results of tofu industry activities carried out by most of the people of Teguhan Village, Sragen. Based on the analysis of water quality and the calculation of the Pollutant Index that has been carried out previously, it was found that the existence of the tofu industry in Teguhan Village in segment B has a considerable influence on the decline in the water quality of the Garuda River. Therefore, in this study, data related to the quality of pollutant sources was obtained through testing of tofu industrial wastewater samples. Sampling was carried out in one of the tofu industries owned by residents on January 31, 2024, at 11.45 WIB, which at that time was the time when the wastewater was discharged into the river. Tofu wastewater samples were taken using a jerry can container with a size of 2.5 liters then tightly closed and preserved in a coolbox for further quality testing at the Environmental Laboratory of Perum Jasa Tirta I. The results of wastewater quality measurements are shown in Table 6.

In the Regulation of the Minister of Environment and Forestry number 5 of 2014 concerning the quality standards of soybean processing (tofu), it is stated that the permissible quality standards are BOD of 150 mg/L, COD of 300 mg/L, TSS of 200 mg/L, and pH 6–9. Meanwhile, based on the measurement results that have been obtained, it is found that almost all of the tofu wastewater quality parameters have passed the set quality standards. Based on the results of field measurements and laboratory tests, it was found that wastewater from the tofu industry in Teguhan Village, Sragen has a TSS content of 461.7 mg/l, BOD_5 of 1204 mg/l, COD of 5477 mg/l, temperature of 56 °C, and a moderately acidic pH of 3.59.

Model calibration and validation

Calibration is a method used to adjust the water quality of the analysis with the water quality in the model. In this modeling, the calibrated parameters are hydraulic parameters in the form of discharge and flow velocity as well as water quality parameters including TSS, COD, and BOD parameters (Figure 3). Calibration is carried out using the trial and error method. Where in hydraulic parameters, trial and error is carried out by changing the values in the manning column of the formula on the reach worksheet until it produces a model that is close to the state or following the desired state (Fajaruddin, 2017). As for water quality parameters, trial and error is carried out by changing the discharge value and concentration of pollutants, both point source pollutants and non-point source pollutants. The existence of time differences and variations in

Table 6. Results of tofu industrial wastewater quality measurement

Parameters	Unit	Result	Quality standards	Analysis methods
Temperature	°C	56	-	SNI 06-6989.23-2005
pH	-	3.59	6–9	SNI 6989.11:2019
TSS	mg/L	461.7	200	APHA 2540 D-2017
BOD_5	mg/L	1204	150	APHA 5210 B-2017
COD	mg/L	5477	300	SNI 6989.2:2019

Source: PJT I lab analysis and author analysis results (2024).

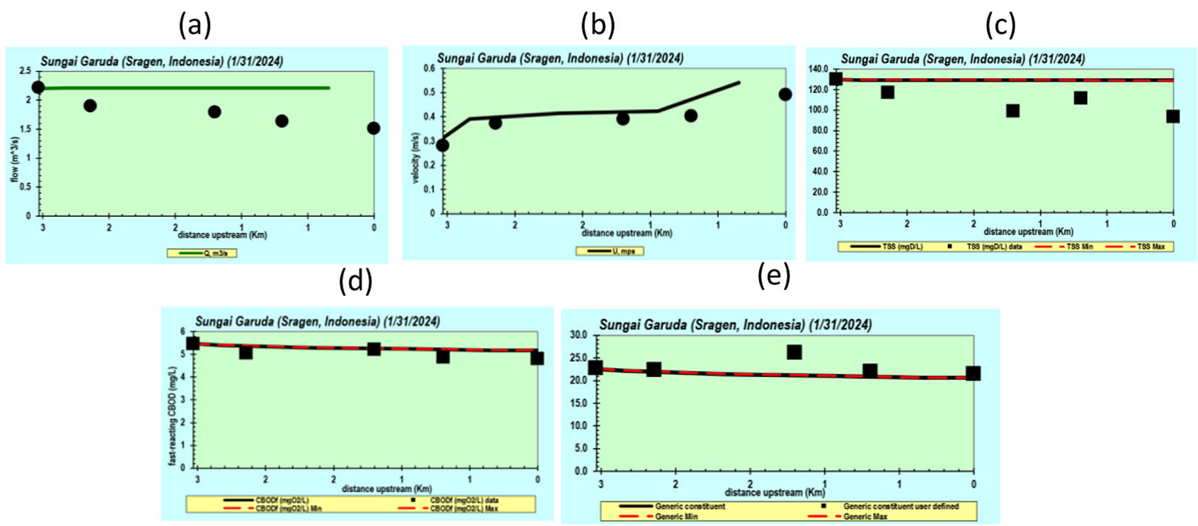

Figure 3. QUAL2Kw calibration model of Garuda River**:** (a) debit model chart, (b) flow velocity model graph, (c) TSS model graph, (d) BOD model graph, and (e) COD model graph **(**QUAL2Kw Modeling, 2024)

data, both river water quality data and wastewater quality, make calibration one of the most important steps to take. The results of the water quality model calibration process using the trial and error method are shown in Figure 3. To find out whether the model is close to the actual condition or not, the next step is to carry out the model validation process. In this modeling, model validation is carried out by calculating the relative percentage difference (RPD) value. The results of the calculation of the RPD value on the QUAL2Kw model can be seen in Table 8 to Table 11. Based on the RPD calculations that have been carried out, it was found that the RPD value for the discharge model is 25%, the flow rate model is 7%, the TSS parameter model is 19%, the BOD parameter model is 5%, and the COD parameter model is 5%. The value has been following the provisions because the magnitude is ≤ 25% (Kamal et al., 2020) so the modeling is accepted and can be used to simulate several modeling scenarios.

Table 7. Relative percentage difference debit analysis

Measurement location	Existing concentration	Model concentration	Result	RPD
Point 1	2.21	2.21	0.00	25%
Point 2	1.89	2.21	0.17	
Point 3	1.78	2.21	0.24	
Point 4	1.63	2.21	0.36	
Point 5	1.51	2.21	0.46	
Average		0.25		

Table 8. Relative percentage difference velocity analysis

Measurement location	Existing concentration	Model concentration	Result	RPD
Point 1	0.28	0.31	0.11	7%
Point 2	0.37	0.39	0.05	
Point 3	0.39	0.41	0.05	
Point 4	0.40	0.42	0.05	
Point 5	0.49	0.54	0.10	
Average			0.07	

Table 9. Relative percentage difference TSS analysis

Measurement location	Existing concentration	Model concentration	Result	RPD
Point 1	129.50	129.50	0.00	19%
Point 2	116.50	129.45	0.11	
Point 3	99.00	129.44	0.31	
Point 4	111.00	129.43	0.17	
Point 5	93.50	129.43	0.38	
Average		0.19		

Table 10. Relative percentage difference BOD analysis

Measurement location	Existing concentration	Model concentration	Result	RPD
Point 1	5.46	5.46	0.00	5%
Point 2	5.04	5.41	0.07	
Point 3	5.20	5.30	0.02	
Point 4	4.86	5.24	0.08	
Point 5	4.80	5.18	0.08	
Average		0.05		

Table 11. Relative percentage difference COD analysis

Measurement location	Existing concentration	Model concentration	Result	RPD
Point 1	22.55	22.25	0.00	5%
Point 2	22.24	22.20	0.00	
Point 3	26.11	21.45	0.18	
Point 4	21.98	21.06	0.04	
Point 5	21.47	20.65	0.04	
Average		0.05		

Water quality simulation

After calibrating and validating the model until the model is close to the existing condition, the results of the Garuda River water quality modeling that have been formed from the results of the QUAL2Kw program can be used to estimate water quality with the desired scenario. The process of estimating water quality according to the modeling scenario used is called the simulation process. The data from the model simulation will be used to determine the amount of pollutant load and the carrying capacity of the Garuda River pollutant load against certain parameters. In this study, the water quality parameters to be simulated are TSS, BOD, and COD parameters with BOD and COD parameter data for all simulations still meeting quality standards (because the values are still below class III quality standards). In this study, the simulation was carried out through 3 modeling scenarios by assuming water quality data and data on pollutant sources that enter the Garuda River water body.

Scenario 1

The simulation in scenario 1 was carried out using existing data from headwater data, water quality data, and pollutant source data obtained from field measurements and laboratory tests. This scenario was carried out to see how much the existing pollutant load affects the quality of river water in each segment. The simulation results in scenario 1 can be seen in Figure 4 and Table 12.

The simulation results in scenario 1 show quite varied results. The increase and decrease that occurred in the simulation results showed the process that occurred in the river, where the presence of pollutants entering it and the ability of self-purification greatly affected the quality of river water. In this modeling, the results of the scenario 1 simulation can be seen on the WQ Out sheet as presented in Table 12. Based on the simulations carried out, it was obtained that the water quality of the Garuda River in the existing condition for TSS parameters has passed the class III quality standard, while the BOD and COD parameters still meet the class III quality standard.

Scenario 2

The simulation in scenario 2 was carried out using water quality data following existing data obtained from field measurements and laboratory tests. As for the pollutant source data, it is assumed that it meets the wastewater quality standards following the rules set out in the Regulation of the Minister of Environment and Forestry number 5 of 2014 for the quality standards of industrial wastewater (point source), as well as following the rules stipulated in the Regulation of the Minister

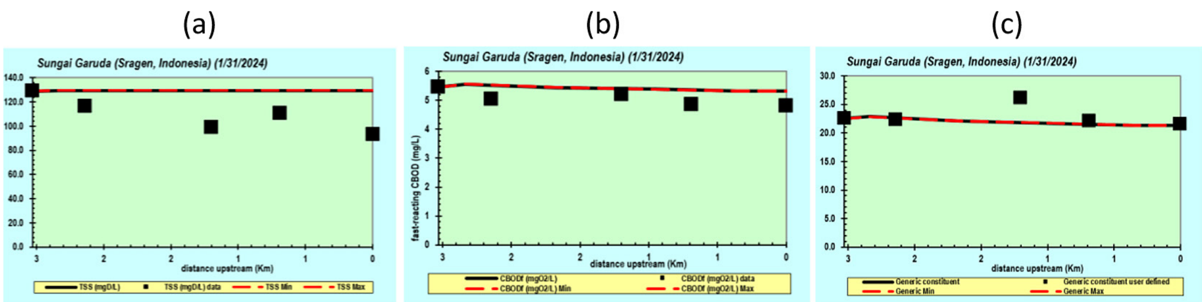

Figure 4. Scenario 1 simulation results**:** (a) TSS parameter simulation results; (b) BOD parameter simulation results; and (c) COD parameter simulation results **(**QUAL2Kw Modeling, 2024)

Table 12. Results of WQ out simulation data sheet scenario 1

Measurement location	TSS (mg/l)		BOD (mg/l)		COD (mg/l)	
	Models	QS	Models	QS	Models	QS
Point 1	129.50		5.46		22.50	
Point 2	129.54		5.56		22.89	
Point 3	129.53	100	5.45	6	22.11	40
Point 4	129.53		5.39		21.71	
Point 5	129.53		5.33		21.30	

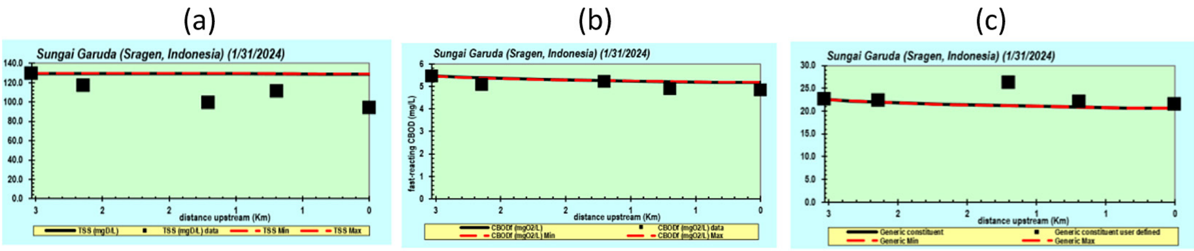

Figure 5. Scenario 2 simulation results**:** (a) TSS parameter simulation results; (b) BOD parameter simulation results; and (c) COD parameter simulation results **(**QUAL2Kw Modeling, 2024)

of Environment and Forestry number 68 of 2016 for domestic wastewater quality standards (non-point source). This scenario was carried out to see how much the influence of reducing the pollution burden on the water quality in the Garuda River was achieved. The simulation results in scenario 2 can be seen in Figure 5 and Table 13.

The simulation results in scenario 2 show results that are not too different from the results of scenario 1 simulation. Similar to the results of the scenario 1 simulation, the results of the scenario 2 simulation can be seen on the WQ Out sheet as presented in Table 13. Based on the simulations carried out, it was found that the water quality of the Garuda River with efforts to reduce the concentration of pollutants entering it was still not able to meet the TSS parameters following class III quality standards. This could happen because the Garuda River in its natural condition already contains a high concentration of TSS. One of the factors that causes high concentrations of TSS in natural conditions is the rainy season which can cause turbid water conditions that can inhibit the penetration of light into the waters (Marlina et al., 2017). This condition, of course, inhibits the photosynthesis process which can eventually lead to a lower availability of dissolved oxygen in the waters. Meanwhile, the BOD and COD parameters still meet class III quality standards, because in existing conditions they also meet class III quality standards.

Scenario 3

The simulation in scenario 3 was carried out using upstream water quality data (headwater) following existing data obtained from field measurements and laboratory tests. In this scenario, it is assumed that there are no sources of pollutants that come in with water quality data, each segment is assumed to meet the class III river water quality

Table 13. Results of WQ out simulation data sheet scenario 2

Measurement location	TSS (mg/l)		BOD (mg/l)		COD (mg/l)	
	Models	QS	Models	QS	Models	QS
Point 1	129.50		5.46		22.55	
Point 2	129.48		5.41		22.21	
Point 3	129.48	100	5.30	6	21.46	40
Point 4	129.47		5.24		21.07	
Point 5	129.47		5.18		20.66	

standards following Government Regulation of the Republic of Indonesia No. 22 of 2021. This scenario was carried out to see the self-purification ability of the Garuda River without any input of pollutant loads that enter the river, both industrial and domestic waste. However, in this scenario, there is still an assumption that there are natural sources of pollution that enter the river from tributary channels, drainage systems, groundwater, and rainwater. The simulation results in scenario 3 can be seen in Figure 6 and Table 14.

The simulation results in scenario 3 show results that are not too different from the simulation results of scenarios 1 and 2. Similar to the simulation results of scenario 1 and scenario 2, the simulation results of scenario 3 can be seen on the WQ out sheet as presented in Table 14. Although the water quality condition has been assumed to meet class III quality standards and there are no domestic waste pollutants and industrial waste entering the river, this simulation produces a concentration of TSS model parameters that still exceed the class III river water quality standards. This condition can be influenced by the existence of inflows that come from natural flows such as drainage channels, tributaries, and groundwater. Meanwhile, the BOD and COD parameters still meet class III quality standards.

Garuda River pollution load capacity

In this study, the calculation of the large pollutant load and PLCC was limited to segment B (between point 2 and point 3) of the Garuda River only. This is based on the high percentage increase in the pollution index value in this segment compared to other segments. This condition occurs because point 3 is a location with quite a lot of pollutant inputs, one of which is caused by the input of domestic waste and liquid waste from the tofu industry which is located between point 2 and point 3. So through this research, the results of pollutant load values and PLCC in segment B of the Garuda River will be obtained.

The calculation of the pollutant load carrying capacity for TSS, BOD, and COD parameters in the Garuda River is first carried out by calculating the pollution load on each of these parameters. The amount of the pollution load of the Garuda River can be calculated based on the results of modeling simulations with 3 scenarios that have been carried out previously that represent the existing, maximum, and minimum conditions of the river. Where the results of the simulation of scenario 1 represent the existing pollutant load following the results of field measurements and laboratory tests that have been carried out, the results of the simulation of scenario 2 represent the maximum conditions with the presence of incoming sources of pollutants but still meet the quality standards of wastewater, and the results of the simulation of scenario 3 represent the minimum condition of the river without the input of any pollutant sources other than tributaries, drainage channels, and

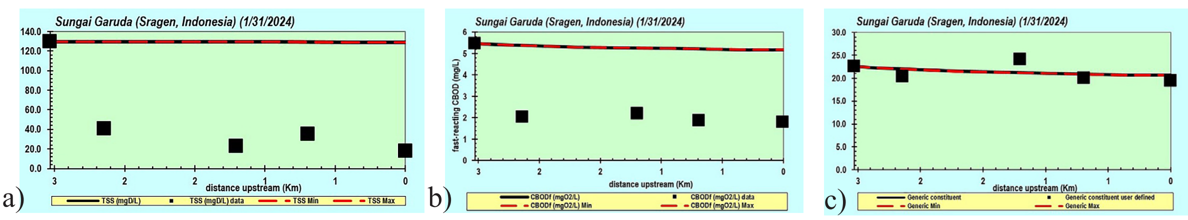

Figure 6. Scenario 3 simulation results (QUAL2Kw Modeling, 2024), (a) TSS parameter simulation results; (b) BOD parameter simulation results; and (c) COD parameter simulation results

Table 14. Results of WQ out simulation data sheet scenario 3

Measurement location	TSS (mg/l)		BOD (mg/l)		COD (mg/l)	
	Models	QS	Models	QS	Models	QS
Point 1	129.50	100	5.46	6	22.55	40
Point 2	129.50		5.41		22.21	
Point 3	129.50		5.30		21.46	
Point 4	129.50		5.24		21.07	
Point 5	129.50		5.18		20.66	

rainwater. The calculation of the pollutant load value was carried out by utilizing the results of the water quality scenario simulation contained in the source summary sheet. The pollutant load is calculated by multiplying the discharge value by the pollutant concentration in each scenario. The results of the concentration of pollutant sources for each scenario can be seen in the source summary sheet as presented in Table 15.

The pollutant concentrations produced in each scenario are then calculated to obtain the pollutant load of the model. In addition, in this section, the standard pollutant load will also be calculated, which is the maximum amount of pollutant load that can be tolerated in the waters so that the amount meets quality standards and does not cause water pollution. The calculation of the pollutant load is carried out following the calculation formula stipulated in Government Regulation Number 82 of 2001 concerning Water Quality Management and Water Pollution Control. Where the pollutant load is obtained by multiplying the waste discharge by the pollutant concentration and conversion factor of 86.4. The results of the calculation of the pollutant load for each scenario are presented in Table 16.

Based on the calculation of the pollutant load, it was found that the standard pollutant load for TSS parameters was 259.20 kg/day, BOD was 15.55 kg/day, and COD was 103.68 kg/day. Meanwhile, the results of the calculation of the model pollutant load for the TSS parameter in scenario 1 are 1,196.73 kg/day, scenario 2 is 25.93 kg/day, and scenario 3 is 0 kg/day, then for the BOD parameter in scenario 1 is 3,120.77 kg/day, scenario 2 is 2.59 kg/day, and scenario 3 is 0 kg/day, and for the last parameter, namely the COD parameter in scenario 1 is 14,196.38 kg/day, Scenario 2 is 51.84 kg/day, and scenario 3 is 0 kg/day. Based on these calculations, it was found that the pollutant load in scenario 1 had exceeded the standard pollutant load, while the pollutant load in scenarios 2 and 3 still met the standard pollutant load.

After obtaining the standard and model pollutant load, it can be calculated on the size of the Garuda River PLCC. PLCC is obtained by reducing the results of the calculation of the standard pollutant load and the model pollutant load. The results of the PLCC calculation for each scenario are presented in Table 17.

Based on the calculation of the Garuda River PLCC, it was found that under existing conditions (scenario 1) the PLCC value was below 0 kg/day or had a negative value. The negative value in the PLCC calculation shows that the Garuda River no longer can carry the pollution load for the TSS, BOD, and COD parameters because the incoming pollution load has exceeded the existing pollution load standards. Furthermore, it can be seen that efforts to reduce and eliminate pollutant sources

Table 15. Results of sheet source summary of Garuda River

Debit (m^3/s)	TSS (mg/l)			BOD (mg/l)			COD (mg/l)		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
0.03	461.7	10	0	1204	1	0	5477	20	0

Note: S1 (Scenario 1); S2 (Scenario 2); and S3 (Scenario 3).

Table 16. Results of sheet source summary of Garuda River

Pollutant load	TSS (mg/l)			BOD (mg/l)			COD (mg/l)		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
Model	1196.73	25.92	0	3120.77	2.59	0	14196.38	51.84	0
Standard	259.20			15.55			103.68		

Note: S1 (Scenario 1); S2 (Scenario 2); and S3 (Scenario 3).

Table 17. Results of the Garuda River PLCC calculation

TSS (mg/l)			BOD (mg/l)			COD (mg/l)		
S1	S2	S3	S1	S2	S3	S1	S2	S3
-937.53	233.28	259.20	-3.105.22	12.96	15.55	-14.092.70	51.84	103.68

Note: S1 (Scenario 1); S2 (Scenario 2); and S3 (Scenario 3).

that enter river water bodies through simulation of scenario 2 and scenario 3, obtained much better results and positive values (meeting PLCC). Based on the results of the calculation, it was found that the maximum PLCC of the Garuda River for TSS parameters was 259.20 kg/day, BOD was 15.55 kg/day, and COD was 103.68 kg/day. Meanwhile, the minimum PLCC of the Garuda River for TSS parameters is 233.28 kg/day, BOD is 12.96 kg/day, and COD is 51.84 kg/day.

Reducing the pollutant load of the Garuda River

The reduction of the pollution burden is the amount of pollutant burden that must be lowered so that the water quality condition of the Garuda River is better than the current condition and can still meet the class III water quality standards. The existing condition of the Garuda River, which has currently passed the class III water quality standard, indicates the need for efforts to reduce the burden of pollutants entering the Garuda River. This step is very necessary to be taken so that the water quality in the Garuda River can continue to be in good condition and meet quality standards. The calculation of the magnitude of the decrease in the concentration of pollutant load on the Garuda River can be done by comparing the amount of pollutant load in existing conditions with the pollutant load that is a priority.

In this study, the large pollutant load of the Garuda River in existing conditions uses the data generated from the simulation of scenario 1 modeling, while the priority pollutant load uses the results of the simulation of scenario 2 modeling. This is because, in scenario 1, the water quality data and pollutant source data used are based on existing data, field measurements, and laboratory tests so that they can describe the large pollutant load of the Garuda River in actual conditions. Meanwhile, the priority pollutant load uses the results of scenario 2 simulation because in this scenario the maximum pollutant load that can be tolerated in the waters is generated. After all, it represents the water quality of the Garuda River in an existing state with a pollutant source that still meets the quality standards. The amount of pollutant load reduction that must be done so that the Garuda River can meet the PLCC is TSS with a decrease of 1,170.81 kg/day, BOD with a decrease of 3,118.18 kg/day, and COD with a decrease of 14,144.54 kg/day.

CONCUSIONS

Based on the analysis of Garuda River's water quality, it does not meet Class III standards because several parameters exceed the established limits, including temperature, TSS, nitrite (NO_2^-), and total Coliform. The water quality standards used refer to Class III water quality standards from Government Regulation Number 22 of 2021 concerning the implementation of environmental protection and management. The pollution index calculation shows that Garuda River is lightly polluted, with a pollution score ranging from 1.49 to 2.91. The QUAL2Kw modeling conducted reveals that the minimum and maximum pollutant load capacities of Garuda River for TSS are 233.28–259.20 kg/day, for BOD are 12.96–15.55 kg/day, and for COD are 51.84–103.68 kg/day. The simulation results indicate that to control water pollution in Garuda River, one of the effective measures is to reduce the pollution load from each point source, particularly from tofu industry wastewater.

REFERENCES

1. Amalia, R.N., Devy S.D., Kurniawan A.S., Hasanah N., Salsabila E.D., Ratnawati D.A.A., Fadil F.M., Syarif N.A., Atarudin G.A. 2022. Liquid waste potential known as liquid organic fertilizer in RT 31 Lempake City of Samarinda. ABDIKU: Jurnal Pengabdian Masyarakat Universitas Mulawarman, 1(1), 36–41. https://doi.org/10.32522/abdiku.v1i1
2. Antunes, I.M.H.R., Albuquerque, M.T.D., Oliveira, S.F., Germán, S. 2018. Predictive scenarios for surface water quality simulation - a watershed case study. Catena, 170, 283–289. https://doi.org/10.1016/j.catena.20
3. Fajarudin, A.H., Solichin, M., Prayogo, T.B. 2018. Study on determining the pollution load carrying capacity of the Brantas River in the Malang City section using the QUAL2Kw program package. Jurnal Mahasiswa Teknik Pengairan, 1(2), 1–13.
4. Hidayati, D. 2016. The fading value of local wisdom in community water resource management. Jurnal Kependudukan Indonesia, 11(1), 39–48.
5. Hidayati, N.R., Trisnawati, A., Sudarni, D.H.A., Setiawan, M.A., Wahyuningsih, S. 2021. Waste Utilization Technology. Magetan: Media Grafika.
6. Ilfan, F., Gusri, L., Winny, C.R.M., Siregar, S. 2022. Analysis of the pollution load carrying capacity of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) in the Tembuku River, Jambi City, Using the QUAL2Kw Model. Jurnal Daur Lingkungan, 5(2), 68–74. https://dx.doi.org/10.33087/daurling.v5i2.145

7. Isma, M.F., Isma, F. 2019. Water quality suitability zones in the Langsa Estuary, Aceh Province. Prosiding Seminar Nasional Pertanian, 2(1), 105–115.
8. Kadarsih, P., Caesar, D.L. 2017. Total coliform in clean water at passenger terminal restaurants in Tanjung Emas Port, Semarang. Cendekia Utama: Jurnal Keperawatan dan Kesehatan Masyarakat, 2(5), 31–36. https://doi.org/10.31596/jcu.v2i5.161
9. Kamal, N.A., Muhammad, N.S., Abdullah, J. 2020. Scenario-based pollution discharge simulation and mapping using integrated QUAL2K-GIS. Environmental Pollution, 259, 1–10. https://doi.org/10.1016/j.envpol.2020.113909
10. Kudubun, R., Kisworo, Rahardjo, D. 2020. Effect of land use, riparian vegetation type, and pollution sources on the water quality of the Winongo River in Yogyakarta Special Region. Prosiding Seminar Nasional Biologi di Era Pandemi Covid-19, 6(1), 392–400. https://doi.org/10.24252/psb.v6i1.15902
11. Lestari, R.I., Ramadhani, R., Sherawali, S., Yudha, A.T.R.C. 2021. Water and the impact of its scarcity on the urban economy: A literature study of Java Island. OECONOMICUS: Journal of Economics, 6(1), 38–49. https://doi.org/10.15642/oje.2021.6.1.38-48
12. Mahyudin, Soemarno, Prayogo, T.B. 2015. Analysis of water quality and pollution control strategies for the Metro River in Kepanjen City, Malang Regency. Jurnal Pembangunan dan Alam Lestari, 6(2), 105–114.
13. Marlina, N., Hudori, Hafidh, R. 2017. Effect of channel roughness and river water temperature on COD and TSS water quality parameters in the Winongo River using QUAL2Kw software. Jurnal Sains dan Teknologi Lingkungan, 9(2), 122–133. https://doi.org/10.20885/jstl.vol9.iss2.art6
14. Novita, E., Pradana, H.A., Dwija, S.P. 2020. Study on the assessment of water quality in the Bedadung River, Jember Regency. Journal of Natural Resources and Environmental Management, 10(4), 699–714. http://dx.doi.org/10.29244/jpsl.10.4.699-714
15. Nurlinda, S., Kasim, M., Nur, A.I. 2019. Community structure of macrozoobenthos on artificial coral reefs in the waters of Tanjung Tiram Village, North Moramo District, South Konawe Regency. Jurnal Manajemen Sumber Daya Perairan, 4(2), 123–133.
16. Pagoray, H., Sulistyawati, Fitriyani. 2021. Wastewater from tofu production and its impact on water quality and aquatic biota. Jurnal Pertanian Terpadu, 9(1), 53–65. https://doi.org/10.36084/jpt.v9i1.312
17. Pangestu, W.P., Sadida, H., Vitasari, D. 2021. The Influence of BOD, COD, pH, and TSS levels in Tofu industry wastewater using natural adsorbent media and electrocoagulation methods. Media Ilmiah Teknik Lingkungan (MITL), 6(2), 1–7. https://doi.org/10.33084/mitl.v6i2.2376
18. Perkasa, O.W. 2014. Optimization of time and biomass growth of water fern (Azolla pinnata) for reducing nitrate, nitrite, and ammonia concentrations in Tofu industry wastewater. Undergraduate Thesis, Universitas Sebelas Maret, Program Studi Biologi, Surakarta, Indonesia.
19. Rachmawati, S., Faturahman, A.D., Restanti, A.D., Rizky, F.A., Sholiqin, M., Firmansyah, F., Fauzi, R.P. 2023. Analysis of the relationship between community behavior on physical-chemical conditions of waters in the waterways of Debegan Village. IOP Conference Series: Earth and Environmental Science, 1(1190), 012045. https://dx.doi.org/10.1088/1755-1315/1190/1/012045
20. Rahman, R.A.S., Fajriati, I. 2021. Determination of water quality in the waste discharge channel of Tofu production into the Pengging River, Boyolali. Analytical and Environmental Chemistry, 6(1), 1–11.
21. Rahmawati, S.D., Siwiendrayanti, A. 2023. Analysis of key water quality parameters of the Kaligarang River using the water pollution index method. Higeia Journal of Public Health Research and Development, 7(2), 186–196. https://doi.org/10.15294/higeia.v7i2.64299
22. Simbolon, M.Y., Saputro, S., Hariyadi. 2015. Distribution of suspended sediments based on tidal currents at the mouth of the Kuto River, Kendal Regency. Jurnal Oseanografi, 4(4), 731–740.
23. Sumantri, A., Rahmani, R.Z. 2020. Analysis of chromium (VI) pollution based on chemical oxygen demand (COD) levels in the upper Citarum River in Majalaya District, Bandung Regency, West Java Province. Jurnal Kesehatan Lingkungan Indonesia, 19(2), 144–151. https://doi.org/10.14710/jkli.19.2.144-151
24. Wahyuningsih, S., Novita, E., Ningtias, R. 2019. Deoxygenation rate and reaeration rate of the Bedadung River Segment in Rowotamtu Village, Rambipuji District, Jember Regency. Jurnal Ilmiah Rekayasa Pertanian dan Biosistem, 7(1), 1–7. https://doi.org/10.29303/jrpb.v7i1.97