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RESEARCH ARTICLE

IMPACT EVALUATION OF SOYBEAN SMALL AND MEDIUM-SIZED ENTERPRISES (SMEs) WASTEWATER ON THE WATER QUALITY OF THE BEDADUNG RIVER IN JEMBER DISTRICT, INDONESIA

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ABSTRACT

Small-scaled agroindustry or SMEs of soybean (*tofu-tempe* production) wastewater, discarded into bodies of water without processing, negatively impacts river water quality. Water quality modeling using software can identify the distribution and total pollution load capacity in rivers due to soybean agroindustry wastewater. QUAL2Kw and WASP software was applied in this study to compare the accuracy and output from the impact of such wastewater on river water quality and the total pollution load capacity of the Bedadung River based on class 1 and class 2 water quality allocation. Input water quality parameters were DO, BOD, TSS, and water discharge. The accuracy of the model was determined using the RSME method. The research results show that modeling water quality (BOD) with QUAL2Kw better reflects the distribution of material organic dissolved in the Bedadung River than WASP. It is supported by QUAL2Kw RSME values lower than WASP, at 0.128 and 0.20 respectively. The modeling results of the total pollution load capacity of BOD and TSS using QUAL2Kw based class 1 sequentially is (– 2,497.69) – 1,002.52 kg/ day and (– 39,383.30) – 2,216.69 kg/ day, while for class 2 sequentially is 503.07 – 4,003.13 kg/ day and 107,028.96 – 152,729.64 kg/ day. Furthermore, the total pollution load capacity of BOD and TSS pollution using WASP-based class 1 sequentially is 654.02 – 846.67 kg/day and (-2,658.42) – (-988.79) kg/ day, and for class 2 overall sequentially 3,764.48 – 3,986.32 kg/day and 143,747.08 – 152,057.21 kg/ day. Modeling of the impact of small-scaled agroindustry or SMEs pollution on water quality and the conditions of Bedadung River aquatics is more accurate using QUAL2Kw. Contamination control and total pollution load capacity determination should take into consideration the class of water quality allocation.

KEYWORDS

Agroindustry impact, tofu-tempe, water quality modeling, Jember, SMEs

1. INTRODUCTION

The agroindustry is one of the important sectors that supports the positive development of the economy in Indonesia. It includes the downstream industry of inputs from the agriculture sector, production equipment and agricultural machinery, and farming industry service sector (Ali et al., 2023). Small-scaled agroindustry or SMEs areas in the Jember Regency are developing quickly, especially those located in the Kaliwates district. Kaliwates subdistricts include the Regional Activity Center (RAC) area, with urban areas designated as centers for trade and services according to Jember Regency Regional Regulation Number 1, 2015. According to the Department of Trade and Industry and the Department of Cooperatives and Micro Enterprises Jember Regency, the mall-scaled agroindustry or SMEs recorded in the Kaliwates district in 2019 amounted to 80 units, which experienced an increase to 95 units in 2021. Agroindustry development in the Kaliwates district increased by 15.8% in 2019-2021. However, such development also has an impact negative on the environment, especially on the banks of the Bedadung River. Solid waste and wastewater resulting from the production process including washed and submersion soybeans can decrease the water quality of the Bedadung River if streamed directly into the river without tretament. The manifestation of water resources affects the continuity and existence of surface water resources both in terms of quality and quantity (Rahayu et al., 2019; Wang et al., 2023).

Bedadung River is one of the large river areas in Jember Regency which is utilized as raw water resources by Perumdam Tirta Pandalungan as municipal waterworks of Jember Regency. The locations of the these water intake is located in the Patrang and Kaliwates districts (Novita et al., 2020). Raw water resources, Bedadung River must fulfill standard quality class 1, in accordance with Government Regulation Number 22 of 2021 concerning Maintenance, Protection, and Management of the Environment. However, based on the monitoring results of Bedadung River water quality status in conditions lightly polluted on the Patrang – Kaliwates segment based on the indexation method using Pollution Index in 2019, it is predicted that water quality will decrease until 2026 (Novita et al., 2020: Pradana et al., 2022). A study shows that the quality of the Bedadung River water used as Perumdam Tirta Pandalungan intake located in Tegal Besar Village, Kaliwates district, based on several parameters including BOD, COD, TSS, phosphate, and fecal coliform classified in class 3 and is not suitable to be utilized as a raw water resource (Pradana et al., 2020).The study Bedadung River water quality with source polluter waste calculated using domestic use QUAL2Kw modeling shows the Bedadung River does not fulfill standard river water quality class 1, as the total pollution load capacity in the BOD parameter is -2.43 kg/ day (Novita et al., 2022). It showed that water quality in the

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Kaliwates Bedadung River segment has decreased, indicating pollution. One of the pollution factors in the river originates from the entry of waste production from the agroindustry located on the banks of the river.

Naturally, rivers can purify incoming pollutants or self-purification phenomena. However, it depends on the deoxygenation and reaeration processes, which are influenced by the conditions and hydrology of rivers and incoming loads (Higashino and Stefan, 2017; Long, 2020). The ability of rivers to repair themselves will be slow in certain conditions, such as the input of element pollutants in large amounts (Mendivel-Garcia et al., 2022). The amount of pollutant elements that enter the river must be by the river's capacity so that the river's self-purification performance goes well. Several tools can be used to investigate self-purification and capacity assimilation to control pollution in rivers, namely QUAL2Kw and the Water Quality Analysis Simulation Program (WASP). Simulation can be used to identify total pollution load capacity based on existing water quality allocation criteria (Keller et al., 2023: Fernandez and Camacho, 2023: Patel and Jariwala, 2023). However, both tools have advantages and disadvantages, such as the location model testing environment and the types of data input (Ejigu, 2021: Keller et al., 2023). So far, river water quality modeling has been exploratory and has not yet formulated tools that are relatively suitable for tropical regions and specific pollution sources. The purpose of this study to compare the accuracy and output from the impact of agroindustry soybean wastewater on river water quality and the total pollution load capacity of the Bedadung River based on class 1 and class 2 water quality allocation, concerning Government of the Republic of Indonesia Regulation number 22 of 2021. It is hoped that the research results will become reference tools or software that will provide more realistic modeling of the phenomenon of pollution in tropical rivers for policies to control pollution for SMEs and protecting natural resources and the environment. So far, pollution control for SMEs in Indonesia is limited so effective and efficient decision-making is needed for this matter.

2. Materials and Methods

2.1 Study Area and Data Input

Small-scaled agroindustry or SMEs wastewater sampling in the Bedadung River was conducted in August – October 2022. The study location was the Bedadung watershed, which crosses Kaliwates Jember Regency Subdistrict with distances 5.49 km from upstream - downstream. The determination of the monitoring point was based on the existence of agroindustry locations on the banks of the river and beyond, which were determined as the main source of polluters in the development of the water quality model. The land used in this segment is dominated by settlements, followed by paddy fields, bushes, shrubs, and fields (Pradana et al., 2020). The segment condition is classified as polluted water quality based on the pollution index method and the total pollution load capacity deceased causes pollution load from agriculture and domestic based on simulation use system dynamic (Novita et al., 2020; Pradana et al., 2022). An overview of the sampling location or study area is presented in Figure 1.

The input research data were water discharge, total suspended solids (TSS), dissolved oxygen (DO), and biochemical oxygen demand (BOD). Furthermore, supporting data were employed, for example, pollution source, air temperature, and wind speed in the Jember Regency in 2022. Climatological data were obtained from the official website of the Climatology and Geophysics Agency Republic of Indonesia (BMKG). A location point (sampling location) was used to measure the river profile and river discharge data. In addition, water samples were taken at six points to monitor the river, and wastewater sampling is conducted at the soybean SMEs wastewater outlet. The model segmentation of the Bedadung River is presented in Table 1. Retrieval of samples of wastewater and river water used the grab sampling method to determine real-time conditions (Piniewski et al., 2019; Tadic et al., 2022). DO measurements were made directly in the field using a DO meter, and then water discharge measurements were made by measuring water velocity using current meters based on SNI 8066-2015 and (Lu et al., 2022). Water quality analysis on TSS parameters using method gravimetry based on SNI 06-6989.3-2004. BOD parameter measurements were made using the iodometry method or volumetric Winkler (azide modification), by SNI 06-6989.14. River water quality and wastewater samples were taken three times to identify data patterns and quality. Analysis of the water quality parameters was conducted at the Water Quality - Environmental Control and Conservation Engineering Laboratory, Faculty of Agricultural Engineering, Faculty of Agricultural Technology, University of Jember.

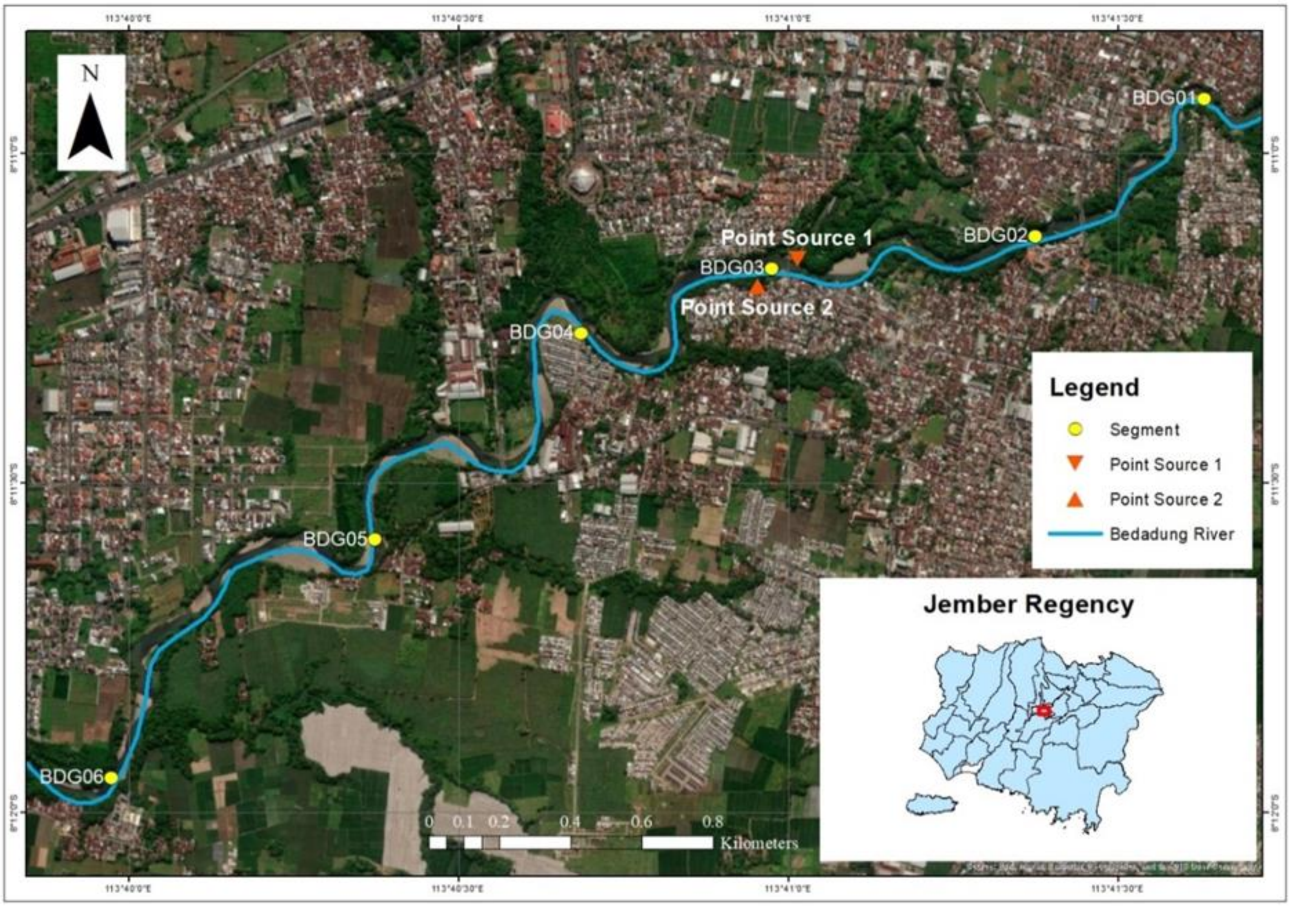


Figure 1: Map of the Bedadung River segment of Kaliwates District, water sampling or monitoring points, and pollution source points. Source: https://www.arcgis. com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9

Table 1: Segmentation of the Bedadung River section of Kaliwates District				
Segment	**Distance from downstream (m) – QUAL2Kw**	**Distance from upstream (m) - WASP**	**Elevation**	
			Upstream (m)	**Downstream (m)**
BDG01	791 – 0	5490 – 4775	62	63
BDG02	791– 2010	4775 – 3985	63	59
BDG03	2010 – 3251	3985 – 3251	59	58
BDG04	3251 – 3985	3251 - 2010	58	55
BDG05	3985 – 4775	2010 – 791	55	52
BDG06	4775 – 5490	791 – 0	52	51

2.2 Model Formulation: QUA2Kw and WASP

The water quality modeling employed the numerical model QUAL2Kw (developed by EPA: The US Environmental Protection Agency) and WASP 8.32 (developed by USEPA: the United States Environmental Protection Agency), which is open source. The data prepared to be entered into QUAL2Kw and WASP were the hydraulic data relating to the Bedadung River in the form of river profile and discharge; Bedadung River water quality and pollutants sources; and supporting data in the form of climatological data (air temperature and wind speed) from Jember Regency in 2022 obtained via the BMKG Indonesia website. The stages of modeling water quality involved two tools (QUAL2Kw and WASP software): river segmentation and boundering, data processing, data input, and model calibration and validation. The parameters entered into the model were hydraulic data for each segment; load pollution (load); river discharge (flows); and concentration of water quality parameters based on reaches for QUAL2Kw and boundaries for WASP. An overview of the segmentation in modeling water quality is presented in Figure 2. The river water quality model was formed based on several simulations, as shown in Table 2. River conditions represent river profile with existing circumstances or river circumstances in actual conditions. The existing pollutant sources are the water quality parameter values of the pollutant sources according to the actual measurement results. The model scenarios were input as standard quality classes 1 and 2, which refer to the Regulations of the Government of the Republic of Indonesia number 22 of 2021. A comparison with the standard surface water quality was used as a normative reference in controlling pollution and protecting the environment (Patel and Jariwala, 2024).

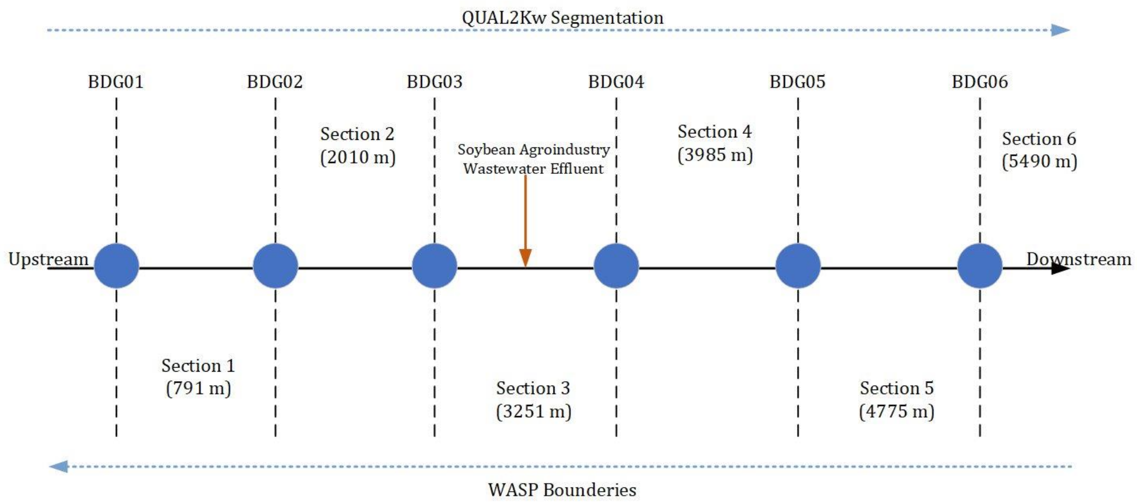


Figure 2: Segmentation model of QUAL2Kw and WASP

Table 2: Scenarios in the water quality modeling (QUAL2Kw & WASP)			
Scenario	River conditions	Water quality conditions	Pollution sources
1	Existing	Model	Existing
2	Existing	Model	Wastewater quality standards
3	Existing	Water quality standard 1	Wastewater quality standards
4	Existing	Water quality standard 2	Wastewater quality standards

2.3 Accuracy Comparison Model

Identification of the accuracy of water quality modeling was approached using the calibration and validation method to obtain accurate model results describing the actual conditions. The calibration method was implemented by trial and error input of data, such as climatology data, hydraulic profiles, speed of deoxygenation, and reoxygenation so that the model values are normal when simulated (Sharma et al., 2017; Bowen and Harrigan, 2018). Subsequently, calibration is performed with the Root Mean Square Error (RMSE) method due to its alternative approach to evaluating forecasting techniques and measuring the level of accuracy of the results in the estimation of a model (Hodson, 2022). The RMSE equation used is shown in equation (1).

$$RMSE = \sqrt{\sum \frac{(Y' - Y)^2}{n}} \quad (1)$$

where Y' = predicted values; Y = actual value; and n = the numbers of data

2.4 Analysis of Total Pollution Load Capacity (TPLC)

The ability of rivers to absorb pollution loads is limited and is known as the total pollution load capacity (TPLC). In general, the total pollution load capacity based on the pollution load minimum value (river concentration to water quality allocation) minus pollution load (Pradana et al., 2022). Measuring the total pollution load capacity of the river is done after the model data results have been assessed for accuracy. Measurement of the pollution load and total pollution load capacity of the river can performed using equations (2) and (3). In addition, TPLC I was obtained with subtraction results of the pollution load in scenario 3 minus scenario 1, and TPLC II was obtained with subtraction results of the pollution load in scenario 4 minus scenario 1.

$$PL = Q \times C (2)$$

$$TPLC = PL_{min} - PL_{act} (3)$$

where PL = pollution load (kg/day); Q = streamflow (m^3/s); C =

concentration of water quality parameters (mg/L); TPLC = total pollution load capacity (mg/L); PLmin = minimum pollution load refer to water quality designation (kg/day); and PLact = actual pollution load (kg/day)

3. Results and Discussion

3.1 Water Quality Model Test

Model accuracy was assessed based on the results of good model calibration and validation using QUAL2Kw and WASP. The RSME values of those model, Bedadung River water quality models obtained from the BOD and TSS parameters are presented in Tables 3 and 4. These RSME values were obtained from the results of simulation 1, which refers to the condition of existing Bedadung River water quality and wastewater of soybean SMEs as the pollution source. The test model has already been applied in several previous cases of surface water quality modeling and is considered capable of supporting the data simulation pattern results (Crus-Retana et al., 2023; Almdani and Kheimi, 2023; Uddin et al., 2023). Both models have varying validation values and the QUAL2Kw model tends to be more accurate than the results of water quality modeling using WASP. The modeling results of Bedadung River water quality using QUAL2Kw have an RSME value of less than 0.15. Therefore, the QUAL2Kw model is considered to represent the actual conditions of Bedadung River water quality more closely. The model features make it possible to arrange deoxygenation and reaeration values in customize or they can be customized according to the conditions. The rate of deoxygenation (rD) and that of reaeration (rR) are important factors in the accuracy of estimated river water quality parameter values. The values can be customized set on the QUAL2Kw model and consider the actual condition rate deoxygenation and reoxygenation of the Bedadung River which crosses urban areas in Jember Regency with a sequential range of value that is, 0.028 mg/ day.L and 0.053 mg/ day.L (Pradana et al., 2019). The results of this research are still in line with the Decree of the Minister of the Environment of the Republic of Indonesia Number 110 of 2003 as a local regulation concerning Guidelines for the Determination of Water Pollution Load Carrying Capacity in Water Resources. In this regulation, determining the carrying capacity of river pollution loads can use the QUAL2Kw model.

Table 3: Model test results of water quality modeling (QUAL2Kw)

Segment	Actual BOD (mg/L)	BOD model (mg/L)	Actual TSS (mg/L)	TSS model (mg/L)	Actual BOD – model BOD (mg/L)	Actual TSS – model TSS (mg/L)
BDG01	0.740	0.740	39.110	39.110	0.000	0.000
BDG02	0.990	0.740	50.000	49.980	0.062	0.000
BDG03	0.980	0.980	35,560	35.330	0,000	0.050
BDG04	2.000	1.810	50.890	51.470	0.033	0.335
BDG05	1.320	1.380	44.000	44.430	0.003	0.187
BDG06	1.130	1.110	55.110	54.610	0,000	0.254
Total					0.128	0.83
Number of datasets					6	6
RSME					0.13	0.37

Table 4: Model test results of water quality modeling (WASP)

Segments	Actual BOD (mg/L)	BOD model (mg/L)	Actual TSS (mg/L)	TSS model (mg/L)	Actual BOD – model BOD (mg/L)	Actual TSS – model TSS (mg/L)
BDG01	0.863	0.850	42.000	42.002	0,000	0,000
BDG02	0.983	1,060	43.111	42.670	0.006	0.194
BDG03	1,486	1,180	44.000	43.795	0.092	0.042
BDG04	1.659	1.270	44.330	44.097	0.150	0.054
BDG05	1.224	1.220	44.670	44.255	0.000	0.173
BDG06	1.126	1.160	44.670	44.328	0.001	0.117
Total					0.25	0.58
The number of datasets					6	6
RSME					0.20	0.31

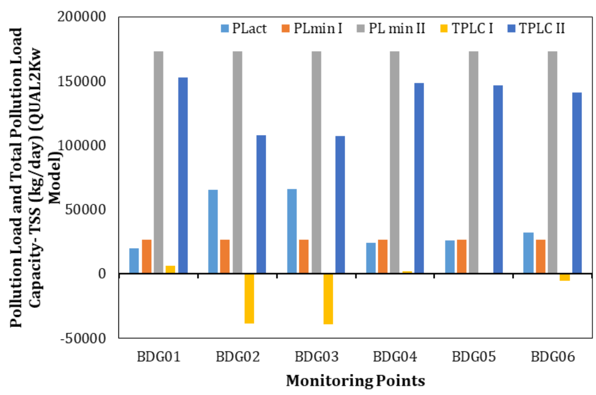
3.2 Simulation of Pollution Loads and Total Pollution Load Capacity Using QUAL2Kw and WASP

The simulation results of pollution load show that soybean SMEs wastewater influences fluctuations in the pollution load of the Bedadung River. Wastewater dynamics impact soybean SMEs in tofu and *tempe* production to change of Pollution Load actual (PLact) in the Bedadung River; Pollution Load minimum based on quality class 1 (Plmin I); Pollution Load minimum based on class quality 2 (Plmin II); Pollution Load Capacity based on class quality 1 (TPLC I); and Pollution Load Capacity based on class quality 2 (TPLC II) using QUAL2Kw and WASP models, respectively presented in Figures 3 and 4.

Figure 3 shows the results of the calculation of the total pollution load capacity of the Bedadung River in existing or actual conditions based on TSS parameters unable to accept the load of pollution entering again from the pollution source If refers to standard class 1 water quality using QUAL2Kw or WASP models. This matter can be seen from the large negative or deficit pollution load capacity in Figure 3. (a) starting at points BDG02, BDG03, and BDG06. Furthermore, as shown in Figure 3(b), the results of the TPCL modeling are valuable negative or deficit from the simulation using WASP. TPLC I – TSS values is sequentially, (-39,388.30) – 6,305.28 kg/day (QUAL2Kw model) and (-2,658.42) – (-988.79) kg/day (WASP model). Physically negative pollution load capacity values indicate the amount of dissolved solids in the water. The high concentration of pollutants entering the river means that the Bedadung River is no longer able to degrade naturally. Characteristics of the waste in the liquid resulting from the processing of soya beans include solid suspended organic materials (skin, mucous membranes and organic materials), which enhance TSS values in a water body (Hardyanti et al., 2023: Hartini et al., 2024). It is also suspected to be influenced by the type of Bedadung watershed land. The type of soil in the Bedadung watershed that is easily eroded and soybean processing wastewater contribute to increasing the TSS pollution load value in the Bedadung River. The phenomenon of forest land conversion in the upper reaches of the Bedadung watershed also influences the increase in sedimentation values in its main rivers (Basuki et al., 2023). It is supported by the study who showed that sedimentation values correlated positively to TSS values in the Usumacinta River and will impact pollution load levels (Rodriguez-Martinez et al., 2021).

The TPLC I and TPLC II simulation results based on TSS values result in different values. As shown in Figure 4, the results of the TPLC II – TSS simulation using the QUAL2Kw and WASP models show a positive value. TPLC II values using the QUAL2Kw and WASP models sequentially are 107,028.96 – 152,720.64 kg/day and 143,747.08 – 152,057.21 kg/day. Therefore, the Bedadung River in the Kaliwates segment is utilized as raw water resources by the Perumdam Tirta Pandalungan Jember Regency, then the water quality requirements must be in class 1. Calculation of the results from the total pollution load capacity of the Bedadung River segment in Kaliwates shows a negative value for the TSS parameter, meaning that the Bedadung River is not suitable for fulfilling the condition for use as raw water resources by Perumdam Tirta Pandalungan Regency. One of the steps that can be taken to improve the water quality of the Bedadung River as a source of raw water to optimize the reduction of TSS parameters and organic matter is to use coagulation-flocculation and photo-Fenton treatment in the river water that will be utilized. It is in line with researchers who describe methods widely used in water treatment in processing soybeans to remove pollutant waste in the form of suspended solids or colloids (Hardyanti et al., 2024). Fluctuations and changes in Bedadung River water quality also occur in the dissolved organic matter parameters indicated by BOD.

(a)



(b)

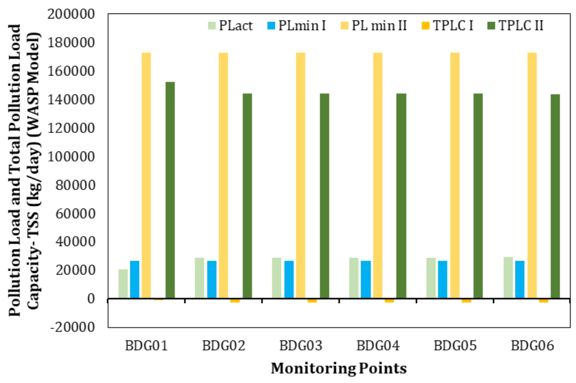
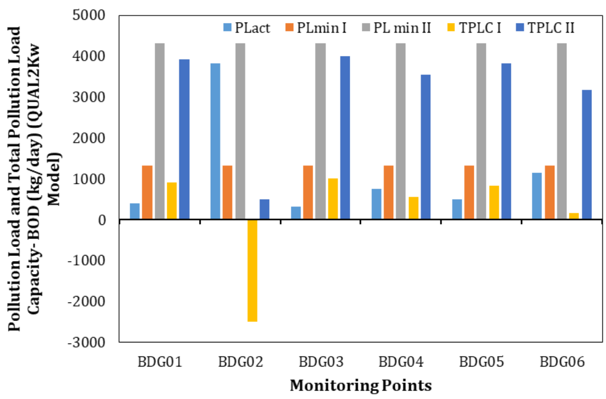


Figure 3: Pollution Load (PL) and Total Pollution Load (TPLC) Simulation – TSS Parameters using (a) the QUAL2Kw Model, (b) the WASP Model

According to the results of total pollution load capacity using the QUAL2Kw and WASP models shown in Figures 4 (a) and (b), it can be seen that TPLC I, BOD parameters have a negative value for observation point BDG02 observations using the QUAL2Kw model. The TPLC I value based on the BOD parameter using the WASP model for all observation segments is positive. The TPLC I BOD values using the QUAL2Kw and WASP models sequentially, i.e. (-2,497.69) – 913.73 kg/day and 654.02 – 846.65 kg/day. There is a value deficit in the BDG02 observation caused by existing input source polluters from the activity of processing soy and the necessary time degradation of the organic material. In addition, the QUAL2Kw model feature makes it possible to customize rate deoxygenation and reaeration in real conditions. It affects the actual and model BOD values. Furthermore, the TPLC II BOD value is positive in all observation segments. TPLC II values using the QUAL2Kw and WASP models sequentially is 503.07 – 4,003.13 kg/day and 3,771.02 – 3,986.32 kg/day. Therefore, based on the BOD parameters, Bedadung River water in segment BDG02 is not suitable for use as raw water resources by the Perumdam Tirta Pandalungan of Jember Regency.

(a)



(b)

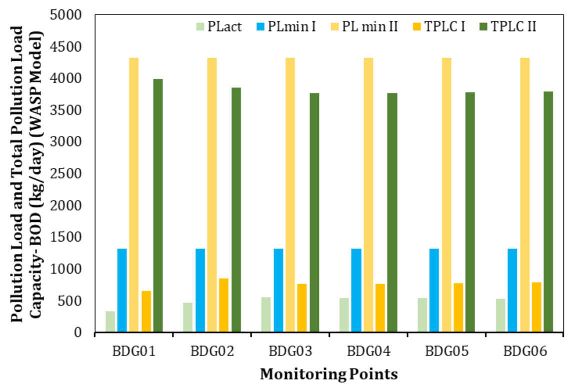


Figure 4: Pollution Load (PL) and Total Pollution Load (TPLC) Simulation – BOD Parameter using (a) the QUAL2Kw Model, (b) the WASP Model

Referring to the trends of the TPLC I and II BOD values using QUAL2Kw and WASP, these tend to be positive for the downstream segment. It shows that the river's self-purification process is going well. That of study improvement in the overall pollution load capacity of a river is caused by its ability to conduct the purification process naturally, supported by sufficient time contact and a long distance, helping downstream river pollution to decline (Darji et al., 2022). The results of TPLC I modeling using QUAL2Kw and WASP need to consider the treatment first of soybean SMEs wastewater before it flows into the Bedadung River.

Possible recommendations for reducing the risk of river pollution from the agroindustry sector are not to discharge waste production directly into a river and process the waste in a wastewater treatment plant (WWTP). Based on the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.11/MENLHK/SETJEN/KUM.1/1/2017, the const ruction of small-scale business WWTPs is carried out through the provision of wastewater treatment units produced from small-scale business activities which can be carried out by the government Regency/City. The recommended WWTP to be built for soybean processing industries such as tofu is the WWTP digester or biogas

4. Conclusion

Comparison modeling using QUAL2Kw and WASP has been used as an election method for modeling the water quality of tropical rivers such as those in Indonesia. The research results show that modeling water quality (BOD) with QUAL2Kw better reflects the distribution of organic material dissolved in the Bedadung River than WASP. It is supported by the fact that the modeling of RSME values using QUAL2Kw is lower than WASP, at 0.128 and 0.20 respectively. This result aligns with the Decree of the Minister of Environment of the Republic of Indonesia Number 110 of 2003 related to local regulations concerning determining the total pollution load capacity can use the QUAL2Kw model. Based on its utilization of raw water resources, Bedadung River water quality meets the BOD parameters for standard water quality in class 1, but the TSS and BOD parameters is not fulfilled. The modeling results show total pollution load capacity of BOD and TSS pollution using QUAL2Kw based class 1 sequentially, namely (–

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2,497.69) – 1,002.52 kg/ day and (– 39,383.30) – 2,216.69 kg/ day, and for class 2 503.07 – 4,003.13 kg/ day and 107,028.96 – 152,729.64 kg/ day. In addition, modeling of the total pollution load capacity of BOD and TSS pollution using class 1-based WASP show 654.02 – 846.67 kg/day and (-2,658.42) – (-988.79) kg/ day and for class 2 3,764.48 – 3,986.32 kg/day and 143,747.08 – 152,057.21 kg/ day. Modeling of the impact of small-scaled agroindustry or SMEs pollution on water quality and conditions of the Bedadung River aquatics is more accurate using QUAL2Kw. Contamination control and total pollution load capacity determination should take into consideration the class of water quality allocation.

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Conflicts of Interest

All authors declare that they have no conflict of interest.

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