JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2022, 23(3), 154–161
https://doi.org/10.12911/22998993/145543
ISSN 2299–8993, License CC-BY 4.0

Received: 2021.12.17
Accepted: 2022.01.13
Published: 2022.02.01

Pollution Load Capacity Assessment by Utilizing QUAL2E Modelling: A Case Study of Rambut River, Indonesia

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ABSTRACT
Water quality modelling can be a way to determine the potential pollutant load capacity in the river water. As the number of population and intensity of activities around the river increased, it is possible that the water quality in the river will be negatively impacted. The Rambut river, which located in Pemalang and Tegal, Indonesia, has an important role as a water source in both areas. However, this demand is not accompanied by the availability of river capacity information yet. Five points from different segments along the upstream and downstream of Rambut River were assessed with the QUAL2E model. There were four different parameters in the research, e.g., BOD, fecal coliform, nitrite, and nitrate. The results showed that some segments did not comply with the minimum requirements by the local government. Additionally, the BOD and fecal coliform value were predicted to be increased in 2023 due to higher population number living near the river. The values for all parameters fluctuated between the different segments.

Keyword: QUAL2E, Rambut river, pollutant load, river capacity.

INTRODUCTION

Assesments of water quality conducted routinely in river for different water use purposes, such as irrigation, conservation and industrial usage, are an important strategy for food safety and human health. This evaluation provides important information on the status of these waterways and can help the authorized party to target the management actions (Son et al., 2020). Nowadays, the condition of all rivers in Indonesia is generally heavily polluted (Honingh et al., 2020; Kido et al., 2008; Sikder et al., 2015). Among 471 heavily polluted rivers which have been identified in 2015 and 2016, there are 17 rivers that is in a steady state where the quality remain unchanged. Besides that, there are also 211 rivers the quality of wich significantly increased, while 343 rivers were found to deteriorate (BPS, 2017). Moreover, in Central Java province, there are 4 rivers that have been categorized as intermediately and heavily polluted, namely Bengawan Solo, Cisanggarung, Citanduy, and Progo. It is assumed that a similar pollution also happens in a river that flows near them, especially in the border of Tegal and Pemalang cities. This condition proves that most of the rivers do not meet the minimum requirements to be implemented for drinking water, water recreation, cultivation of freshwater fish, animal husbandry, crops irrigation, and other purposes (Adrian et al., 2020; Krisanti et al., 2020; Muin & Nandiasa, 2019; Roosmini et al., 2018; Sulaeman et al., 2020).

The Rambut river is one of the rivers the quality of which has not been analyzed yet. Its upstream area is located in Tegal city, while the downstream area is situated in the Pemalang city, making it a geographical border for both cities. The Rambut river has the total area of 166.1 kilometers square and the total length of 63,975 kilometers. This river is flowing across ten subdistricts with a total population of 722,034 people (Sugiarto et al., 2020). In addition, Tegal and Pemalang cities are considered to have high rate of population growth, directly affecting the usage intensity of the Rambut river for various purposes. The high dependency of the people towards the Rambut river is affecting the anthropogenic activity in that surrounding area, which can lead to river pollution increase. Hence, an assessment to highlight the quality of the Rambut river is needed to understand the existing condition and help to propose an effective river management strategy (Efiana et al., 2019; Faradiba et al., 2019).

In order to assess the current condition of the Rambut river, a well-recognized free-to-use modelling software called QUAL2E was used. It is able to evaluate the quality of water stream and has been implemented for various settings and parameters. This modelling software is also widely used for regulatory and policy decision-making due its versatility. This modelling software also has a powerful module for uncertainty analysis (Melching & Yoon, 1996; Palmieri & De Carvalho, 2006; Yuceer et al., 2007). Several authors stated that QUAL2E is highly suited for point sources of pollutants and limited to the rivers that have temporal variations in pollution load streamflow over a short period (Azzellino et al., 2006; Ning & Chang, 2007).

Many researchers consider the use of QUAL2E because it can be integrated with geographical information system (GIS) which makes the analysis of pollution load more illustrative and easier to comprehend. Moreover, the use of mathematical models is predominant and becomes a useful decision-making tool for river basin management, combined with the additional data input of wastewater treatment technologies and impact estimation from discharged wastewater towards the quality of receiving streams. By considering average annual scenario and point loads input only, QUAL2E demonstrated a quite good accuracy with 20% of error percentage (Azzellino et al., 2006; Ning & Chang, 2007).

On the basis of the existing condition of the Rambut river, this area is now mostly used as a place to discharge domestic wastewater without any proper treatment before. This is an intriguing issue that has remained unsolved until now. There are many people that still use the river as the end zone of their solid waste, grey water, and also black water. However, the existence of domestic wastewater is significantly decreasing the river quality due to physical, chemical, and microbiological process that occurs (Ling et al., 2012; Ullah et al., 2013).

This article aimed to find the quantification of pollution load capacity in the Rambut river by implementing QUAL2E. The pollution load capacity is calculated by considering the driving forces of landuse and anthropogenic activities around the river. Because of the lack of the same research in the Rambut river, this article clearly has good urgency and novelty points in identifying the river in Indonesia which is prone to be severely polluted by human. Furthermore, the result of this research is crucial to depict other river conditions in Central Java.

METHODS

Geographically, the Rambut river is located at the coordinate of 7°13'50" – 6°52'15" S and 109°6'8" – 106°18'55" E, while administratively it flows through ten subdistricts, i.e. Pulosari, Moga, Bojong, Warungpring, Jatinegara, Randudongkal, Kedungbanteng, Bantarbolang, Pemalang, and Warureja. The upstream area (water spring) of this river is in a place called Balekambang, located in Suniarsih village, Bojong subdistrict, Tegal city (7°9'15.26" S and 109°11'19.93" E). The sample collection took place in five different points along the Rambut river (Table 1), determined according to the condition of landuse, topography, physical condition of river, and administrative border. All of these factors significantly affect the pollution load capacity due to the difference of anthropogenic activity around the river area (Sugiarto et al., 2020).

The observed parameters include BOD, fecal coliform, nitrite (NO_2), and nitrate (NO_3). There are also several supporting variables that will be used, such as river hydromorphology, pollution source inventory, and water quality. The result of mathematical modelling from QUAL2E will be compared with PP No. 82 Year 2001 as the water quality standard in Indonesia. Th e pollution load capacity of a river, especially coming from organic pollutants, can be assessed through the amount of biological oxygen demand (BOD) in the water.

Table 1. Sampling location and coordinate

Point	Sampling location	Coordinate
1	Kajenengan village, Bojong subdistrict, Tegal city. Located at an altitude of ±520 meter above sea level	7° 6' 44.37" S and 109° 13' 23.76" E
2	Jatinegara village, Jatinegara subdistrict, Tegal city. Located at an altitude of ±246 meter above sea level	7° 4' 4.17" S and 109° 15' 4.69" E
3	Kedungjati village, Warureja subdistrict, Tegal city. Located at an altitude of ±45 meter above sea level	6° 59' 18.25" S and 109° 18' 31.45" E
4	Sukareja village, Warureja subdistrict, Tegal city. Located at an altitude of ±13 meter above sea level	6° 55' 11.9" S and 109° 19' 48.51" E
5	Kedungkelor village, Warureja subdistrict, Tegal city. Located at an altitude of ±7 meter above sea level	6° 52' 20.17" S and 109° 20' 35.70" E

Higher amount of BOD can lead to worse pollution in the river. In addition, excressed substances from human, such as faeces, contains pathogenic bacteria like Eschericia coli, Shiglia sp, Vibrio cholera, Campylobacter jejuni, and Salmonella sp which are categorized as fecal coliform. The polution load capacity was analyzed in accordance with Appendix 1 from the Regulation of Minister of Environment and Forestry No. 1 Year 2010.

The calculation formula of potential pollutant loads from domestic sector (PPL 1) are as follows:

$$PPL\ 1 = \alpha\ x\ TP\ x\ EF\ x\ CERI \quad (1)$$

where: PPL 1 – Potential pollutant loads (kg/day); α – Run-off coefficient ration; direct disposal into river = 1, open channel = 0.5, septic tank = 0.25; TP – Total populations of the surrounding area (person); EF – Emission factor per person (kg/person/day); CER – City equivalent ration; city = 1, suburbs = 0.8125; hinterland = 0.652.

In turn, the calculation formula of potential pollutant loads from agricultural sector (PPL 2) are as follows:

$$PPL\ 2 = A\ x\ EMF \quad (2)$$

where: PPL 2 – potential pollutant loads (kg/day); A – land area (Ha); EF – emission factor per unit area (kg/Ha/day).

The test results of each parameter were then used as a basis for determining water quality based on water class in PP No. 82 Year 2001, a national regulation from the government of Indonesia regarding water quality standard. The water classes are divided into 4 different categories, namely class I (raw water for drinking water and/or other designation that requires same water quality), class II (water recreation infrastructure, freshwater fish cultivation, animal husbandry, crops irrigation, and/or other designation that requires same water quality), class III (freshwater fish cultivation, animal husbandry, crops irrigation, and/or other designation that requires same water quality), class IV (crops irrigation, and/or other designation that requires same water quality).

RESULTS AND DISCUSSION

The physical characteristic containing measurement of river hydraulcs and morphology were needed as supporting data in QUAL2E. Table 2 below shows the physical characteristics data for each segment in the Rambut river. The segments were acquired by connecting the upstream area called Balekambang and all sampling points, resulting in five different segments.

According to the data below, each segment had different physical characteristic. The values

Table 2. Physical characteristics of each segments

From	To	Manning coefficient (n)	Side slope 1 (m)	Side slope 2 (m)	Length of segment (x10^3 m)	River width (m)	Basic slope (m)
Balekambang	Point 1	0.040	0.250	0.250	13.3	2.33	0.051
Point 1	Point 2	0.045	0.435	0.435	9.48	11.6	0.029
Point 2	Point 3	0.050	0.204	0.204	14.4	15.14	0.014
Point 3	Point 4	0.050	0.313	0.313	17.2	3.8	0.002
Point 4	Point 5	0.060	0.033	0.033	10.8	26	0.001

Table 3. BOD concentration from each sampling locations

Point	BOD (mg/L)	BOD threshold level for each water classes (mg/L)				Remarks
		I	II	III	IV	
1	<2	2	3	6	12	Complied with class II
2	<2					Complied with class II
3	<2					Complied with class II
4	<2					Complied with class II
5	<2					Complied with class II

of Manning's coefficient (n) varied in the range of 0.040-0.060, while the basic slope values laid from 0.001 until 0.051. The longest segment could be found between point 3 and 4 with 17,200 meters and the shortest segment was between point 1 and 2 with 9,480 meters. Additionally, there was a significant difference of river width in the first and last segment with the value of 2.33 and 26 meters, respectively.

The test results of each parameter were compared with four different water class according to PP No. 82 Year 2001. According to that rule (article 55), since the Rambut river has not been categorized in any of the water class yet, it was targeted to comply with the class II water quality standard. As shown in Table 3, the BOD concentration of all sampling points had the value below 2 mg/L. It means that the Rambut river generally had low BOD value and complied with the class II water quality standard. These results indicated that the Rambut river still has significantly high oxygen content in the water. In other words, due to the low BOD concentration, the organic compounds which usually comes from domestic waste were not the main pollutant in this river.

Table 4 below demonstrated the concentration of fecal coliform from all sampling points in the Rambut river. It seems that each sampling point had significantly different amount of fecal coliform. The highest concentration was shown in sampling point 4 with 23,200 bacterial colonies per 100 mL of sample water, while the lowest concentration was in sampling point 1 with 100 bacterial colonies per 100 mL of sample water. The sampling points 1 and 5 were only ones which compled with class II water quality standard, while the others still exceed the threshold level. The high amount of fecal coliform was influenced by the domestic waste originating from residential settlements discharged into the river.

Table 5 below illustrated the nitrite concentration from each sampling location in the Rambut river. The sampling point which had the highest amount of nitrite is in point 5 with 0.063 mg/100mL. Besides, the lowest nitrite concentration was 0.004 mg/100mL, located in

Table 4. Fecal coliform concentration from each sampling locations

Point	Fecal coliform (amount/100 mL)	Fecal coliform threshold level for each water classes (amount/100 mL)				Remarks
		I	II	III	IV	
1	100	100	1,000	2,000	2,000	Complied with class II
2	4,800					Uncomplied with class II
3	11,500					Uncomplied with class II
4	23,200					Uncomplied with class II
5	400					Complied with class II

Table 5. Nitrite concentration from each sampling locations

Point	Nitrite (mg/100 mL)	Nitrite threshold level for each water classes (quantity/100 mL)				Remarks
		I	II	III	IV	
1	0.021	0.06	0.06	0.06	-	Comply with class II
2	0.007					Comply with class II
3	0.005					Comply with class II
4	0.004					Comply with class II
5	0.063					Uncomply with class II

the sampling point 4. All sampling locations had slight difference of nitrite concentration and comply with the class II water quality standard, except the sampling point 5. According to the field investigation, 85% of the total land area around sampling point 5 was an agricultural area.

The last oberved parameter in the Rambut river was nitrate concentration, shown in Table 6 below. Similarly to the previous table, all sampling points had slight difference amount of nitrate concentration. Moreover, all sampling points complied with the class II water quality standard. The highest amount of nitrate concentration was shown in sampling point 3, while the lowest was in sampling point 1. After the measurement of each parameter in the Rambut river, a calculation of potential pollution load from domestic sector (PPL 1) and agricultural sector (PPL 2) was conducted.

The wastewater which entered the Rambut river originated from non-point source pollutants, such as the domestic and agricultural waste. The potential pollutant load in the Rambut river from domestic waste (Table 7) showed that the highest populated segment (from Point 4 to Point 5) had the highest value of BOD, fecal coliform, nitrite, and nitrate. On the other hand, the first segment (from Balekambang to Point 1) had the least amount of population, BOD, fecal coliform, nitrite, and nitrate. The total population number indicated the amount of domestic waste producer, which could later affect the pollution load value.

Similar trends were also shown in the potential pollution load from agricultural waste (Table 8). The segment which has the largest agricultural land area (from Point 4 to Point 5) showed the highest amount of BOD, nitrogen total, nitrite, and nitrate. In line with the population number in the domestic waste, the agricultural land area in agriculture waste in indicated as the producer of agricultural waste. Among the different parameter of polluter, the highest value was shown in the BOD.

The comparison of potential pollution load on 2019 and 2023 showed that BOD and fecal coliform had increased values, while nitrite and nitrate were decreasing (Table 9). Additionally, the highest inclining difference was shown in BOD,

Table 6. Nitrate concentration from each sampling locations

Point	Nitrate (mg/100 mL)	Nitrate threshold level for each water classes (quantity/100 mL)				Remarks
		I	II	III	IV	
1	0.5	10	10	20	20	Comply class II
2	0.6					Comply class II
3	0.9					Comply class II
4	0.8					Comply class II
5	0.6					Comply class II

Table 7. Potential pollution load from domestic waste

From	To	Total population	Pollution load value			
			BOD (kg/day)	Fecal coliform (amount/day)	Nitrite (kg/day)	Nitrate (kg/day)
Balekambang	Point 1	25,607	832.21	0.416×10^{10}	0.0446	0.223
Point 1	Point 2	43,770	1,422.53	0.711×10^{10}	0.0745	0.373
Point 2	Point 3	39,981	1,229.40	0.469×10^{10}	0.0679	0.339
Point 3	Point 4	33,815	1,099.00	0.549×10^{10}	0.0561	0.281
Point 4	Point 5	48,346	1,571.26	0.785×10^{10}	0.0793	0.396

Table 8. Potential pollution load from agricultural waste

From	To	Agricultural land area (Ha)	Pollution load value			
			BOD (kg/day)	Nitrogen total (kg/day)	Nitrite (kg/day)	Nitrate (kg/day)
Balekambang	Point 1	598.83	41.92	11.98	0.60	9.58
Point 1	Point 2	1,069.07	74.83	21.38	1.07	17.11
Point 2	Point 3	1,253.17	87.72	25.06	1.25	20.05
Point 3	Point 4	2,470.75	172.95	49.42	2.47	39.53
Point 4	Point 5	4,089.90	286.29	81.80	4.09	65.44

Table 9. Total of potential pollution load on 2019 and 2023

From	To	Pollution load value							
		BOD (kg/day)		Fecal coliform (amount x 10^{10}/day)		Nitrite (kg/day)		Nitrate (kg/day)	
		2019	2023	2019	2023	2019	2023	2019	2023
Balekambang	Point 1	933.99	1,372.3	4.46	5.65	0.64	0.64	9.80	9.59
Point 1	Point 2	1,565.2	1,868.5	7.45	8.97	1.14	1.13	17.48	17.07
Point 2	Point 3	1,445.2	1,701.9	6.78	8.08	1.32	1.30	20.39	19.89
Point 3	Point 4	1,295.1	1,387.5	5.61	6.09	2.53	2.46	39.81	38.72
Point 4	Point 5	1,871.4	1,920.1	7.92	8.20	4.17	4.06	65.83	63.99

especially from Balekambang to Point 1. On the other hand, the nitrate from Point 4 to Point 5 had the highest declining difference. The increased value of BOD and fecal coliform was most likely caused by the higher population number in the future. The increased population number tended to increase the amount of domestic waste released into the water body, which later increased the organic compound presence (Amira et al., 2021; West & Van Woesik, 2001).

The comparison between the results from the QUAL2E modelling and the actual field were shown in the Figure 1 below. The grapics showed that the modelled results from all parameters fluctuated. The modelled results functioned to determine the profiles of each parameter from the different segment. It could be seen that the BOD value was decreasing in the 1st until 9th km distance and remain on the lowest level until the 17th km. It was most likely to be caused by the high presence of dissolved oxygen in the river on those segments. The presence of dissolved oxygen was inversely proportional to the BOD value (Dobbins, 1964; Hutchins et al., 2021). There was a low amount of organic compound in the water, making the oxygen needed to decompose it to be lower, thus affecting the increase of dissolved oxygen (Gomolka et al., 2020; Lima Neto et al., 2007; Radwan et al., 2003). Theis was in accordance with the fecal coliform results, where the values were very low from the 1st until 17th km distance. Furthermore, there was also a decrease in the nitrite values between the 17th and 25th km distance, while nitrate was increasing on that segments. It showed those nitrification occurred. Nitrification was a conversion process of nitrite into nitrate due to the oxygen presence (Wang et al., 2018; Xia et al., 2017). These trends were in line with the findings of Zhang et al. (2018).

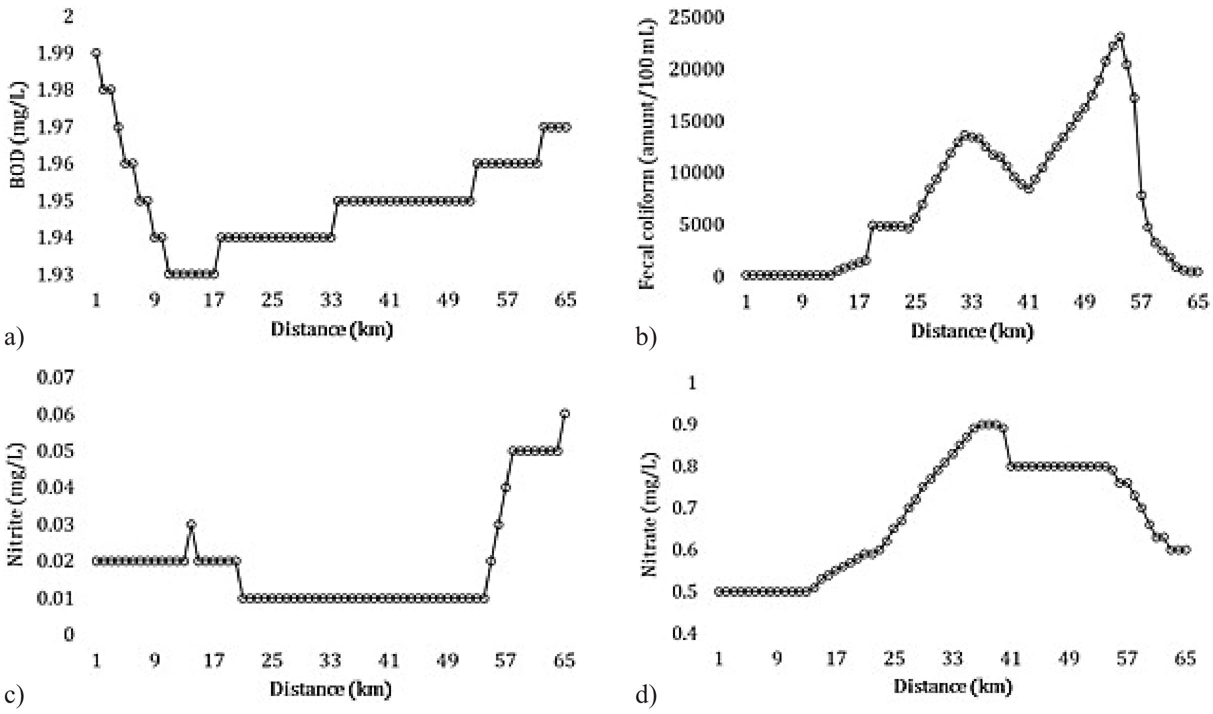

Figure 1. The results of QUAL2E modelling; (a) BOD, (b) fecal coliform, (c) nitrite, (d) nitrate

CONCLUSIONS

This research implied that each segment in the Rambut river had different quality. Some segments complied with the class II water quality standards, while the others did not. It showed that some of the parts in the Rambut river were still available to be used as infrastructures, recreations, fisheries, or other purposes that demanded the similar quality. The water quality in Rambut River was highly affected by the domestic and agricultural waste presence. The larger population which lives near the watershed had a direct impact to the amount domestic waste discharge. Additionally, the larger agricultural area also had a direct impact towards the amount of agricultural waste that entered the water body. On the basis of projection modelling of potential pollution load in 2019 and 2023, the BOD and fecal coliform were expected to have a higher value. On the other hand, nitrite and nitrate were predicted to have a slight decrease. Moreover, the QUAL2E modelling results for all parameter on each distance showed a fluctuating trend.

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