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Analysis of organic pollution load on the oxygenation rate at Sumbersari-Kaliwates Segment of Bedadung River, Jember Regency

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Abstract. *Bedadung River is one of the main rivers in Jember Regency. The anthropogenic activities in the urban area segment (Sumbersari and Kaliwates District) that are directly related to the river have the potential to increase the burden of pollution. The resulting pollution load can potentially lower water quality. The purpose of this study is to analyze the water quality and the rate of deoxygenation and reoxygenation of the Bedadung River Segment in Sumbersari-Kaliwates District using the Streeter-Phelps method. Data input were streamflow, TSS, DO, BOD, and COD with grab sampling. The results of calculating the rate of deoxygenation and reoxygenation are synthesized using quantitative descriptive methods. The TSS and DO values meet the grade I of water quality standard, but the BOD and COD values do not meet the standard. The mean deoxygenation rate (rD) and reoxygenation (rR) were 0.798 mg/L.day and 2.753 mg/L.day, respectively. The value of the reoxygenation rate is greater than the value of the deoxygenation rate. These findings indicate that ability of Bedadung River to reduce organic matter naturally is still in a good performance. The size of rR and rD is influenced by the reoxygenation constant, deoxygenation constant, and the hydraulic profile of the river.*

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INTRODUCTION

Watersheds have the function to store, accommodate, and drain water from rainfall through rivers to sea and lakes in a specific area. Tanggul, Bondoyudo, and Bedadung watersheds are the main watersheds in Jember Regency (Minister of Public Works and Public Housing Regulation No. 4 of 2015). According to research conducted by Pradana *et al.* (2019b), the Bedadung River is part of the Bedadung watershed, which is widely used for the activities of the people of Jember Regency for bathing and washing by local society. Then, it is used as a raw material source for drinking water by the Regional Drinking Water Company-Tirta Pendalungan Jember Regency. The water intake location of the Water Treatment Plant (WTP) is in Sumbersari District and Kaliwates District.

Referring to the Regional Regulation of Jember Regency No. 1 of 2015 about the Regional Spatial Plan of Jember Regency, Sumbersari and Kaliwates districts will be designed as urban areas. It will increase the risk of water pollution sources and reduce the quality of the river. The results of the examination of the water quality of the Bedadung River in the Jember urban segment using the pollution index and CCME-WQI methods indicate that it is in the polluted category and has an unfit status to be used as a raw water source (Pradana *et al.*, 2019a: Pradana *et al.*, 2020; Novita *et al*., 2020a). Then, the results of the Bedadung River water quality testing using the water quality index method that has been carried out have not considered the hydraulic profile and flow characteristics of the Bedadung River (Novita *et al*., 2020a; Novita *et al*., 2020b). Pollution control and conservation of river water quality must consider the hydraulic profile of the river and water discharge or streamflow (Wang *et al*., 2012; Liu *et al*., 2019a). The total pollution Load capacity analysis is used to identify how many pollutants the river can still accept using factor streamflow, hydraulic profile, deoxygenation, and reoxygenation constants (Pramaningsih *et al*., 2020; Djuwita *et al*., 2021).

Referring to the Decree of the State Minister of the Environment Number 110 of 2003, identification of the carrying capacity of the pollution load is useful for determining exposure to sources of pollution that can still be degraded and without causing pollution to the river through a self-purification mechanism. Then, the Streeter-Phelps Formulation is a method to determine the total pollution load capacity of a river through two natural phenomena, i.e., reoxygenation and reaeration process (Yustiani *et al*., 2018). According to (Pradana *et al*. (2019a), The main Bedadung River that passes through Patrang and Sumbersari Subdistricts has a reoxygenation rate value greater than the deoxygenation rate. This indicates that the self-purification performance of the Bedadung River in this segment is still good. However, examining the value of the deoxygenation and reoxygenation rates is in a segment that is not too densely populated and is dominated by abandoned land and agriculture (Pradana *et al.*, 2020). Land use affects the distribution of pollution sources and the carrying capacity of river pollution loads (Camara *et al*., 2019; Tahiru *et al*., 2020). Therefore, it is necessary to carry out further studies on the calculation of the capacity of the pollution load in the next segment, considering that river flows and land use are interrelated (Pradana *et al*., 2022). The purpose of this study was to determine the value of the reoxygenation rate (rR) and deoxygenation rate (rD), which were used to determine the natural purification process using the method Streeter-Phelps on the Bedadung River segment between Sumbersari District and Kaliwates District, Jember Regency.

METHOD

This research was conducted from September to August 2019 with 3 segments and 4 sampling points with the name of the sampling point being at Pondok Bedadung Indah Housing (BDG01), Makam Demang Mulya (BDG02), Sentot Prawirodirjo 14 street (BDG03), and Tegal Besar Blok E Village (BDG04) Jember Regency can be seen in Figure 1. This point starts after the Gladak Kembar Bridge. The segment is located between the flow before the entry of the flow from the Antirogo tributary and the Kalijompo tributary.

Data Collecting and Analysis

Data were collected in two places, namely, in the field and the Laboratory of Environmental Control and Conservation Engineering, Department of Agricultural Engineering, Faculty of Agricultural Technology, the University of Jember with parameters, i.e., DO, BOD, COD, and TSS. The secondary data used is land use data. Land use data is obtained from the processing results satellite data from google maps and calculated by the GIS application. A map of land use data can be seen in Figure 2.

According to Effendi (2003) and Kalkhajeh *et al.* (2019), the method of water sampling in this study is the grab sampling method. Grab sampling is a method of sampling directly from a water body and at a moment's time. The sampling location of the research points can be seen in Figure 1 and Table 1. In determining the water quality standard, a water quality analysis is carried out by referring to the Government Regulation of the Republic of Indonesia Number 82 of 2001 on Water Quality Management and Water Pollution Control.

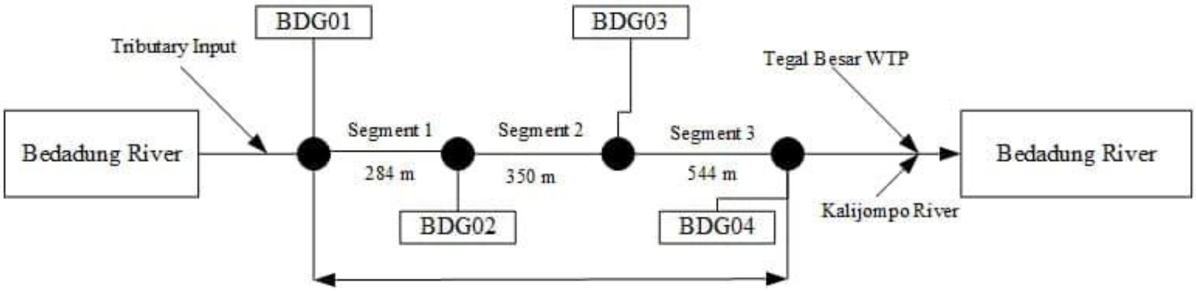

Figure 1 Distribution of research points

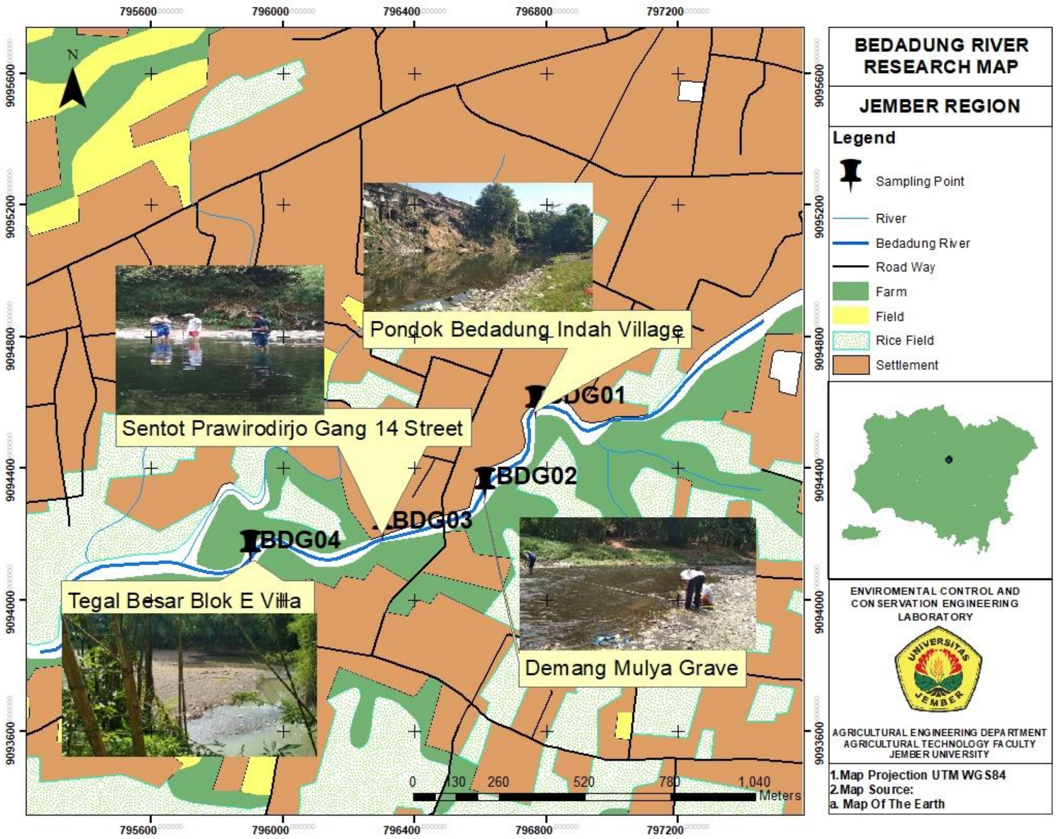

Figure 2 Map of sampling location at Sumbersari-Kaliwates segment of Bedadung River from Upstream to Downstream

River Hydraulic Profile

The river hydraulic profile is to determine the shape of the river, which is determined by the measurement of river depth (Gleason, 2015). Measurement of river depth using 10 sections at each research point. The river profile can be seen in Figure 3. The depth of this river is the basis for measuring the flow velocity. Determination of the depth of flow velocity measurement can be seen in Table 2. Streamflow and pollution load measurements at each cross-section can be calculated by Equations 1 and 2 (Djoharam *et al.*, 2018; Novita *et al.*, 2020a).

$$Q = V X A \tag{1}$$

Description:

Q : streamflow (m^3/ sec)

V : flow velocity (m/sec)

A : cross sectional area (m^3)

$$BP = Q \times C \tag{2}$$

Description:
BP: pollution load (kg/day)
Q : river water flow (m3/sec)
C : waste concentration (mg/L)

Table 1 Sampling point or location

Point		Village	District	Coordinate(°)	
				Longitude	Latitude
Segment I	BDG01	Kebonsari	Sumbersari	113.693219	-8.182072
Segment II	BDG02	Kebonsari	Sumbersari	113.691855	-8.183987
Segment III	BDG03	Talangsari	Kaliwates	113.689503	-8.185193
	BDG04	Tegal Besar	Kaliwates	113.685071	-8.186457

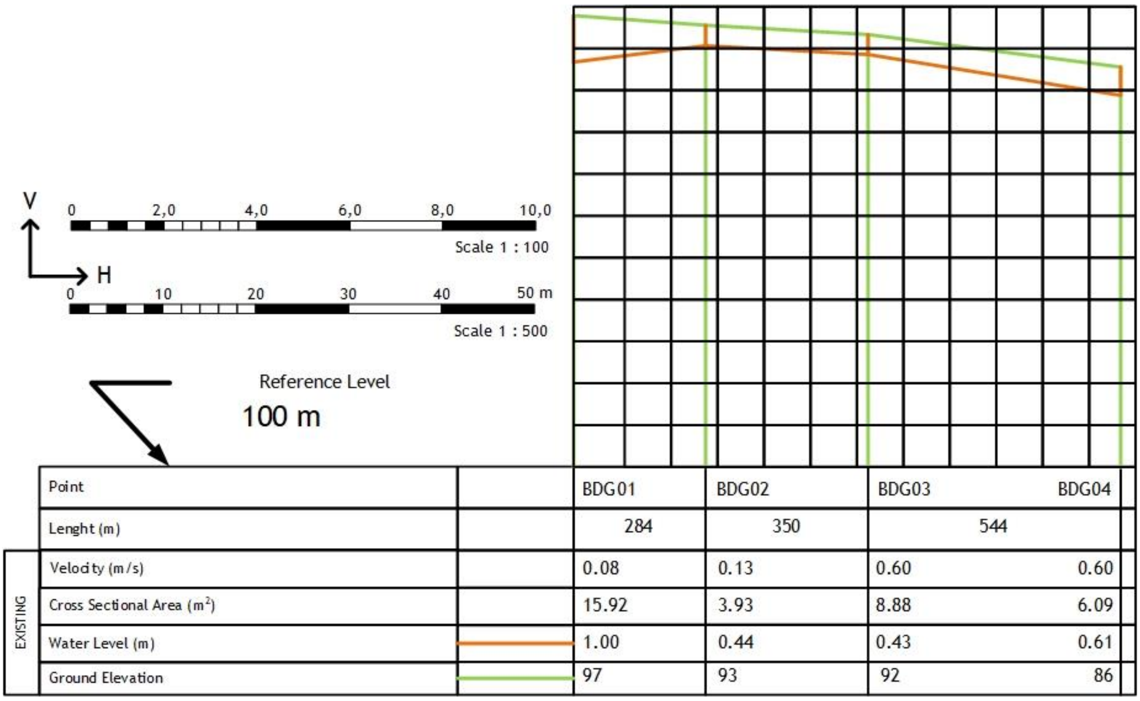

Figure 3 Relationship of streamflow and River Hydraulic Profile of Bedadung River

Table 2 Determination velocity measurement

N (Rotation)	Velocity Equation (m/s)
N < 0.74	V= 0.1322 N + 0.0141 m/s
0.74 < N < 11.53	V= 0.1277 N + 0.0175 m/s
N > 11.53	V= 0.1248 N + 0.0095 m/s

Source: Indonesian National Standard (2015)

Analysis of Reoxygenation Rate and Deoxygenation Rate

Streeter-Phelps introduced the oxygen sag curve, which is the management of water quality that is determined based on the critical oxygen deficit (Dc) (Wu and Yu, 2021). It is used as a water quality modeling tool for research on water pollution. Then, the model is associated with the reduction of DO and BOD decreased phenomena in water bodies. This model was further developed and disseminated. This model refers to a fixed one-dimensional category. Reoxygenation the process of reducing dissolved oxygen due to bacterial activity in grading organic matter in water, and deoxygenating, the process of increasing dissolved oxygen caused by turbulence that occurs in river flows, are two phenomena that are limited in this modeling (Decree of the State Minister of the Environment Number 110 of 2003; Zurita *et al.*, 2021).

According to the Decree of the State Minister of the Environment Number 110 of 2003, guidelines for carrying capacity of water pollution loads in water sources that the K' and K2' values are a function of temperature whose constant value depends on the temperature of the river, so the equations used are equations 3 and 4 as follows.

$$\mathrm{K'T} = \mathrm{K'}\ (1.047)^{\mathrm{T}-20} \tag{3}$$

$$\mathrm{K'\ 2T} = \mathrm{K'2}\ (1.016)^{\mathrm{T}-20} \tag{4}$$

Based on the Decree of the State Minister of the Environment Number 110 of 2003, guidelines for carrying capacity of water pollution loads in water sources that the rate of biochemical oxidation of organic compounds using Streeter-Phelps method determined by the concentration of residual organic compounds as in the calculation of equation 7. If the initial concentration of organic compounds as BOD is Lo which is expressed as ultimate BOD, and Lt is BOD at time t, then Equation 5 results from the integration. Determination of K' can be done by Equation 6. The rate of deoxygenation due to organic compounds can be expressed by Equation 7 as follows. Then, if L is replaced with Loe-K't, conversion in equation 8.

$$\mathrm{Lt} = \mathrm{Lo.\,e}^{\ (\mathrm{k.t})} \tag{5}$$

$$\mathrm{K'} = 0.3\ \left(\frac{H}{8}\right)^{-0.434} \tag{6}$$

Description:
K' : first order reaction constant (day^{-1});
H : water depth in the channel (m)

$$\mathrm{rD} = -\mathrm{K'L} \tag{7}$$

Description:
K' : first-order reaction constant (day^{-1})
L : ultimate BOD at the required point (mg/L)

$$\mathrm{rD} = -\mathrm{K'.\,Lo.\,e}^{-\mathrm{K.t}} \tag{8}$$

Description:
Lo : ultimate BOD at the point after mixing (mg/L)

According to the Decree of the State Minister of the Environment Number 110 of 2003, guidelines for load-carrying capacity Water pollution in water sources states that the oxygen content in water will increase due to turbulence, resulting in the transfer of oxygen from the air to water. This process is called the reaeration process. Equation 9 is used to calculate the process of increasing dissolved oxygen as follows. Then, in the O'Cornor and Dobbins equations, the reaction constant K'2 can be calculated by Equation 10.

$$\mathrm{rR} = -\mathrm{K'\ 2(Cs - C)} \tag{9}$$

Description:
K'2 : constant of reaeration day^{-1} (natural number basis)
Cs : concentration of saturated dissolved oxygen (mg/L)
C : concentration of dissolved oxygen (mg/L)

$$K'2 = \frac{294(D_{Lt}.V)^{\frac{1}{2}}}{H^{\frac{3}{2}}} \quad (10)$$

Description:
DL : molecular diffusion coefficient for oxygen (m^2/day)
U : mean flow velocity (m/sec)
H : mean water depth (m)

RESULTS AND DISCUSSION

Bedadung River Water Quality

Monitoring of water quality in Bedadung River at 4 points (BDG01, BDG02, BDG03, and BDG04) involving physical and chemical parameters. The results of the examination of the water quality of Bedadung River are presented in Table 3. The sampling locations BDG01 to BDG04 are in Sumbersari and Kaliwates sub-districts which have a TSS value of 4.26 mg/L-6.74 mg/L. The highest TSS value found in BDG02 was 6.74 mg/L, while the lowest TSS value was found in BDG03 with a value of 4.26 mg/L. The highest TSS value is because, at that point, it has the highest speed value of 0.13 m/second. Then on the banks of the river, there is also a lot of sand which makes the TSS value at BDG02 high. The phenomena are influenced by water velocity and runoff characteristics (Shah *et al.*, 2014; Liu *et al.*, 2019b). Referring to Government Regulation of the Republic of Indonesia Number 82 of 2001, the river water quality standard for the TSS parameter in the class I category has a threshold value of 50 mg/L. Thus, the results of the examination of TSS parameters at 4 monitoring points did not exceed the class I quality standard with an average value of 5.26 mg/L. In line with the TSS parameter, the dissolved oxygen parameter indicated by the DO value is still in a fairly good category.

Table 3 Water quality of Bedadung River segment Sumbersari-Kaliwates District

Parameter	Unit	Sampling Point				Average	Standard Deviation (SD)	Water Quality Criteria *)			
		BDG01	BDG02	BDG03	BDG04			I	II	III	IV
TSS	mg/L	5.09	6.74	4.26	4.96	5.09	0.58	50	50	400	400
DO	mg/L	6.28	6.94	6.54	6.74	6.28	0.88	6	4	3	0
BOD	mg/L	2.86	2.61	2.74	2.53	2.86	0.32	2	3	6	12
COD	mg/L	36.56	41.56	27.00	34.78	36.56	17.51	10	25	50	100

*Source: Government Regulation Number 82 of 2001

The highest DO value is at point BDG02. The high value of DO at the monitoring location is thought to be due to the high value of the water flow velocity so that the reaeration or reoxygenation becomes high. The Reaeration of air from the atmosphere to water bodies is influenced by the hydraulic profile of the river and the water velocity (Haider *et al.*, 2013; Pradana *et al.*, 2019a). The lowest DO value is found in BDG01 because the surrounding environment is a densely populated residential area used for bathing, washing, and latrines. In addition, at the BDG02 point, there is a trash can in the river body, resulting in a low DO value. The DO value of the Bedadung River that crosses the Sumbersari-Kaliwates sub-district still meets the class I water quality standard with an average DO value of 6.64 mg/L. However, the BOD and COD parameters have exceeded the class I water quality standards.

The highest BOD parameter value is BDG01, with a value of 2.86 mg/L. This phenomenon is caused by environmental conditions around or river bank the water sampling location, which is a densely populated residential area that usually includes bathing, washing and latrine activities. Then at that location, there is also a trash can that pollutes the river so that the BOD value is high. The lowest BOD parameter value is at the BDG02 monitoring point with a value of 2.53 mg/L. The low BOD value is caused by the lack of population activities carried out at the BDG01 location. In line with this condition, the value of the COD parameter has similar conditions to the BOD parameter. The highest COD value was found at the BDG02 monitoring point, with a value of 41.56 mg/L. This is due to the accumulation of point 1, which is an area with densely populated housing. Then at the time of sampling, the community was doing bathing, washing, and latrine activities on the Bedadung River.

Furthermore, the lowest COD parameter value was found in BDG03, with a value of 27.00 mg/L. The low COD value is caused by the reaeration process that occurs in the previous bend flow and rocks so that the concentration is reduced. In general, fluctuations in BOD and COD values until they reach the highest values are influenced by domestic activities. Domestic wastewater reduces DO value and increases exposure to organic matter (BOD and COD parameters) from dilution of detergents and dyes, thereby reducing river water quality (Khatri and Tyagi, 2015; Mazari-Hiriart *et al*., 2019). Then, the wastewater will cause an oxygen deficit zone due to the natural degradation of organic matter (Liu *et al*., 2019b).

Pollution Load of Bedadung River

In general, pollution load in the river factor is streamflow and pollutant concentration. Based on Figure 4, the highest streamflow value is found in BDG01, with a streamflow value of 1 509.34 L/s. The highest streamflow value at the monitoring point BDG01 is caused by the highest depth value of point 1 compared to the other 3 points. The depth value affects the value of the cross-sectional area, and the streamflow value becomes high. Then, the lowest streamflow value is located at the monitoring point BDG04 with a value of 169.28 L/s. This condition occurs due to the relatively low water velocity. The fluctuation of the discharge value will be influenced by the baseflow index, rainfall, and the hydraulic profile of the river (Gleason, 2015). The streamflow value will certainly affect the value of the river pollution load.

Streamflow and BOD affect the fluctuation of the pollution load (Jang *et al*., 2021). If the streamflow and BOD values increase, the pollution load value also increases, otherwise, if the streamflow and BOD values decrease, the pollution load value also decreases. At the monitoring location, BDG01 has the highest pollution load value, with a value of 334.51 kg/day. This condition is caused by the highest streamflow and BOD values located at the monitoring location BDG01. Then, the lowest pollution load value is found at the monitoring location BDG02, with a value of 69.76 kg/day. The monitoring location has a fairly low streamflow and BOD value compared to other monitoring locations. In addition, at the monitoring location BDG02 receives exposure to pollutants from domestic activities when conducting water sampling. Thus, the pollution load will have a directly proportional relationship with the BOD value and streamflow (Song *et al.*, 2022).

Analysis of Deoxygenation Rate and Reoxygenation Rate

The value of the reoxygenation constant at the monitoring locations BDG01 to BDG04 has a fluctuating value (Table 4). The description of the relationship between the hydraulic profile of the river, the deoxygenation-reoxygenation constant, and the rate of deoxygenation-reoxygenation can be seen in Figures 4, 5, and 6. The lowest reoxygenation constant value was found in BDG01 with a value of 1 500 mg/L.day. This phenomenon occurs due to the relatively low water velocity value of 0.08 m/s. The low value of the water velocity is caused by the large value of the depth and width of the river so that the oxygen supply as an indicator of the reoxygenation constant was low. Then, the highest reoxygenation constant value was found at the monitoring location BDG02 with a value of 6 229 mg/L.day. The high value of reoxygenation is because BDG02 has a small depth and width value of the river at the monitoring location, so the high flow velocity value is 0.13 m/s. In addition, there are also many rocks that cause turbulence and then increase the value of the reoxygenation constant. Then, the deoxygenation constant values at the monitoring points BDG01-BDG04 have various values.

Table 4 Results of calculation of Deoxygenation Rate (rD) and Reoxygenation Rate (rR)

Sampling Point	V	H	Kd	Kr	Lt	D	rD	rR
	m/s	M	day-1	day-1	mg/L	mg/L	mg/L.day	mg/L.day
BDG01	0.085	0.995	0.741	1.346	0.737	1.416	0.826	2.198
BDG02	0.133	0.444	1.052	5.666	0.674	0.721	1.072	4.715
BDG03	0.065	0.428	1.069	4.173	1.067	1.157	1.725	5.572
BDG04	0.065	0.609	0.917	2.401	0.654	1.085	0.853	2.941
Averages	0.087	0.619	0.945	3.397	0.783	1.095	1.119	3.856

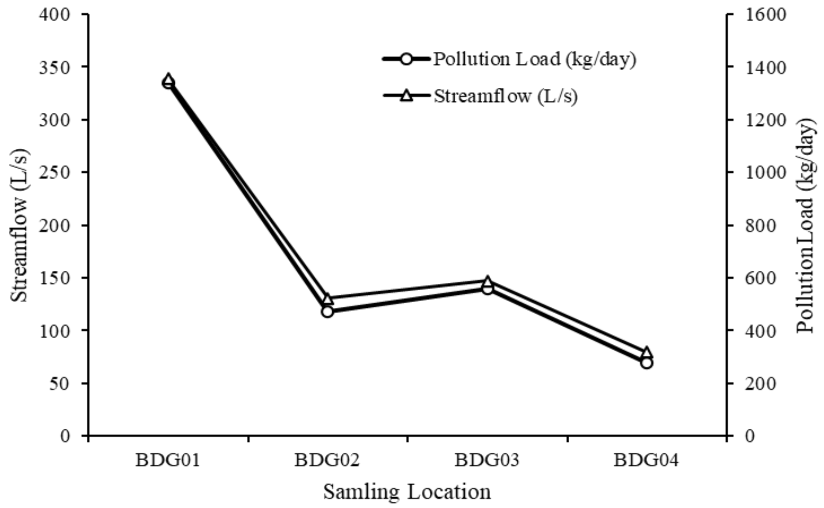

Figure 4 Streamflow graph at each sampling location of Bedadung River

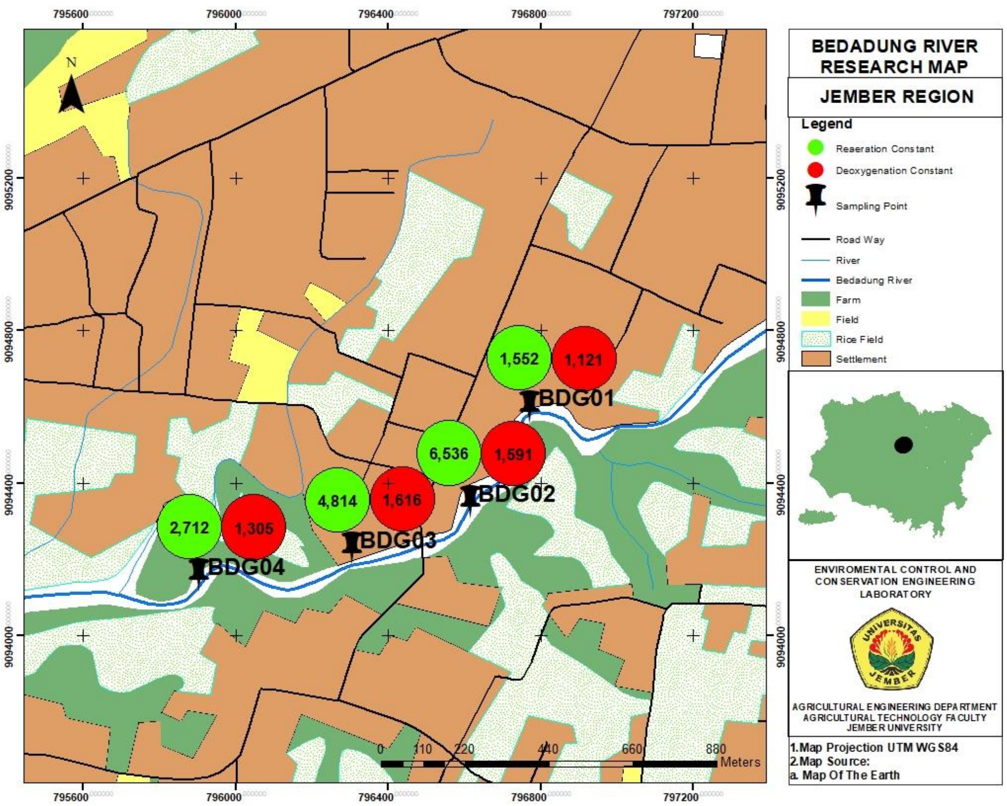

Figure 5 Map of values of reoxygenation constant and deoxygenation constant

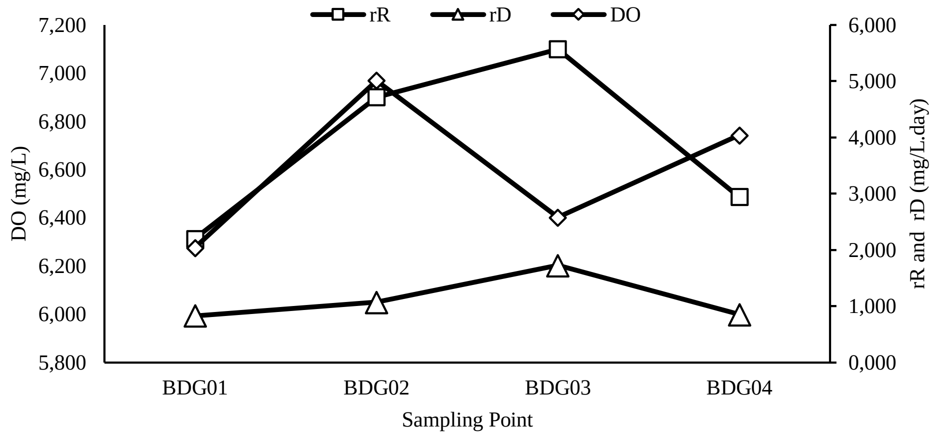

Figure 6 Relationship between rR, rD, and DO

The monitoring location with the lowest deoxygenation constant value is at the monitoring location BDG01 with a value of 1.110 mg/L.day, and the highest deoxygenation constant value is at the monitoring point BDG03 with a value of 1.665 mg/L.day. The lowest value of the deoxygenation constant was due to the large flow velocity value of 0.085 m/s and the small residual BOD concentration of 0.737 mg/L. Furthermore, the highest value was caused by the low-velocity value of 0.065 m/sec and the high residual BOD value of 1.067 mg/L. The high-velocity value results in a high reoxygenation value due to turbulence which is also the opposite of the deoxygenation value. A small residual BOD value indicates that the microbes are able to decompose well because of the high oxygen concentration (Huang *et al*., 2017; Pradana *et al*., 2019b).

CONCLUSION

The results showed that the Bedadung River crossing the Sumbersari and Kaliwates sub-districts had a lower dissolved oxygen reduction process than the oxygen increase process, with an average deoxygenation rate (rD) value of 1.119 mg/L.day and a reoxygenation rate (rR) value of 3.856 mg/L.day. The natural purification or automatic purification process of organic matter pollution that occurs in the Bedadung River is still in a good performance so that the deoxygenation rate (rD) value is lower than the reoxygenation rate (rR) value.

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