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Original Research

Assessment of the Impact of POME on Water Quality of The Oko-Oko River, Indonesia

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ABSTRACT

Palm oil mill effluent (POME) is one of the primary sources of water pollution in tropical watersheds, especially in areas where waste treatment is not yet optimal. This study aims to evaluate the impact of reducing POME pollutant loads on water quality in the Oko-Oko River in Kolaka District, using parameters such as Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD). The method employed uses the QUAL2Kw water quality model, which has been calibrated and validated. Three pollution load reduction scenarios—baseline/no reduction (Sim1), 30% POME load reduction (Sim2), and 70% POME load reduction (Sim3)—were analyzed to assess changes in DO concentration, BOD, and COD at four monitoring stations. The accuracy of calibration and validation is tested based on the calculation of Root Mean Square Error (RMSE) and Nash-Sutcliffe Efficiency (NSE) coefficient functions. Model validation demonstrated excellent agreement between simulation results and observational data, with NSE values of 0.832 (RMSE = 0.584) for BOD, 0.962 (RMSE = 0.655) for DO, and 0.816 (RMSE = 2.548) for COD. Simulation results indicate that a 70% reduction in POME load could increase DO concentration in the downstream section from 6.09 to 6.16 $mg.L^{-1}$, while BOD and COD would decrease by 7.2% and 5.4%, respectively. These results support the effectiveness of the integrated anaerobic-aerobic filtration system in reducing pollutant loads and ensuring water quality meets Class II national water quality standards.

INTRODUCTION

The palm oil industry, which in 2019 contributed ± 32–35% of the total global vegetable oil production, is an important pillar for food security and the global bio-commodity supply chain. Indonesia leads this market, but the surge in plantation expansion has raised a series of ecological issues, ranging from deforestation and biodiversity loss to increased greenhouse gas emissions (Abogunrin-Olafisoye et al. 2024). One of the most significant environmental pressures from the palm oil industry is palm oil mill effluent (POME), which is produced at a rate of 2.5–3.5 tons for every ton of crude palm oil (CPO) processed. All human activities, particularly the palm oil industry, generate waste that contributes to the decline in river water quality (Zulfikar Efendy et al. 2022). Raw POME is known to have a BOD of ± 25,000 mg L^{-1}, COD of ± 50,000 mg L^{-1}, TSS of ± 40,500 mg L^{-1}, and oil and grease of up to 18,000 mg L^{-1} (Balan et al. 2021). POME poses significant environmental challenges because of its high organic load, which can lead to a decrease in DO levels in water bodies. Inadequate management of POME in tropical producer countries has a direct impact on riverine aquatic ecosystems (Syamriati, 2021).

Oil palm plantations in Southeast Sulawesi have multiplied to approximately 59,000 ha, making them the third-largest oil palm plantation on the island of Sulawesi. The expansion of oil palm plantations in Southeast Sulawesi is expected to increase the volume of POME that must be managed sustainably (Central Statistics Agency, 2024). The Oko-oko River, located in Kolaka Regency, spans approximately 105 km in length and has an average width of around 13 m. It flows through the plantation area, serving as the primary source of drinking water and irrigation for the Tanggetada District. The Oko-oko River faces significant challenges in water quality management due to the discharge of palm oil mill effluent (POME) from nearby palm oil mills. However, in the last decade there have been indications of a decline in the water quality of the Oko-oko River, as shown in the 2024 Regional Environmental Management Performance Information (IKPLHD) of Kolaka Regency, which indicates that the Oko-oko River is slightly polluted, and monitoring results downstream show high BOD and COD values, exceeding the standards. This situation is further exacerbated by the absence of strict regulations regarding the disposal of palm oil mill effluent and weak enforcement of existing regulations.

Previous research has been conducted by Hermawan et al. (2024), who modeled the impact of POME on river water quality in Kalimantan (Indonesia) using QUAL2Kw to evaluate POME pollution. However, the results varied due to hydrological heterogeneity and the characteristics of the waste. Furthermore, the Cigentis River in Karawang Regency (Indonesia) was modeled using QUAL2Kw to determine the distribution of BOD and COD parameters (Yanto et al. 2025). Research has not been explicitly conducted to calibrate and validate QUAL2Kw to map the dynamics of BOD, COD, and DO due to POME discharge in the Oko-oko River. This knowledge gap hinders evidence-based policy formulation, particularly within the framework of Technical Agreements, as mandated by the Ministry of Environment and Forestry Regulation of the Republic of Indonesia No. 5 of 2021 (Permen LHK No. 5/2021) regarding wastewater quality standards. Therefore, this study aims to evaluate the impact of POME load reduction on the water quality parameters of the Oko-oko River (BOD, COD, and DO) using the QUAL2Kw model. The initial hypothesis is that the greater the reduction in POME load, the more the river water quality will improve longitudinally

2. MATERIALS AND METHODS

Location and Field Data

This study uses a quantitative-explanatory method with a field-measurement-supported modeling approach, which is a verification research method combining field measurements and calibrated modeling (Sari et al. 2022). The study was conducted in the Oko-oko River, which is located within the administrative area of Pomalaa Sub-district, Kolaka Regency, Southeast Sulawesi, Indonesia (Figure 1).

Fig. 1: Map of sampling locations in Oko-oko River. Scale 1:6,000; source: own study

The river was divided into four segments to determine representative sampling points for the conditions and water quality of the Oko-oko River. The segmentation was based on input from the PT. X wastewater treatment plant outlet and changes in river dimensions. Water sampling was conducted in March, which is the middle of the transition from the rainy season to the dry season, with moderate discharge and pollutant loads, which historically approximates the average annual water quality conditions in rivers in Kolaka (based on 5-year hydrological data). The sampling location descriptions are summarized in Table 1. Surface water sampling at each station used the grab sampling method to measure BOD and COD at specific times, three times from a depth of 0.6 m between 9:00 h and 11:00 h. Samples were preserved at a temperature ≤ 4°C under SNI 6989.57:2008 guidelines on surface water sampling methods. River discharge (Q) was calculated using velocity-area integration from three transects per station. Manning's n was recalculated using the hydraulic radii and slopes from RTK-GNSS elevations.

Table 1: Sampling locations

Sampling Point	Location	Koordinat	Distance from Downstream (Km)
ST-1	Upper River	S = 4°16’51.5208” E = 121°36’59.4792”	2.245
ST-2	Outfall	S = 4° 17’0.111” E = 121° 36’42.859”	1.126
ST-3	Middle of the River	S = 4° 17’10.5108” E = 121° 36’34.6968”	0.555

Sampling Point	Location	Koordinat	Distance from Downstream (Km)
ST-4	Downstream of the River	S = 4° 17’22.47” E = 121° 36’42.93”	0

Source: own study

Modelling with QUAL2Kw

QUAL2Kw is a mathematical model capable of simulating water quality parameters, including BOD, COD, and DO. Primary and secondary data collected from the Oko-oko River were then used to input data into the Software QUAL2Kw version 5.1 worksheet (Table 2). The program was run after the data was entered into the QUAL2Kw program. The QUAL2Kw program automatically generated the output and input files. Tabular output can be viewed in the WQ output worksheet, and graphical output can be viewed in the spatial chart worksheet.

Table 2. Types of data required

Data Type	Parameter	Data Source
River water quality	BOD, COD, and DO	Laboratory analysis results
Hydraulic profile of the river	Length, flow velocity, depth, slope, river width, and river discharge	Measurement with a Current meter
River elevation and geographical position	River elevation and Coordinates	Measurement with a Garmin GPS device
Date meteorologists	Air temperature, dew point, wind speed, cloud cover, cover of other objects, and solar irradiation	BMKG Kolaka and www.accuweather.com
Factory effluent data	Palm oil mill wastewater quality analysis results	Laboratory analysis results

Model calibration is the first step in using the QUAL2Kw program and involves calibrating the data. This was carried out using field data in relation to discharge, depth, and the concentrations of BOD, COD, and DO. After the calibration process, a test was performed to validate the parameters used in the model. Validation was performed by calculating indicators using the RMSE and NSE equations, which are expressed as follows:

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Pi - Oi)\hat{}\,2} \qquad \ldots(1)$$

Description:

P_i : Simulated value at time t

O_i : Observed or actual value at time t

n : Number of observations (t = 1,2,….,n)

The NSE equation is as follows (Moriasi et al. 2007):

$$\text{NSE} = 1 - [\,\textstyle\sum(i{=}1 \text{ to } n)\,(Y\_obs\_i - Y\_sim\_i)\hat{}2\,] / [\,\sum(i{=}1 \text{ to } n)\,(Y\_obs\_i - Y\_mean)\hat{}2\,] \qquad \ldots(2)$$

where Yi^{obs} is the ith observation for the constituent being evaluated, Yi^{sim} is the ith simulated value for the constituent being evaluated, Y^{mean} is the mean of the observed data for the constituent being evaluated, and n is the total number of observations.

Modeling with calibrated QUAL2Kw software was used to simulate river water quality and provide management strategies for improving it (Taherisoudejani et al. 2018). A pollutant load reduction scenario simulation was conducted to evaluate the effectiveness of reducing liquid waste emissions on the recovery of Oko-oko River water quality. There are three scenarios applied to the efficiency of palm oil mill wastewater treatment, namely Simulation 1 (Sim1) – Existing conditions: baseline using actual measurement data of discharge and concentration of palm oil mill effluent at the outlet, Simulation 2 (Sim2) – 30% POME reduction: simulation of improved efficiency in the initial stage of wastewater treatment (anaerobic reactor optimization) and Simulation 3 (Sim3) – 70% POME reduction: simulation of the optimal scenario with an integrated treatment system (anaerobic-aerobic).

The effectiveness of the wastewater management scenarios was evaluated by comparing the parameters in the river sections that met the quality standards in each scenario. Comparisons between scenarios were made using a paired t-test ($\alpha = 0.05$) to assess significant differences in the effects of waste reduction on water quality parameters. The results of the scenario simulations can assist in formulating technical strategies for pollution control, considering the capacity of liquid waste treatment units.

3. RESULTS

3.1. Water quality data for the Oko-oko River

The hydraulic conditions of the Oko-oko River were measured on March 15, 2025. Table 3 presents the field observation data for the Oko-oko River at the four sampling points. The source of pollution in this study is the palm oil factory PT.X, which discharges its liquid waste 1.07 km upstream at a total discharge rate 0.0094 $m^3.s^{-1}$.

Table 3. Hydraulic Data of Oko-oko River

Sampling Code	Hydraulic characteristics							
	mean velocity ($m.s^{-1}$)	water depth (m)	width (m)	discharge ($m^3 \cdot s^{-1}$)	Elevasi (m)	Cross-sectional area (m^2)	Slope	Manning
ST 1	0.76	0.44	20.75	6.96	58	9.20	0.002	0.03
ST 2	1.02	0.67	10.20	6.97	51	6.80	0.002	0.03
ST 3	0.95	0.35	21.80	7.14	48	7.56	0.006	0.04
ST 4	1.15	0.80	10.12	9.33	40	8.10	0.006	0.04

Source: own study

Table 4 presents the analysis of river water quality at four monitoring points, as well as the quality of palm oil mill wastewater. In summary, DO concentrations ranged from 6.44 mg L^{-1} (ST 2) to 7.05 mg L^{-1} (ST 4), while COD showed a much wider range, from 3.70 mg L^{-1} (ST 1) to 15.65 mg L^{-1} (ST 4). This reflects the accumulation of nonbiodegradable organic matter and oxidized chemical compounds along the river flow. Although there was a further increase, these values remained within safe limits according to the water quality standards of Class II under Indonesian Government Regulation No. 22 of 2021.

Table 4. Water quality analysis results of Oko-oko River and PT. X's wastewater effluent

Parameter	Measurement unit	Values of Oko-oko River Water				PT. X wastewater
		ST 1	ST 2	ST 3	ST 4	
Temperatur	°C	27	26.8	26.5	27	26.80
pH	-	7.78	7.16	8.17	7.94	8.26
DO	mg.L^{-1}	6.64	6.44	6.8	7.05	-
BOD	mg.L^{-1}	3.67	2.99	2.95	2.81	310
COD	mg.L^{-1}	3.703	3.878	3.98	15.65	963
TSS	mg.L^{-1}	134	99	133	196	132
Nitrogen Total as N	mg.L^{-1}	-	-	-	-	613
oil & grease	mg.L^{-1}	0.15	0.36	0.38	0.6	3.8

Source: own study

The highest BOD concentration was found in the upstream segment, indicating the presence of pollutants from the source. In contrast, the lowest concentration was found in the downstream segment. This value is still within the safe limits, but caution is needed regarding the increase in pollutants from anthropogenic activities in the surrounding area. These BOD concentrations indicated a decrease in organic matter levels from upstream to downstream, consistent with the natural self-purification process.

3.2. Model Calibration and Validation

Table 5 presents the kinetic parameters required by Qual2Kw for calibration. These parameters are recommended from a number of literature sources, including Pelletier & Chapra (2008), which was also applied by Hossain MA et al. (2014) and Kannel et al. (2007).

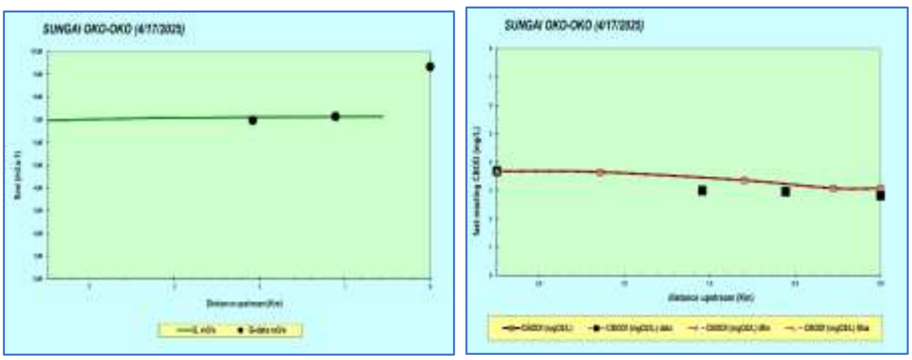
Table 5. Calibrated system parameters in the Oko-oko River

Parameter	Value	Units	Auto-calibration	Min value	Max value
Stoichiometry:					
Carbon	40	gC	No	30	50
Nitrogen	7,2	gN	No	3	9
Phosphorus	1	gP	No	0,4	2
Dry weight	100	gD	No	100	100
Chlorophyll	1	gA	No	0,4	2
ISS Settling velocity	0,06128	m/d	Yes	0	2
Oxygen inhib parameter CBOD oxidation	0,60	L/mgO2	No	0,60	0,60
Oxygen inhib parameter nitrification	0,60	L/mgO2	No	0,60	0,60
Oxygen enhance parameter denitrification	0,60	L/mgO2	No	0,60	0,60
Oxygen inhib parameter phyto resp	0,60	L/mgO2	No	0,60	0,60
Oxygen enhance parameter bot alg resp	0,60	L/mgO2	No	0,60	0,60
Slow CBOD Hydrolysis rate	1,93545	/d	Yes	0	5
Slow CBOD Oxidation rate	1,18385	/d	Yes	0	0,5
Fast CBOD Oxidation rate	0,5447	/d	Yes	0	5
Organic N Hydrolysis	0,8365	/d	Yes	0	5

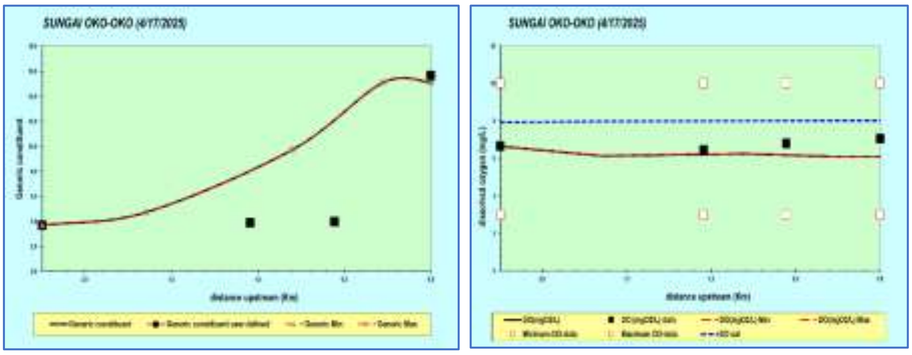
Parameter	**Value**	**Units**	**Auto-calibration**	**Min value**	**Max value**
Organic N Settling velocity	0,24964	m/d	Yes	0	2
Ammonium Nitrification	2,1554	/d	Yes	0	10
Nitrate Denitrification	1,02986	/d	Yes	0	2
Sed denitrification transfer coeff	0,05126	m/d	Yes	0	1
Organic P Hydrolysis	3,4361	/d	Yes	0	5
Organic P Settling velocity	0,62926	m/d	Yes	0	2
Inorganic P Settling velocity	0,01384	m/d	Yes	0	2
Sed P oxygen attenuation half sat constant	1,69154	mgO_2/L	Yes	0	2
Max Growth rate	49,3845	$gD/m^2/d$ or /d	Yes	0	100
First-order model carrying capacity	100	gD/m^2	No	50	200
Basal respiration rate	0,48434	/d	No	0	0,3
Excretion rate	0,46367	/d	Yes	0	0,5
Death rate	0,40579	/d	Yes	0	0,5
External nitrogen half sat constant	163,368	ugN/L	Yes	0	300
External phosphorus half sat constant	47,556	ugP/L	Yes	0	100
Inorganic carbon half sat constant	1,05E-05	moles/L	Yes	1,30E-06	1,30E-04
Light constant	2,09098	langleys/d	Yes	1	100
Ammonia preference	1,48807	ugN/L	Yes	1	100
Subsistence quota for nitrogen	29,95736472	mgN/gD	Yes	0,072	72
Subsistence quota for phosphorus	0,3928168	mgP/gD	Yes	0,01	10
Maximum uptake rate for nitrogen	446,5885	mgN/gD/d	Yes	350	1500
Maximum uptake rate for phosphorus	114,4235	mgP/gD/d	Yes	50	200
COD Decay rate	0,8	/d	No	0,8	0,8
COD Settling velocity	1	m/d	No	1	1

Source: own study

Model calibration is adjusting the input parameter values and initial or boundary conditions within a reasonable range, until the simulation results closely match the observed variables (Moriasi et al. 2015). Figure 2 shows that the model was close to the input data (black dots). Figure 2. An indicates that the highest discharge occurs at the 0.00 km point because this segment is unaffected by bends, and the river width also narrows.



(a) (b)



(c) (d)

Fig. 2: Calibration of measurement and simulation data results with QUAL2Kw for the River. (a) River discharge (b) BOD (c) COD (d) DO. Source: own study

The calibration and validation results generally show good agreement between model simulation results and field measurements (NSE > 0.80), especially for the river water quality variables BOD, COD, and DO, reported in Tables 6, 7, and 8. Validation with available data ensures that the model accurately represents the dynamics of water quality. According to Moriasi et al. (2007), validity test results with NSE values ≥ 0.50 indicate that the model performance is acceptable. Camargo et al. (2010) stated that the accuracy of the tropical river model is acceptable when the root-mean-square error (RMSE) is < 20% of the data range.

Table 6. RMSE and NSE values for the BOD parameter

Sampling point	**Observation Results (X)**	**Qual2Kw simulation results (Y)**	**$(X-Y)^2$**	**$(X-Xrat)^2$**
Headwater	3.67	3.67	0.00	9.64
ST 2	2.99	3.64	0.42	0.013
ST 3	2.95	3.35	0.16	0.024
ST 4	2.81	3.07	0.07	0.087
Model Validation Results			RMSe = 0.4	NSE =0.93
Interpretation			The model fits perfectly.	

Source: own study

Table 7. RMSE and NSE values for COD parameters

Sampling point	**Observation Results (X)**	**Qual2Kw simulation results (Y)**	**$(X-Y)^2$**	**$(X-Xrat)^2$**
Headwater	3.703	3.703	0.00	46.277
ST 2	3.878	4.752	0.76	8.554
ST 3	3.98	9.744	33.22	7.967
ST 4	15.65	15.086	0.32	78.273
Model Validation Results			RMSe = 2,93	NSE =0,757
Interpretation			The model is quite good.	

Source: own study

Table 8. RMSE and NSE values for DO parameters

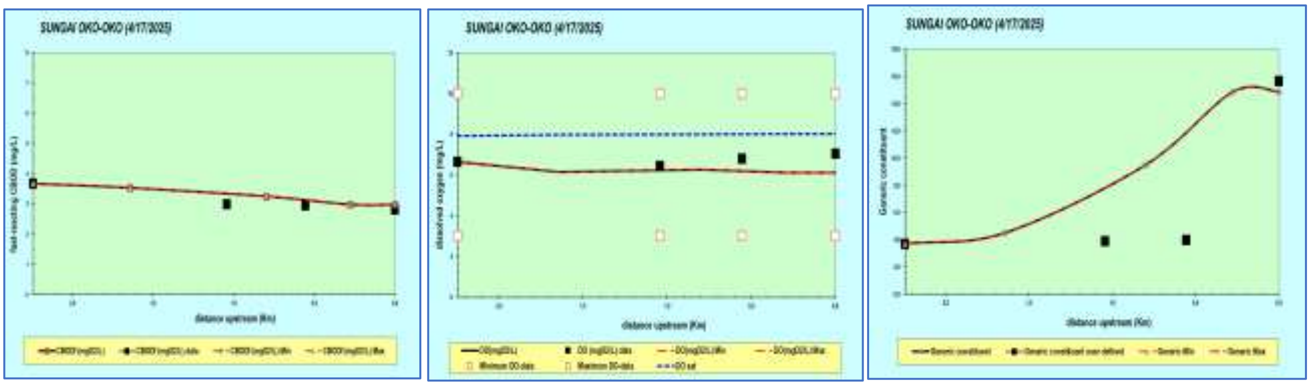
Sampling point	**Observation Result (X)**	**Qual2Kw simulation results (Y)**	**$(X-Y)^2$**	**$(X-Xrat)^2$**
Headwater	6.64	6.64	0.00	45.326
ST 2	6.44	6.14	0.09	0.086
ST 3	6.8	6.26	0.29	0.005

Sampling point	Observation Result (X)	Qual2Kw simulation results (Y)	$(X-Y)^2$	$(X-Xrat)^2$
ST 4	7.05	6.09	0.92	0.1
Qual2Kw simulation results (Y)			RMSe = 0.57	NSE =0.97
Interpretation			The model fits perfectly.	

Source: own study

3.3. Simulation of river water quality scenarios

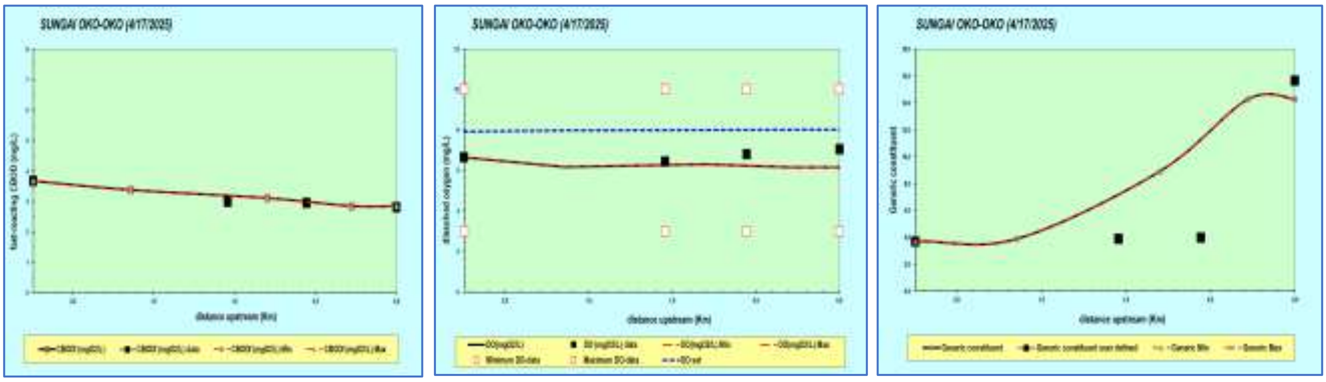
The Oko-oko river water scenario was simulated with a 30% reduction in palm oil mill effluent (POME) load and a 70% reduction at four monitoring points (ST 1-ST 4), which were then compared with field measurement data. Simulation 1 (Sim1) is the baseline model simulating river water quality. Simulation 1 uses measurement data of the discharge and concentration of palm oil mill effluent at the outlet. Simulation 2 (Sim2) was conducted with a 30% POME reduction scenario assuming an increase in the efficiency of the initial stage of waste treatment (anaerobic reactor optimisation), and Simulation 3 (Sim3) was conducted with a 70% POME reduction scenario assuming an integrated waste treatment system (anaerobic-aerobic and filtration).



(a) (b) (c)

Fig. 3: Spatial variation of QUAL2Kw in the 30% reduction scenario (a) BOD, (b) DO, (c) COD.
Source: own study

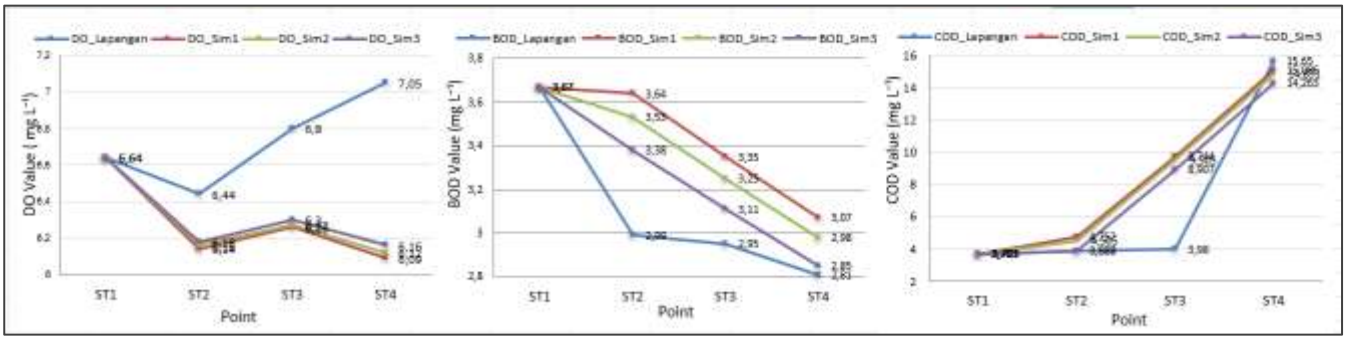
Figure 3 shows the spatial variation of the simulation results of BOD, DO, and COD parameters in the scenario of 30% POME load reduction (Sim2). This illustrates the trend of water quality changes from upstream to downstream, which are significantly influenced by effluent discharge. The BOD concentration shows a relatively stable decreasing trend along the river (shown by the red line). This indicates that a 30% reduction in POME load can reduce the load of organic matter easily degraded by microorganisms. For the DO value variation, there is a slight fluctuation in the middle of the river segment, which the deoxygenation process can cause due to the organic load, which is still relatively high despite the reduction. Overall, Simulation 2 (Sim2) showed improved water quality compared to the baseline (Sim1), but not yet optimal in removing the organic load. This can be seen from the relatively high BOD and COD values in the middle of the river.



(a) (b) (c)

Fig. 4: Spatial variation of QUAL2Kw in the 70% reduction scenario (a) BOD, (b) DO, (c) COD. Source: own study

Figure 4 shows the spatial distribution of the 70% POME load reduction scenario in the Oko-oko River for the three main water quality parameters. The simulation results confirm that a 70% reduction in pollutant load can reduce BOD and COD values and increase DO values beyond the Class II water quality threshold. Figure 5 presents the comparison between field data and simulation results for three pollutant load scenarios: Sim1 (baseline), Sim2 (30% reduction), and Sim3 (70% reduction). The POME reduction scenario of 70% (Sim3) improves water quality conditions best.



(a) (b) (c)

Fig. 5: Longitudinal profile of QUAL2Kw simulation results for (a) DO, (b) BOD, (c) COD parameters.

3.4. Paired t-test Statistical Analysis

A paired t-test was conducted to compare simulation 1 with simulation 2 and simulation 1 with simulation 3 for the DO, COD, and BOD parameters at four monitoring points, assessing the significance of the differences between the modeling scenarios. Tests were conducted at a significance level of $\alpha = 0.05$. Statistical test results indicated that the differences between the existing and treatment scenarios were highly significant ($p < 0.05$) for the BOD and COD parameters. The DO parameter indicates that the difference between S_1 and S_3 is not statistically significant ($p = 0.071$), despite an increase in the numerical values. The BOD parameter shows a significant difference between S_1 and S_3 ($p = 0.032$), indicating the real effect of the load reduction scenario on BOD reduction. The COD parameter also shows significant results between S_1 and S_3 ($p = 0.017$), indicating the effectiveness of increased treatment efficiency on reducing dissolved organic compounds. The test results in Table 8 show that the 70% load reduction simulation (Sim3) significantly improves water quality, particularly in terms of the BOD and COD parameters.

Table 8. Results of the paired t-test of DO, BOD, and COD parameters between QUAL2Kw modelling scenarios.

Parameter	Scenario Comparison	p-value	Description
DO	Sim1 vs. Sim3	0.071	Not significant
BOD	Sim1 vs. Sim3	0.032	Significant (p < 0,05)
COD	Sim1 vs. Sim3	0.017	Significant (p < 0,05)

Source: own study

For all parameter–scenario combinations, the Shapiro–Wilk test yielded p-values > 0.05, so the null hypothesis was not rejected. Thus, the assumption of normality was satisfied for the paired differences used in the paired t-test. The sample size per comparison (n = 4) results in relatively low statistical power. Independence between pairs is satisfied because each pair of observations originates from spatially distinct points (ST1–ST4 represent the upstream, midstream, and downstream segments).

4. DISCUSSION

BOD and COD are key parameters for organic matter pollution in palm oil industrial waste (Andika et al. 2020). The results of the BOD analysis at point ST 1 (upstream) exceeded the quality standards, and at points ST 2, ST 3, and ST 4, the quality standards were still met. The resulting BOD concentration decreased because of the decomposition of organic compounds, influenced by Dissolved Oxygen. The high concentration of BOD in the river indicates high organic matter that can be biologically degraded from domestic and industrial wastewater discharges (Wifarulah & Marlina, 2021). The river water measurement data for the COD parameter showed that the COD value at each point met class II quality standards. The water quality characteristics of the Oko-oko River indicate a relatively good oxygen supply, as indicated by the BOD and COD parameters. The river can self-purify, allowing organic matter to be naturally reduced in the recovery zone (Patel & Jariwala, 2023).

The results of the Oko-oko River water quality simulation conducted with the QUAL2Kw model showed that the BOD reduction scenario at the source (up to 70%) significantly improved the water quality of the Oko-Oko River, characterized by a decrease in BOD and COD. An integrated sewage treatment system (anaerobic-aerobic) is recommended to achieve the river water quality target, according to PP No. 22 Year 2021 Class II.

The longitudinal profile of dissolved oxygen (DO) showed an increasing trend in scenarios S_1 to S_3. This indicates that the decrease in organic load from POME directly increases the re-aeration capacity of the river. The decrease in BOD and COD in scenarios S_2 and S_3 is a significant indicator of the effectiveness of the anaerobic-aerobic treatment system for POME. The integrated anaerobic-aerobic bioreactor system is designed to treat wastewater containing high concentrations of organic pollutants such as POME. The effectiveness of this system, based on research conducted by Chan et al. (2015), achieved COD and BOD removal efficiencies of 96.3% and 97.9%, respectively. This is reinforced by the theory of organic degradation kinetics, which states that the reduction in substrate concentration (BOD/COD) is directly proportional to the increase in DO through an increase in the re-aeration coefficient (Pelletier & Chapra, 2008).

Statistical test results show that the 70% load reduction scenario (S_3) significantly reduces BOD ($p = 0.032$) and COD ($p = 0.017$), while the increase in DO is not yet statistically significant ($p = 0.071$) despite showing a positive trend. This indicates that improvements in the water quality of the Oko-Oko River can be achieved through organic load reduction at the source, making technological interventions for Palm Oil Mill Effluent (POME) treatment crucial.

The anaerobic-aerobic treatment approach is recommended as an option that is suitable for the characteristics of POME in Kolaka. The anaerobic stage, such as a covered anaerobic lagoon or anaerobic digester, is capable of reducing BOD by >70% and producing biogas that can be used as an alternative energy source, reducing dependence on fossil fuels. The subsequent aerobic stage (aerated lagoon or activated sludge system) plays a role in oxidising organic residues, reducing COD, and increasing DO in the effluent before it is discharged into water bodies. Barriers to the implementation of anaerobic-aerobic system treatment in Kolaka include not only an initial investment that is 25–40% higher than that of conventional open ponds, but also the need for additional land for aerobic units with optimal hydraulic retention time.

The results of this study provide a strong scientific basis for formulating wastewater treatment policies in the palm oil industry in Kolaka Regency, especially in the Oko-Oko River basin. Spatial simulation shows that the downstream segment (ST 3 and ST 4) is a critical location that requires regular water quality monitoring. The model results can also be used to determine pollutant load capacity and formulate pollution control strategies based on the natural assimilation capacity of the river. This study has limitations in the spatial coverage of water quality data, which is only four monitoring points, thus reducing the accuracy of the simulation in describing the real conditions along the river. In addition, the unavailability of seasonal data variables can affect the effectiveness of natural dilution of the river. Therefore, it is suggested that further research needs to be conducted with a broader coverage of monitoring points and seasonal dynamic hydrological data to strengthen the validity and accuracy of the model.

5. CONCLUSIONS

This study shows that the results of the Oko-oko River water quality simulation indicate that improving the efficiency of the wastewater treatment system can increase dissolved oxygen (DO) levels and reduce BOD and COD concentrations in the river flow. Among the three scenarios tested, the 70% POME reduction scenario yielded optimal results at all monitoring points and met the national water quality standards for Class II as per Indonesian Government Regulation No. 22 of 2021, Annex IV. Model validation demonstrated consistency between simulation results and observational data, with NSE values > 0.8 for all parameters. These findings highlight the potential use of numerical models as decision-support tools in scenario-based water quality management.

This study also emphasises the importance of optimising wastewater treatment systems, particularly in the palm oil industry, to reduce systemic pollution impacts. Future research should be conducted with a broader spatial scope, integrating hydrological and land use factors to enhance model accuracy and the relevance of results for sustainable watershed management policies.

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