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Regional Case Study

The Ability of Dissolved Oxygen and Biochemical Oxygen Demand Parameters to Self-purify in the Garang River

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Abstract
Garang River is administratively located in Semarang Regency, Kendal Regency, and Semarang City. Population growth and the number of community activities around the river can affect the water quality of the Garang River. Wastewater discharged into the Garang River will reduce water quality. The number of pollutants that enter the river changes the quality of river water until it reaches a pollutant level that exceeds the quality standard. The purpose of this study was to determine the self-purification ability of the Garang River using the Streeter-Phelps method based on DO and BOD parameters to obtain an oxygen sag curve for oxygen reduction. There are 3 monitoring stations that are located in the upstream segment of the Garang River. The value of the deoxygenation constant (K) in segment 1 is around 0.340, the reaeration constant (R) is 3.433, and the value of fs = 10.103. While in segment 2. the value of K is 0.335, R is 3.417, and fs is 10.194. It is revealed that segment 1 and segment 2 of the Garang River have not yet experienced optimal natural purification because they are still in the degradation zone.

Keywords: BOD; deoxygenation; DO; reaeration; self-purification; Streeter-Phelps

1. Introduction

Dissolved oxygen (DO) is an essential requirement for respiration of all organisms, and microorganisms need waste in the decomposition process of organic matter contained into simpler compounds (Ferreira et al., 2020). Oxygen in water generally comes from free air by diffusion on the water's surface and is the result of the photosynthetic process of aquatic plants. The oxygen content in water bodies is affected by the temperature and pressure of the air above it (Diamantini et al., 2018). Biochemical Oxygen Demand (BOD) is a parameter commonly used to determine pollution by organic matter in wastewater. Shows the amount of oxygen used by microorganisms in the water to oxidize organic substances in the wastewater for a certain period, usually 5 days and at a specific temperature, usually 20°C (Effendi, 2003).

The influence of land use on the main river flow is closely related to the function of vegetation as land cover and a source of organic matter that can increase infiltration capacity. Moreover, the vegetation will pretend the surface runoff and increase surface detention and depression storage (surface drift), thereby reducing the amount of river flow (Chakraborty, 2021). Land use has a significant factor in the decline in environmental quality, especially the quality of river waters (Tian et al., 2019). Self-purification is the ability of nature to overcome pollution problems that occur in certain circumstances that do not exceed its carrying capacity (Hendrasarie and Cahyarani, 2010). In the nature, water can purify by themselves by a simultaneous complex process which includes physical, chemical, and bilological process. The DO amount in the water is used frequently to determine the river condition (Li et al., 2020). The ability of river purification occurs because of the dilution and the process of reshuffling pollutants. The two main processes that occur in the natural purification of the river water are deoxygenation caused by the decomposition of carbon-containing organic matter by bacteria and atmospheric reaeration. The effect of deoxygenation and reaeration will form an oxygen deficit profile along with the water flow, called the DO curve. This model can be applied with the assumption that the cross-section of the river is the same along the stream under consideration, the flow velocity is constant, the oxygen concentration and BOD are uniforms in the lateral and vertical directions across the entire cross-section, the influence of algae and silt is negligible, and the rate of deoxygenation and reaeration reactions is considered constant (Chapra et al., 2021)

The presence of DO in water bodies is supported by reaeration. Reaeration has resulted from the difference in oxygen concentration in the air and the water. Generally, the source of DO in the water bodies are coming from the ambient air (Goncalves, et al., 2017). The oxygen transfer between the atmosphere and water bodies occur when the oxygen concentration in the water is not equal to the oxygen in atmosphere (Mader et al., 2017). In addition, reaeration is also influenced by photosynthetic activity, mixing, mass movement of water and wastewater that enters the river. If there is an excessive deficit in DO, a condition can occur where DO decreases to zero, and a very unexpected river condition, namely anaerobic conditions, where fish and other aquatic creatures that need oxygen will die. The river is categorized as heavily polluted (Piatka et al., 2021).

River modelling was introduced by Streeter and Phelps in 1925 using the oxygen sag curve equation where the water quality management method is determined based on critical oxygen deficit (Dc). The basic principles of the model include the rate of dilution of oxygen in water (deoxygenation) and the rate of oxygen intake from the atmosphere (reaeration). The deoxygenation rate is directly related to organic wastewater decomposed in the river (Yustiani et al., 2018). In contrast, the reaeration rate is a characteristic function of river water affected by the oxygen exchange from the water, affecting the water's ability to hold oxygen (saturation level). The oxygen saturation level is inversely proportional to the temperature of the water (Diamantini et al., 2018). Changes occur due to the presence of a wastewater source so that the oxygen level in the water decreases. This situation happens because the rate of deoxygenation exceeds the rate of reaeration. Reaeration is related to physical factors in water, diffusion of oxygen from the atmosphere, and artificial structures such as bridges, weirs, and reservoirs. These artificial structures can increase the turbulence of river water, which can cause or increase the exchange of oxygen from the atmosphere into the water (Chakraborty, 2021). In addition, increasing the distance causes mixing wastewater with river water which can cause changes in the concentration of its constituents (Ustaoglu et al., 2021). The greater the value of the reaeration constant, the greater the river's potential to provide DO from the atmosphere and the greater its potential for scientific decomposition, oxidation, and purification. In addition, the constant value of river water reaeration depends on the profile of the river and the magnitude of the turbulence of river water. The values range from 0.05 for small ponds/rivers to 0.50 for large rivers and high turbulence. Reaeration coefficient is determined in the field (Syafrudin, 2017). Rivers can purify themselves or self-purify to decompose pollutants that enter the river as long as the pollution that occurs is still below the specified quality standard (Golubkov et al., 2020). Self-purifying abilities work to remove organic matter, excessive nutrients, or persistent contaminants caused by the microbial activities that live in them and other natural phenomena (Nugraha et al., 2020b). The evaluation of self purifying ability of a river is needed to undertake an appropriate local policy. Therefore, additional information related to the self-purifying ability is needed in each region to boost the environmental preservation practices in each region.

Garang River is administratively located in Semarang Regency, Kendal Regency, and Semarang City (Setiawan and Masduqi, 2019). Population growth around the Garang River and the number of community activities around the river can affect the water quality of the Garang River. This study aimed to determine the water quality of the Garang River for DO and BOD parameters. In addition, it also analyzes the self-purification ability along with the segmented flow that has been determined using the Streeter-Phelps method.

2. Methodology

The research was conducted in the Garang River Basin, Semarang City, located in 3 sub-districts considered necessary to take water samples, namely Sadeng Village, Sukorejo Village and Kalipancur Village. River water sampling locations were determined based on several considerations: regional topography, river morphology, potential water sources, potential sources of pollutants, land use, and administrative boundaries. The research was carried out within 4 months, during November 2018 to February 2019. This study also followed the methodology of the previous research conducted by Nugraha et al., (2020a) where the sampling of river water was carried out based on SNI 6989.57:2008 concerning Surface Water Sampling Methods. The laboratory testing of the DO parameter is also referring to SNI 6989.72:2009, while the BOD is referring to SNI 6989.14:2004 (Nugraha et al., 2020a).

Data processing is carried out by analyzing the DO and BOD parameters concentration at sampling points 1-3, which are the upstream segment of the Garang River (See Figure 1). A comparison is made with the Class I water quality criteria in Government Regulation Number 82 of 2001 concerning Water Quality Management and Water Pollution Control. In determining the self-purification constant, calculations were carried out to determine the deoxygenation magnitude and reaeration constants. Next, the DO deficit (Dc) is calculated at each point and then plotted into the oxygen sag curve.

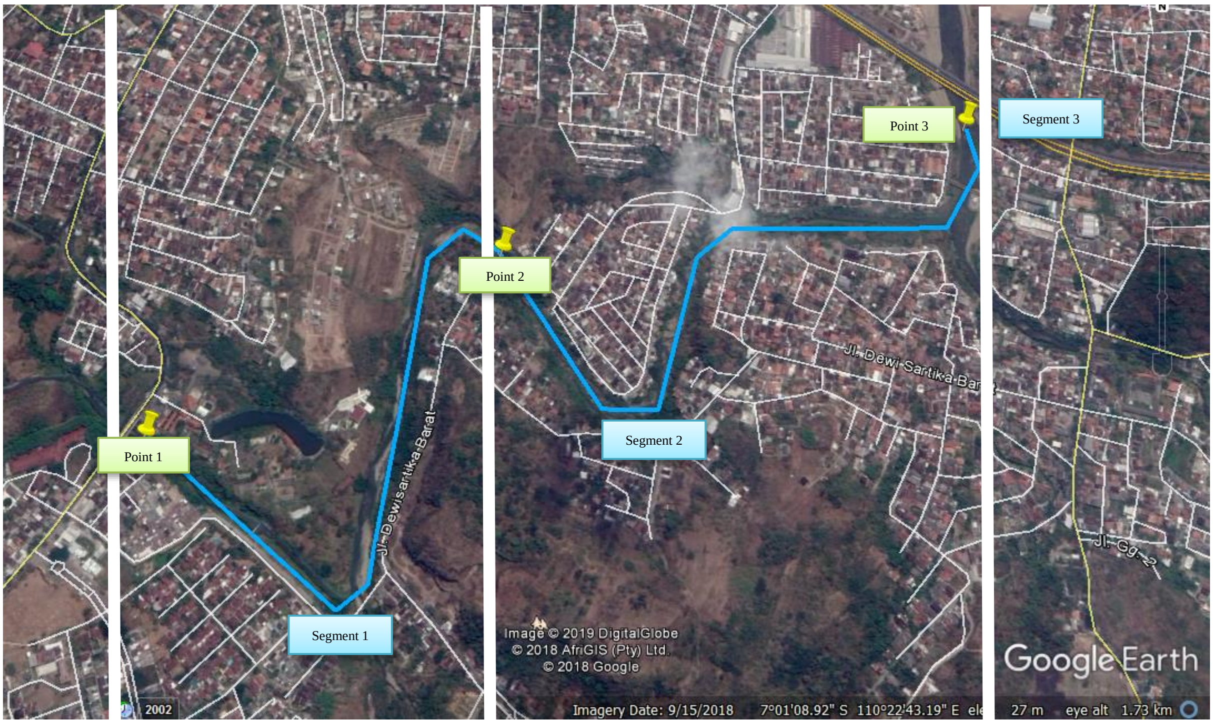

Figure 1. Sampling Location

Mathematical modelling was used, namely Streeter-Phelps, to analyze the self-purification ability of Sungai Garang. Even though the the mathematical modelling has many advantages to see the self-purification ability, this model is limited to the DO reduction because of the microorganism activity in organic matter degradation and the DO addition (reaeration) because of the river flows turbulence. Therefore, the model has some assumptions that should be note, including (1) only one point source of pollutant, (2) the BOD decomposition rate is proportional to the BOD level, (3) the oxygen reduction equals to the BOD decomposition rate, (4) the oxygen addition is proportional to the decomposition, (5) no different condition along the river, and (6) constant flow rate of the river.

The first thing to do in the calculation using the Streeter-Phelps mathematical model is to determine the DO saturation value based on the temperature at the observation point. After that, calculate the DO deficit value by subtracting the DO Saturation value from the DO concentration measured in the laboratory at the point. Then calculate the value of K (deoxygenation coefficient) and R (reaeration coefficient) according to the known temperature at the observation point through a predetermined equation. The calculation results obtained the oxygen sag curve in segments 1 and 2 of the Garang River (Nugraha et al., 2020a).

The reduction of oxygen in the water flow overtime during the natural purification process is the difference between the DO saturation value and the DO actual level at that time (See Equation (1)).

Oxygen deficit, D = Saturation DO – Actual DO (1)

When wastewater enters the river with a certain level of BOD, DO will decrease and cause a reduction in oxygen. The equation (2-3) explain the Streeter-Phelps method that can be used to determine the level of deoxygenation and reaeration.

$$\mathrm{Dt} = \frac{K' Lo}{R'-K'}\left[e^{-K't} - e^{-R't}\right] + Do.e^{-R't} \quad (2)$$

$$Lt = Lo.(1 - e^{-K't}) \quad (3)$$

Where, K is stands for deoxygenation constant; R is the reaeration constant (reoxygenation); Dt is the value of the oxygen deficit at the point of the pollutant source at time t; Lt is BOD concentration (mg/l) at time t; t is the travel time between the two points (in days); Lo is the BOD concentration at t=0; and Do is the oxygen deficit value at t=0 (Nugraha et al., 2020b).

Calculating the critical DO deficit can be done through the equation (4).

$$Dc = \frac{K}{R} Lo.e^{-K'tc} \quad (4)$$

The value of tc can be obtained through the equation (5).

$$tc = \frac{1}{R'-K'} ln\frac{R'}{K'}\left[1 - \frac{Do\,(R'-K')}{K'Lo}\right] \quad (5)$$

The deoxygenation constant K in temperature variations can be expressed in the equation (6).

$$K_T = K_{20}\theta^{(T-20)} \quad (6)$$

Where θ is 1.047 in temperature of 20°C – 30°C and 1.135 in temperature of 4°C – 20°C. The constant of reaeration/reoxygenation is expressed in the equation (7).

$$R_T = R_{20}(1.016)^{(T-20)} \quad (7)$$

3. Result and Discussion

The total length of the river from point 1 to 3 is 2.54 km. Each point has different physical characteristics. The physical characteristics of the sampling location can be seen in the Table 1 and 2.

Table 1. Result of field observations of each sampling location

No	Sample point	Distance between point (m)	ʋ̄ (m/s)	Temperature (C)	pH	Depth (m)			L (m)
						H1	H2	H3	
1.	T1	0	0.987	28.5	7.83	0.25	0.4	0.6	29.0
2.	T2	1,210	1.039	28.2	7.76	0.25	0.7	0.9	16.5
3.	T3	1,330	3.402	28.7	7.71	0.4	0.4	0.4	28.0

After obtaining the temperature, pH, DO, and BOD values, the concentration are compared and evaluated with the Class I Quality Standards referring to Government Regulation Number 82 of 2001 concerning Water Quality Management and Water Pollution Control. The results of the comparison can be seen in Table 3.

Table 2. Result of field measurements and laboratory tests for DO and BOD

Sampling point	field measurement of DO (mg/l)	Laboratory measurement of DO (mg/l)	BOD (mg/l)
1	6.8	6.90	13.5
2	5.7	5.86	13.5
3	3.8	4.30	15.0

Based on the table 3, the pH, temperature, and DO concentration values at point 1 meet the quality standard, while at point 2 and point 3 do not meet the quality standard. The BOD concentration value at all sampling points exceeded the quality standard. Rahmawati (2011) explained that the greater level of BOD in the waters indicates that the water has been polluted. The BOD maximum level that can be allowed for drinking water and supporting aquatic organisms life is in the range of 3 – 6 mg/l.

Table 3. Comparison of concentration of pollutants with the quality standard

Parameter	Unit	Quality Class 1	Concentration		
			Point 1	Point 2	Point 3
pH		6-9	7.83	7.76	7.71
Temperature	°C	Deviation 3	28.50	28.20	28.70
DO	mg/l	6	6.90	5.86	4.30
BOD	mg/l	2	13.50	13.50	15.00

For segment 1, the values for deoxygenation and reaeration constants are as follows: K (28.5 °C) = 0.23 (1.047)28.5-20 = 0.340 /day, R (28.5 °C) = 3.00 (1.016) 28,5-20 = 3,433/day. As for segment 2, the values for the deoxygenation and reaeration constants are as follows: K (28.2 °C) = 0.23 (1.047)28.2-20 = 0.335 /day, R (28.2 °C) = 3.00 (1.016)28.2-20 = 3.417/day. From the results of the constant calculation, the natural purification constant value is 10.103 in segment 1, and 10.194 in segment 2. The deoxygenation and reaeration constant values are then used to calculate the oxygen reduction value and the theoretical BOD value with the equation (2)-(5). The decrease in DO and BOD in segments 1 and 2 is shown in the Figure 2 - 5.

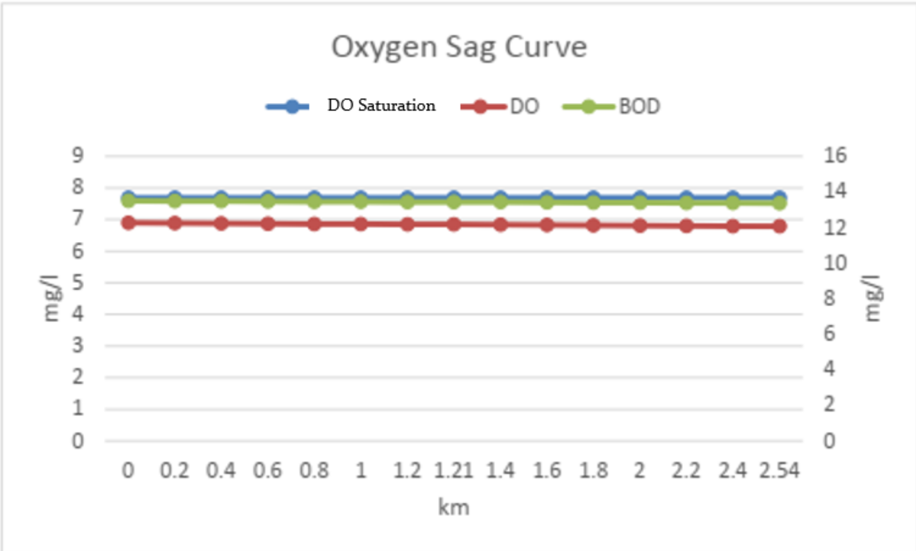

Figure 2. Oxygen sag curve segment 1 Garang River

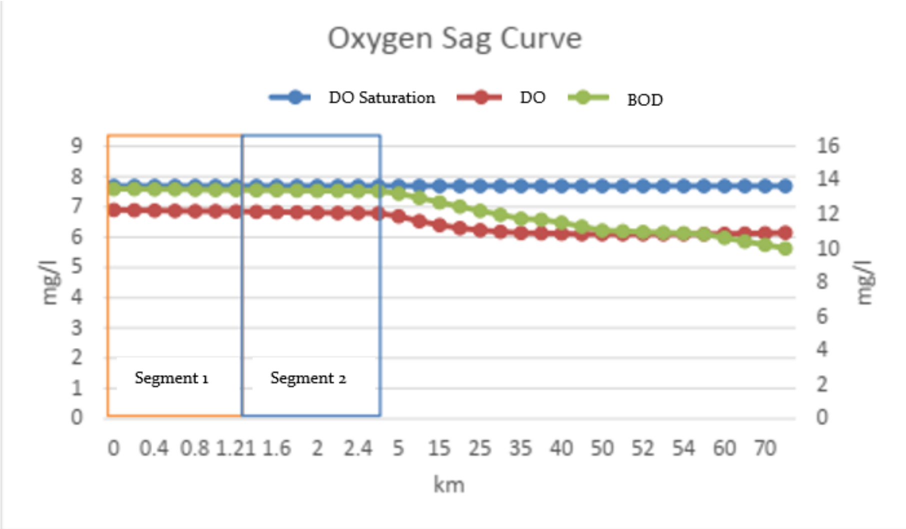

Figure 3. Oxygen sag curve to a critical point (Segment 1)

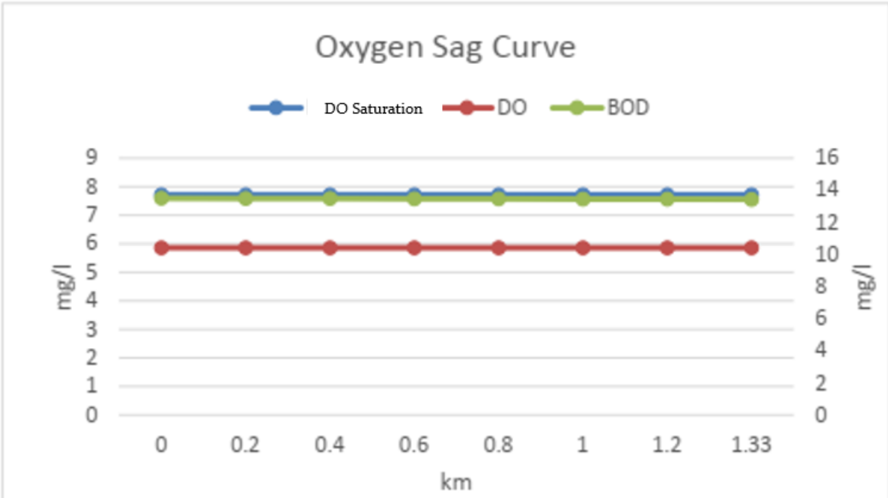

Figure 4. Oxygen sag curve segment 2 Garang River

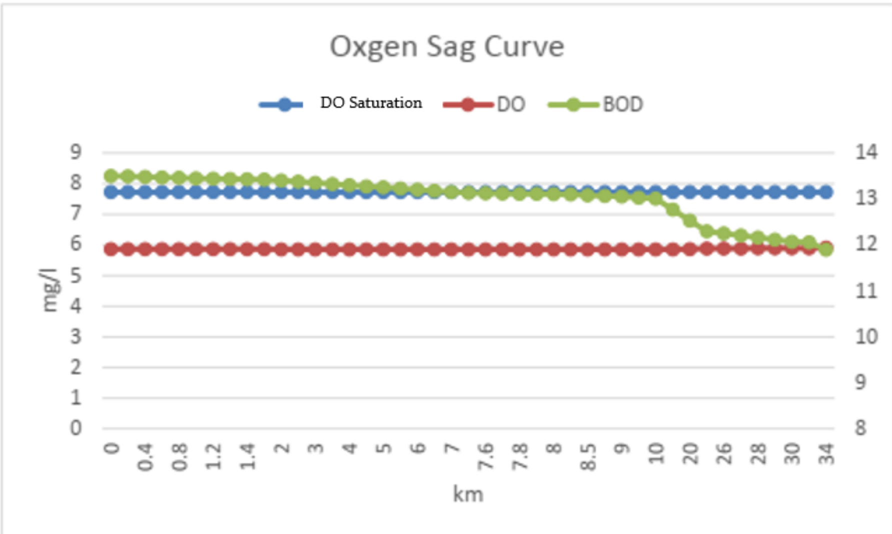

Figure 5. Oxygen sag curve to a critical point (Segment 2)

In segment 1 and segment 2, the decrease of BOD was accompanied by the decrease of oxygen concentration. This condition happens because the deoxygenation rate is greater than the reaeration rate in segment 1 and segment 2. The critical point value, critical time, and critical deficit is also found in segments 1 and 2. In segment 1, 52 km is the critical distance from point 1. The travel time is 0.61 days and the DO deficit is 6.09 mg/l. In segment 2, 32.3 km is the critical distance from point 2. The travel time from point 2 is 0.34 days and the DO deficit is 5.89 mg/l. Chin (2006) explained that at the critical point, the DO condition is the worst because the reaeration rate becomes the same as the oxygen consumption rate, while outside the critical point, the reaeration rate exceeds the oxygen consumption level resulting in a gradual decrease in the oxygen deficit. This results indicates that an active decomposition zone is along with the flow of segment 1 and segment 2. When compared with the actual conditions of all segments, the resulting graph is as presented in Figure 6.

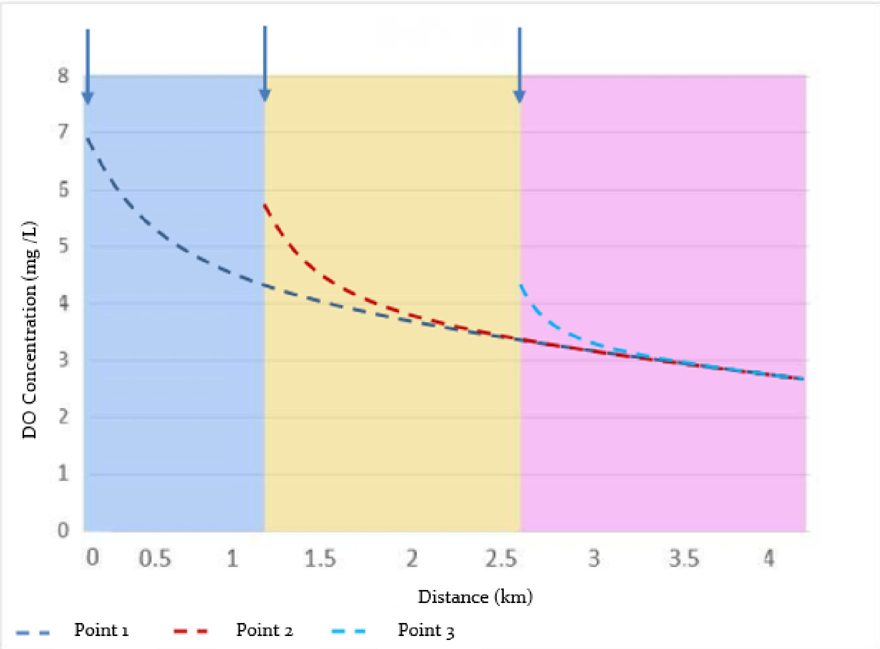

Figure 6. Fluctuations of DO concentration in all segments

The Figure 6 shows a decrease in the DO concentration value after the pollution inputted at point 1. Before the river purify themselves from the pollution that occurred in point 1, there was an input of domestic and agricultural wastewater at point 2, which caused the cessation of the self-purification process. The entry of domestic and agricultural wastewater at point 2 causes the DO concentration value at point 2 to decrease to point 3 gradually. In Segment 2, there has not been a self-purification process due to domestic and agricultural wastewater input at point 3. The critical deficit value has not been achieved until Point 3.

In Figure 7, the value of BOD concentration also fluctuates due to the entry of domestic and agricultural wastewater in each segment. In each segment, there was a decrease in the value of the BOD concentration up to the wastewater input points, which increased due to additional domestic and agricultural wastewater entering the water body. The results obtained with differences that are not too significant or not many differences so that the model or mathematical equations from the results of calculations using the Streeter-Phelps method are considered to indicate DO and BOD quality of Sungai Garang.

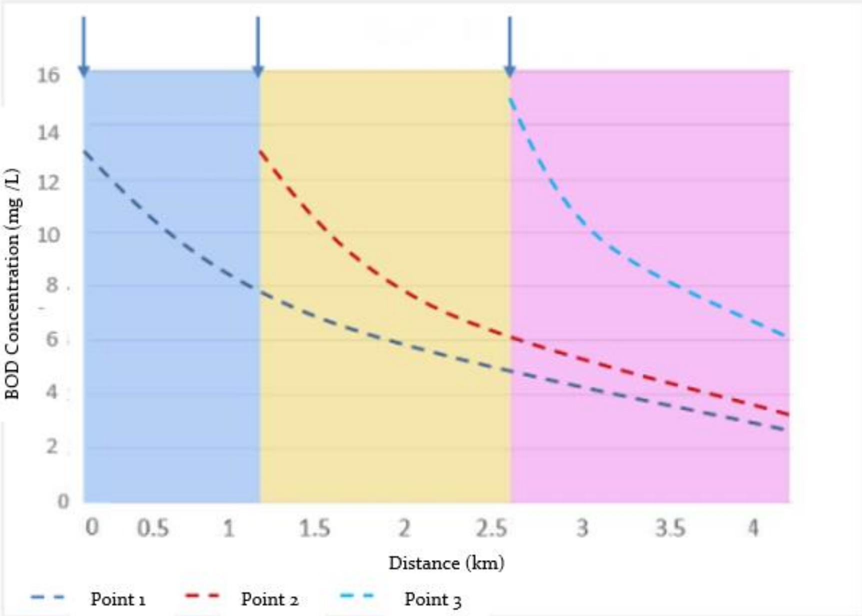

Figure 7. Fluctuations of BOD concentration in all segments

Fluctuations in DO and BOD concentrations in actual conditions are also related to land use around the research area. In segment 1 there is an agricultural land, the confluence of two rivers, and many settlements along the river. The number of settlements along the river has directly increased domestic wastewater, resulting in DO consumption and BOD concentration in the next segment (Suprayogi et al., 2019). In segment 2 of the Garang River, the land use is dominated by residential areas. This condition increases domestic wastewater, which then accumulates with wastewater from the previous segment and the input of wastewater from the confluence of two rivers, thus hampering the natural purification process (Wang et al., 2017). The high concentration of BOD makes it difficult for rivers to carry out natural purification. Therefore, the Garang River has not been able to carry out natural purification.

The self-purification ability of the Garang River is considered to not optimal as it should be because of the relatively high suspended solids content in wastewater originating from domestic wastewater and the heavy intensity of rain that occurred before sampling was carried out, thus preventing purification from occurring (He et al., 2018). Suspended solids in wastewater and many dissolved compound in wastewater can inhibit light penetration into the water. Lack of sunlight makes photosynthesis in the water hampered, so there is no oxygen in the river. This situation makes the reaeration process slower than the deoxygenation process (Huang et al., 2017). The increase in the concentration of BOD must be accompanied by an increase in the concentration of DO so that the decomposition of organic matter can run well and the river can recover (Nugraha et al., 2020b).

4. Conclusion

Between 3 sampling points at the Garang River, only point 1 that meet the water quality standard of the Class I Government Regulation Number 82 of 2001 of DO concentration. Besides, points 2 and 3 do not meet the quality standard. Results testing of water samples in the Garang River for the parameters of Biochemical Oxygen Demand (BOD) showed that at the three sampling points, it exceeded the water quality standard. In this study, there has not been a natural purification process or self-purification in the Garang River because the critical point is outside the length of the segment. The presence of wastewater input in each segment resulted in the value of DO and BOD concentrations in the sample water test results showing inappropriate results. This condition indicates that the Garang River has not decomposed the BOD that enters the river. The DO concentration has not returned to the ideal condition of a Class 1 river due to the entry of wastewater. Further research is needed on the effect of river morphology, input from tributaries, and plant photosynthesis on the natural purification ability of the Garang River. The mathematical modelling used should be more than one model and be adjusted to the Garang River conditions to get more accurate results.

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