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To cite this article: H A Pradana *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **243** 012006

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Analysis of deoxygenation and reoxygenation rate in the Indonesia River (a case study: Bedadung River East Java)

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Abstract. Bedadung River is the main river in the Jember Regency – East Java. The organic and inorganic waste from human activity increases potential pollution loads in the river. The pollution load impacts on the water quality of the river. The oxygen existence as an indicator of river water quality that was determined based on deoxygenation and reoxygenation rate. It was one of decision making for the government on water quality management in the watershed. This research aims analyzed pollution loads, deoxygenation and reoxygenation rate of Bedadung River in the Patrang - Summersari segment. Simple mathematical analysis model oxygen distribution used the Streeter-Phelps method. This method applied dissolved oxygen data (DO) and biological oxygen demand (BOD) as the input data. The results represented that the highest pollution loads at point 7 in value 1198.6 kg/day. Based on the calculation of oxygen distribution with Streeter-Phelps formula, the rate of deoxygenation (r_D) < reoxygenation (r_R) a sequence were 0.028 mg/day.L and 0.053 mg/day.L. It indicated a good functioning for pollutant degradation. The government and stakeholder had been maintained through an integrated water quality management scheme and pollution control on the Bedadung River.

1. Introduction

Generally, water resource management included planning, developing, distributing and controlling water resources optimally both in terms of quality and quantity [1]. Management of water resources related to watersheds. Basically, the water allocation, natural process, and anthropogenic activities in watershed cause potential pollution [2, 3]. It decreased water quality resources and cleans water access. Pollution control could be done by monitoring water quality. Monitoring of river water quality has the aim of assessing the feasibility of water resources for certain purposes [4]. Water quality monitoring was one part of water quality management.

The Bedadung Watershed in Jember Regency has several rivers. The main river is the Bedadung River that crosses Jember Regency with a length of 46,875 meters. It was used irrigation by the regional government in 93,000 hectares of rice fields [5]. It's one of a strategic river of East Java Province. The strategic function of the Bedadung River is as a source of clean water supply for the community and as one of the raw water sources for PDAM Jember Regency [2]. In addition, this river is applied as the place where the activity of washing, bathing, and latrines happening. Patrang and Summersari sub-districts are flowed by Bedadung River.

Population growth and variation of domestic activities increased the potential for pollution in Bedadung River. It was from organic (biodegradable) as nitrate and inorganic (non-biodegradable)



matter as heavy metal. Uniform study stated that urban activities in Jember Regency increased the potential of Bedadung River pollution to reach the heavily polluted points in the Patrang, Summersari, Kaliwates and Mangli sub-district [6,7]. Research carried out in the downstream area of Bedadung River receives pollutants source from domestic activities and irrigations [2]. Human activity in urban areas pollutes Bedadung River based on indicators of pollution load. Identification of pollution loads using data on the distribution of oxygen and organic matter in water bodies [8]. Distribution of oxygen the river water quality and self-purification performance [9, 10]. It becomes the consideration of decision making for a government, to apply strategic in water quality management in watershed [11,12, and 13]. Based on regulation in Indonesian Ministry of Environment and Forestry No. 110 in 2003, water quality management in a watershed is identified with deoxygenation and reoxygenation rate.

Streeter-Phelps is a simple mathematical model that describes the distribution of oxygen in the river by plug flow or it does not consider any flow input from other rivers [3, 14]. Bedadung River in Patrang - Summersari segment did not consider any input from other rivers. Identification of oxygen content in water was indicated by the value of Dissolved Oxygen (DO). Then, Biological Oxygen Demand (BOD) indicated biodegradable organic matter in the water. Input data from Streeter Phelps model have Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD) [15, 16]. Mathematical equations on Streeter Phelps is able to describe the interaction of the oxygen distribution with pollutants based on the kinetics process in water bodies [17]. The process was identified by the rate of deoxygenation and reoxygenation. Deoxygenation rate is a process of oxygen reduction while the rate of reoxygenation is the process of adding oxygen to the body of water [8, 18]. Both processes are influenced by river profiles [2, 19]. Therefore, the purpose of this research analyzed the pollution load and, deoxygenation and reoxygenation rate in the Bedadung River in the Patrang - Summersari segment.

2. Method

This research type was quantitative descriptive. It was done to determine the rate of deoxygenation and reoxygenation based on data Dissolved Oxygen (DO) as the indicator as oxygen availability and Biological Oxygen Demand (BOD) as the indicator as biodegradable organic matter in Bedadung River. Analysis of oxygen distribution in water bodies with the Streeter Phelps method refers to the Indonesian Ministry of Environment and Forestry No. 110 in 2003. This study began in February - April 2017. Generally, the methodology of this research was the sampling location, water quality identification, streamflow collection, pollution load measurement, deoxygenation, and reoxygenation rate analysis.

2.1 Sampling

2.1.1 Survey and Selection Sampling Location

The location sampling was taken after the river branch which enters into the main river Bedadung in Patrang Village, Baratan Patrang District and it ends at Tegalgede Village, Summersari sub-district with a river length of 3.27 km. The coordinates and description of the sampling location are presented in Table. 1, then the profile of the study location can be seen in Figure 1 and 2.

2.1.2 Sampling

The sampling method applied the grab sampling method. Grab sampling is an instantaneous retrieval method to take samples directly from a body of water monitoring. Generally, sampling was based on methods in the Indonesian National Standard (SNI) in 2008 concerning the method of surface water sampling.

2.2 The Analysis of Stream Flow and Water Quality Analysis

Generally, the measurement of streamflow was carried out based on the Indonesian National Standard (SNI) in 2015 concerning the measurement of streamflow in open channels. Measurement of streamflow (Q) at the sampling location can be obtained by multiplying the average velocity or flow of each river with a current meter and the total cross-sectional area which is formulated in equation 1 [20].

$$Q = \sum_{n=1}^n (V_{\text{section}} \times A_{\text{section}}) \quad (1)$$

Explanation:

- V_{section} = Velocity or flow in section (m/s);
- A_{pias} = Sectional are (m²);
- Q = Stream flow (m³/s).

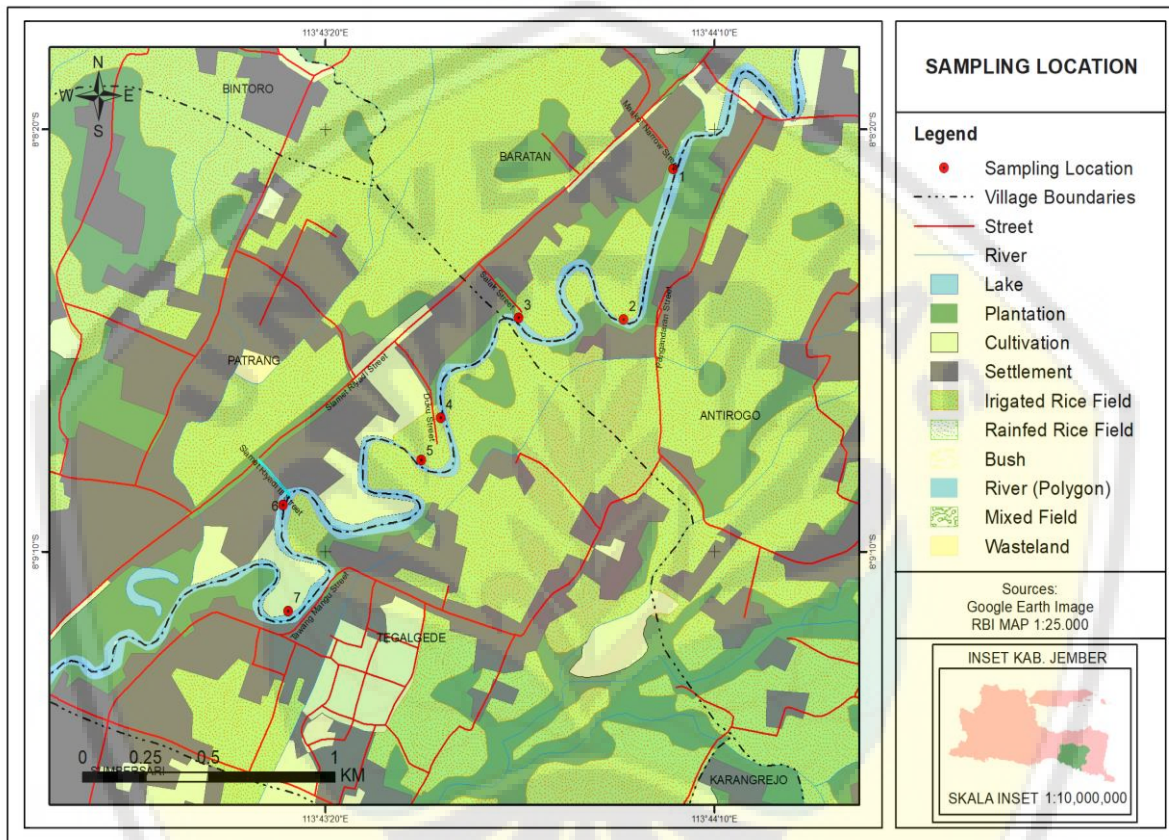


Figure 1. Sampling location profile

Water quality data measured in the study was Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD). The measurement method was Standard Method 2012.

Table 1. Sampling location

Point	Locations	Village	Sub-district	Coordinate	
				Longitude	Latitude
1	Jl. Gg Maskot	Baratan	Patrang	113,7346470	-8,1401770
2	Jl. Pengandaran	Baratan	Patrang	113,7328810	-8,1451270
3	Jl. Salak	Patrang	Patrang	113,7291350	-8,1450870
4	Jl. Duku	Patrang	Patrang	113,7263520	-8,1483590
5	Jl.Slamet Riyadi	Patrang	Patrang	113,7256520	-8,1497490
6	Jl. Slamet Riyadi III	Patrang	Patrang	113,7207340	-8,1512300
7	Jl. Tawang Mangu	Tegalgede	Sumbersari	113,7209160	-8,1547150

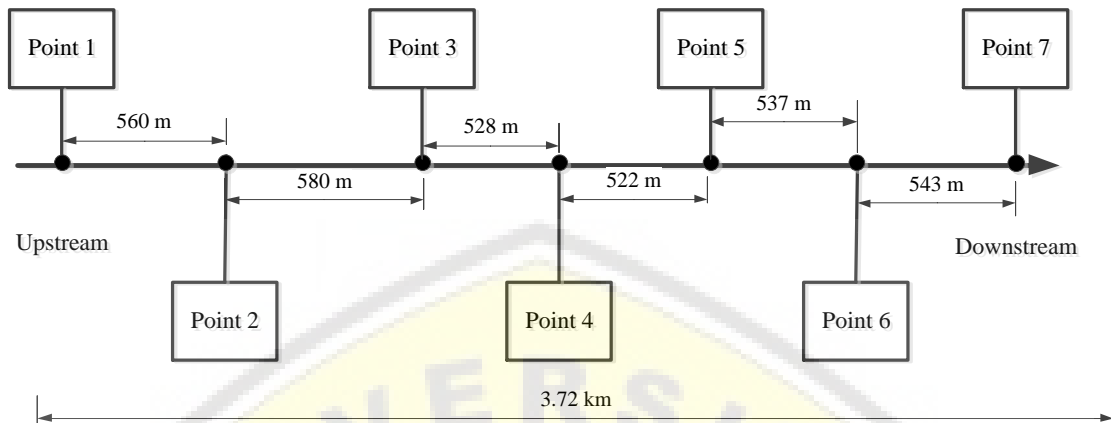


Figure 2. The sketch of length section

2.3 The Measurement of Pollution Load

Pollution load was the amount of a pollutant element contained in water. The pollution load could be determined by measuring directly the stream flow and the pollutant concentration in water or in waste at the sampling location of the river. Based on the measurement of streamflow and concentration of polluters, then load the pollution can be calculated used equation 2 [2].

$$BP = Q \times C \quad (2)$$

Explanation:

- BP = Pollution load (kg/day);
- Q = Stream flow (m³/s);
- C = Concentration (mg/L);

2.4 The Measurement of Deoxygenation and Reoxygenation Rate

The rate of deoxygenation (rD) and reoxygenation (rR) were related to the river biochemical processes. Deoxygenation constants (K') and reoxygenation constants (K'₂) are required to calculate rD and rR in equations 3 and 4 [21] and [14]. The measurement of deoxygenation and reoxygenation rate is represented in equations 5 and 6.

$$Lt = Lo \cdot e^{(K't)} \quad (3)$$

$$K'_2 = \frac{294 (D_L U)^{1/2}}{H^3} \quad (4)$$

$$rD = -K'L \quad (5)$$

$$rR = K'_2 (Cs - C) \quad (6)$$

Explanation:

- K' = Constanta of reoxygenation (1/day);
- K'₂ = Constanta of reoxygenation(1/day);
- L = BOD ultimate a point (mg/L);
- Cs = Concentration of saturated dissolved oxygen (mg/L);
- C = Concentration of dissolved oxygen (mg/L)
- rD = Deoxygenation rate (mg/L.day)
- rR = Reoxygenation rate (mg/L.day)
- Lo = BOD ultimate (mg/L)
- D_L = Coefficient of diffusion oxygen molecular (m³/day)
- U = River flow (m³/s)
- H = River depth (m)

3. Results and Discussion

3.1 Results

Based on the measurement of streamflow, it is obtained some variations at each sampling location in figure 2. The streamflow variations in table 2 affect the data water quality of Bedadung River.

The DO fluctuations of stream flow, DO, and BOD concentration describes pollution load values at any sampling location on table 3. Determination of the pollution load was applied as one indicator to identify the oxygen distribution based on the deoxygenation and reoxygenation rate in the Bedadung River.

3.1.1 The Stream Flow Measurement of Bedadung River

This research was conducted along the Bedadung River in Patrang – Summersari sub-district. The sampling location is divided in the 7 reaches per point with a length of 3.27 km.

From Figure 2, the largest stream flow is located at location 1 and 2. It has the stream flow value $7.26 \text{ m}^3/\text{s}$ and $7.20 \text{ m}^3/\text{s}$. It was affected by the river area and high velocity. Additionally, the elevation condition increased the velocity potential. Uniform fact, the river profile impact for discharge produced [22,21]. Figure 3 represents the correlation between the streamflow and river profile. The streamflow value decreased at the location in point 1 until location 5. It caused due to a pile of garbage, twigs, and rocks that disturbed the velocity of the water flow.

The increasing of streamflow once occur at location 6 with value $7.04 \text{ m}^3/\text{s}$. The upstream had a higher than topography the downstream. It made the water flow faster. The lowest streamflow occurs in a location in point 5 at Slamet Riyadi Street, Patrang Village with value $7.01 \text{ m}^3/\text{s}$. The low streamflow value generated in the area is caused by the river condition along the location 4 until 5. It is influenced by a lot of rocks which cause the water flow becoming slow. Obstacles in the river cause attenuation of flow energy thus slowing down the flow [20,19].

Based on this study, fluctuations in river flow conditions throughout the research also was caused by the accumulation of falling debris, tree branches and leaves, thereby reducing the flow or velocity rate of river water. High and low streamflow also affected the pollution load value.

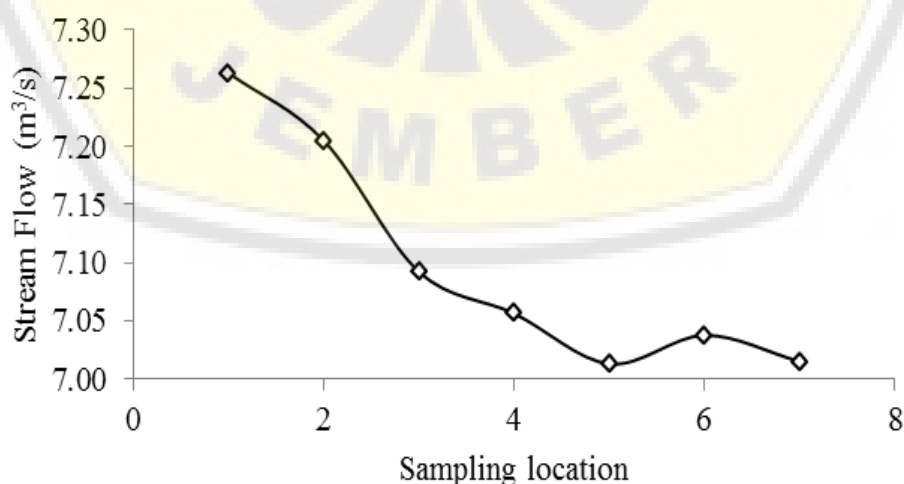


Figure 3. The graph of streamflow

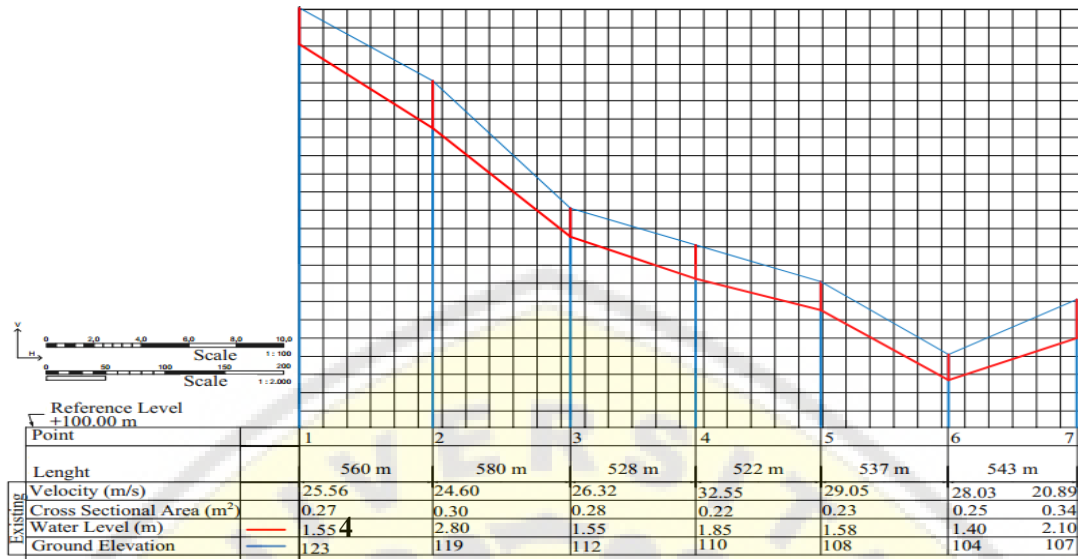


Figure 3.1.2. Correlation streamflow with river profile

3.1.2 The Analysis of Water Quality and Pollution Load

Measured of water physical-chemical parameters such as DO and BOD are some of the parameters that get the most attention because they reflect the water quality and health of aquatic ecosystems [16,1]. Water quality parameters in the form of BOD and DO based on Government Regulation (PP) No. 82 of 2001 didn't exceed Class I categories. This quality class designation was a good quality ecosystem. The comparison of the water quality of the Bedadung River in Patrang and Summersari sub-district with the PP 81 of 2001 is in Table 2.

Table 2. Water quality data and river water quality standard

Parameters	Unit	PP RI No. 82 the Year 2001 (Water Allocation)				Average of water quality on Bedadung River
		I	II	III	IV	
BOD	mg/L	2	3	6	12	1,66
DO	mg/L	6	4	3	0	8,21

Source: data is processed, 2018

Table 3. Pollution load

Point	Q Total		BOD	Pollution load
	(L/s)	(m ³ /s)	(mg/L)	(kg/day)
1	7262.93	7.26	1.22	767.7
2	7204.90	7.20	1.24	773.7
3	7092.34	7.09	1.69	1038.6
4	7056.51	7.06	1.78	1086.3
5	7013.31	7.01	1.78	1078.1
6	7037.82	7.04	1.86	1131.0
7	7015.32	7.02	1.98	1198.6

Source: data is processed, 2018

DO and BOD value is respectively at 8.21 mg/L and 1.66 mg/L. The pollution produced was not classified in the large category and some of the pollution that comes from domestic waste. Besides, the swift flow along the river made the DO value becomes higher. Based on the BOD measurement in Bedadung River, the pollution load value was influenced by the BOD concentration in each location. A range of load pollution from point 1-7 is 767.7-1198.6 mg/L in table 3. The highest pollution load is

located at location 7 = 1198.6 kg/day. The location 7 had the streamflow and pollution load accumulation from location 1–6.

3.1.3 The Analysis of Deoxygenation and Reoxygenation Rate

The Streeter-Phelps modeling is limited to two phenomena, namely deoxygenation, and reoxygenation. The deoxygenation and reoxygenation rate value use the Streeter-Phelps method in Figure 4. The range of deoxygenation and reoxygenation rate is 0.016-0.038 mg/day.L and 0.019-0.055 mg/day.L.

DO values is the opposite of the deoxygenation rate while the reoxygenation rate represents the same pattern according to figure 4. The deoxygenation rate increased if DO and reoxygenation rate decreased. But at the location in point 3, the same condition decreased value between DO and deoxygenation rate. DO and deoxygenation rate at the location in point 3 is 8.43 mg/L and 0.026 mg/day.L. The pollutant matter was difficult to degrade by a microorganism. The consequence, a process of increasing deoxygenation rate becomes slow [23]. But, the location in point 3 has increasing reoxygenation rate at value 0.042 mg/day L. In addition, the deoxygenation and reoxygenation rate at location 5 had a higher increase with the pattern of oxygen content (DO). Hence a lot of rocks along the river flow caused turbulence, so that the potential oxygen content received from air to water. The average rate of deoxygenation and reoxygenation were 0.028 mg/day.L and 0.053 mg/day.L. The Bedadung River had deoxygenation rate (r_D) < reoxygenation (r_R) rate at Patrang–Sumbersari Segment.

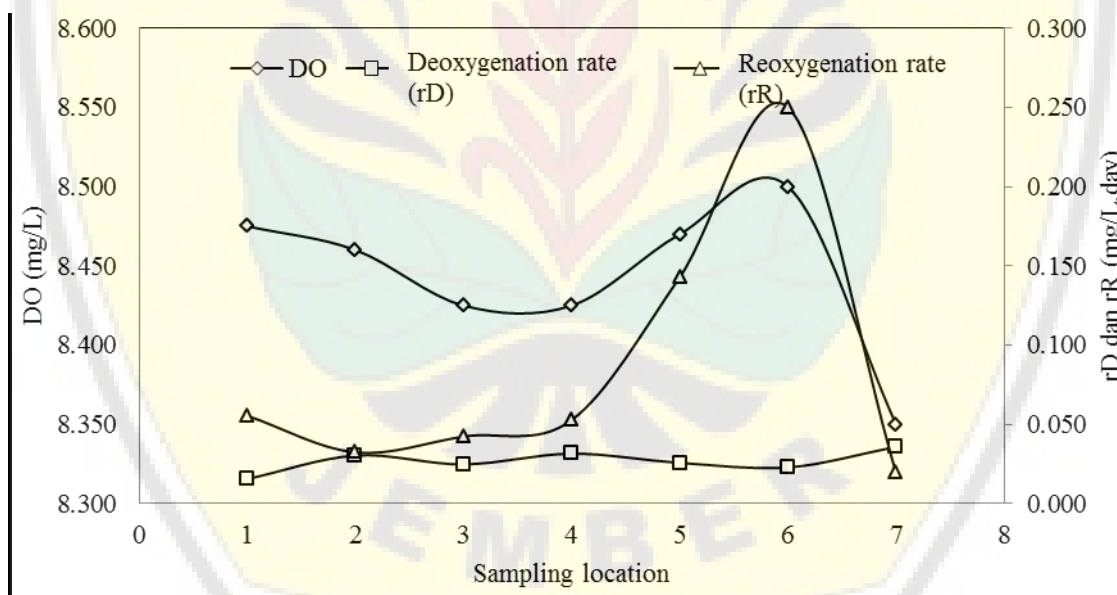


Figure 5. DO, rD and rR correlation

Based on the research was conducted at the identification of river profiles with the availability of oxygen in the Bedadung River, there were several discussions as follows;

- a. Generally, streamflow fluctuation was influenced by river profiles and anthropogenic activity. The sectional area and elevation river of the river accommodates the streamflow [20,9]. The rocks' relief in the river affected the water flow of a river. This condition was represented in the streamflow produced on Bedadung River. The sampling location with a large river crossing had as high water flow. It also created a high stream flow. So that, in equation 1, it is able to describe the phenomena at points 1 and 2. Additionally, at the point 6-7, it described the topographic variation which made the water flow faster. This condition was able to increase the value of streamflow. The Bedadung River as landfill at some points from the results of anthropogenic activity disrupted the river water flow. The disturbance affected the river streamflow measured at the moment. Beside garbage diminished river and region aesthetic.
- b. The water quality of Bedadung River in Patrang - Summersari sub-district on DO and BOD parameter was classified into good condition. The water resource was consumed as a source of

raw water for people. However, a river still contains some of the pollutant matter which was indicated by the BOD value [14, 23]. The study of the pollution load was used to determine the value of potential pollutants that flow or distribution in the river. The amount of pollution load is directly proportional to the streamflow and BOD concentration. The accumulation of stream flow and BOD in the downstream caused the last monitoring point to have the highest pollution load. The control of pollution load fluctuations could be reduced by waste runoff decreasing from anthropogenic activities through (1) reducing waste disposal into rivers, (2) enforcing integrated river management regulations, (3) reforestation upstream areas, and (4) monitoring water quality and quantity on a regular basis.

- c. The oxygen supply was needed by aerobic microorganisms to degrade pollutants in the rivers. Biochemical processes reduce biodegradable pollutants with oxygen availability [1]. It identified a ratio of deoxygenation and reoxygenation rates. DO and the rate of reoxygenation was inversely proportional to the rate of deoxygenation. However, this condition is not applied at point 3. Hence, pollutants are non-biodegradable so the deoxygenation rate remains high. However, the dimension level of river flow and the river crossing area produced higher in the rate of reoxygenation and DO concentration at point 6 in figure 3. The functioning of Bedadung river in the Patrang - Summersari sub-district in degradation of biodegradable pollutants was still good due to the deoxygenation rate (r_D) < reoxygenation rate (r_R). Then, the profile of Bedadung River (Patrang – Summersari sub-district) increased the potential for oxygen input from the atmosphere to the river so that the reoxygenation rate was higher than the deoxygenation rate. Uniform with the condition, the river profile and the type of pollutants affect the body's ability to recover [15,24]. Finally, on this fact, the profile of the river and the type of pollutants affected the water body's ability to recover. The government and stakeholder had been maintained through an integrated water quality management scheme and pollution control on the Bedadung River.

4. Conclusion

The result of the research was variation value of pollution loads, deoxygenation and reoxygenation rate. The range of load pollution from point 1-7 is 767.7-1198.6 mg/L. The highest pollution load is located at location 7 = 1198.6 kg/day. Then, a range of deoxygenation and reoxygenation rate is 0.016-0.038 mg/day.L and 0.019-0.055 mg/day.L from Streeter Phelps formula. Additionally, The Bedadung River had deoxygenation rate (r_D) < reoxygenation (r_R) rate at Patrang–Summersari Segment with value 0.028 mg/day.L and 0.053 mg/day.L. It indicated a good functioning for pollutant degradation. The government and stakeholder had been maintained through an integrated water quality management scheme and pollution control on the Bedadung River.

Acknowledgments

This research was funded by the Indonesia Ministry of Research, Technology, and Higher Education (Number 1318/UN 25.3.1/LT/2018). The authors also acknowledge the University of Jember for providing facilities during the research work.

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