The Study of Self Purification Capacity Based on Biological Oxygen Demand (BOD) and Dissolved Oxygen (DO) Parameters

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Abstract. Jajar River is geographically located between Demak and Grobogan Regency area. For most part, Jajar River which lies on lowland area is mainly utilized for agricultural purposes. The utilization of the land around the area of Jajar River might potentially cause several environmental problems such as river water contamination, causing degradation of river water quality. Generally, river has the capacity to purify itself by decomposing any pollutants blended in the water. This capacity is called self-purification. The aim of this study is to determine the level of self-purification capacity (time and distance of water purification) using Streeter-Phelps equation, by obtaining data about organic pollutant concentrations DO and BOD at a certain pollutant point in a river. By using Streeter-Phelps equation, it is expected to find oxygen reduction curve toward time and distance. Deoxygenation and reaeration constants are needed to draw the curve. Moreover, Streeter-Phelps equation can generate the oxygen reduction curve which shows self-purification distance. The results showed that there was no natural purification process in Jajar River. In other word, the water sample test in each segment showed the existence of waste input, which was indicated by unacceptable results of DO and BOD parameters. In this condition, the river ecosystem had not been able to purify the water from BOD input. It supposedly happened due to the inability of DO concentration to return to the ideal condition of anaerobic river from waste contamination in the extended segments.

1. Introduction

The utilization of land around Jajar River might possibly cause some environmental issues such as river water contamination of household waste, agricultural contamination, and other activities to support basic needs. The wastes which are disposed into the water body could affect river water quality. There are a lot of pollutant types which can change the water quality into exceeding the limit of quality standard when blended into the water body.

River has the capacity to purify its water from any pollutant if the contamination is still below the determined quality standard. This capacity is called self-purification. It can filter the organic substances, plant nutrients, or other contaminants from biological activities in the ecosystem out of water body or river. The self-purification capacity works based on biological activity in the water body. Thus, self-purification is often associate with organic substance oxidation of aerobic organisms.
Self-purification process is affected by living organism in the river and river stream. A study to analyse self-purification capacity of a river is needed to understand its capability to decontaminate any pollutants in the water.

River is a natural and/or artificial water container or path which consists of water flow network from upstream to downstream which is restricted by border line (riverbed) on the right and left side as river border protection [7]. Self-purification occurs when decomposed organic wastes enter the stream and some reactions (physical, chemical, and biological reactions) happen to filter any pollutants. Finally, the stream can release organic contaminant loads in it. Stream with self-purification capacity shows the continual change in water quality along the stream. DO concentration in the stream is a crucial factor to determine the overall effect of organic substances [2].

Biological Oxygen Demand (BOD) is a characteristic which shows the amount of dissolved oxygen needed for microorganisms (usually bacteria) to decompose organic materials under aerobic condition. Decomposition of organic materials happens in two steps; the breakdown of organic materials into inorganic materials, and the breakdown of unstable inorganic materials into stable inorganic materials. Decomposition plays role as a confounding agent in determining BOD value [4].

Microbes will turn organic substances (non-conservative elements) in a water body into more stable elements, CO₂, and H₂O. The microbes require oxygen for respiration to break down the organic substances. The oxygen is taken from dissolved oxygen in the water. The rate of dissolved oxygen consumed by microorganism is represented by K₁, where K₁ value depends on the type of organic substances. Organic substances which are hard to decompose have smaller value of K₁, while easily decomposed substances have greater value of K₁. K₁ constants range from 0,008 to 0,30. K₁ coefficient is called coefficient of deoxygenation. The dissolved oxygen in the water will reduce or eventually run out over time due to microorganism activities. The graphic of dissolved oxygen reduction in the river water is illustrated in the chart below [6].

![Figure 1. Dissolved oxygen phenomenon](image)

However, dissolved oxygen from the air will pass into river due to some turbulences of the river water. Besides, dissolved oxygen in the water might also be formed from photosynthesis process. The rate of dissolved oxygen addition in the river water is represented by K₂, where the value of K₂ depends on the river profile and turbulence measurement of the river. K₂ coefficient is called coefficient of reaeration which values between 0,05 for smaller river/pool to 0,5 for bigger river with high turbulence [6]. To analyze the oxygen reduction curve, Streeter-Phelps equation can be applied to determine deoxygenation and reaeration levels as follow:
\[ D_t = \frac{K_1 L_o}{K_2 - K_1} \left[ e^{-K_1 t} - e^{-K_2 t} \right] + D_o e^{-K_2 t} \]  

(1)

Where:
- \( K_1 = K_{1(20)}(1.047)^{T-20} \)
- \( K_2 = K_{2(20)}(1.016)^{T-20} \)
- \( D_t \) = oxygen deficit value in the pollutant source point at time t
- \( L \) = BOD concentration
- \( t \) = Travel time between two points
- \( T \) = value at temperature of 20°C

Equation 1 is the equation of dissolve oxygen curve which is called Streeter-Phelps model. It is illustrated in the following figure (abscissa = time or distance, and ordinate = oxygen deficit):

Critical time \( t_c \) and critical deficit \( D_C \) need to be considered in this curve. Critical time is the time where the maximum oxygen deficit occurs = \( D_C \).

Critical time is represented by:

\[ t_c = \frac{1}{K_2 - K_1} \log \left( \frac{K_1 L_o - K_2 D_a + K_1 D_a}{K_1 L_o} \right) \]  

(2)

While critical deficit is obtained from:

\[ D_C = \frac{K_1}{K_2} L_o 10^{K_{1t_c}} \]  

(3)

Natural purification or self-purification consists of four zones:
1. Zone of degradation
2. Zone of active decomposition
3. Zone of recovery
4. Zone of clearer water
2. Research methodology

The objectives of this research are:

1. To analyze river water quality for BOD and DO parameters. The variables used in this study are BOD and DO parameter from the laboratory test result of water sampling points along Jajar River, Demak Regency, Central Java.

2. To analyze potential contamination points and the effect on water quality. The potential contamination points are found by analyzing the inventory data of land use and pollution source. It then leads to determining its impact on water quality.

3. To analyze self-purification process which consists of deoxygenation and reaeration process in the river. BDO and DO concentrations from laboratory test results are processed using the mathematical model from various existing literature to determine deoxygenation and reaeration coefficients in water body, thus self-purification capacity of Jajar River, Demak Regency, Central Java is found.

This research was conducted in several stages as follow:

1. Preparation Stage
   This is the first step in a research which includes:
   a. Preliminary survey and literature study to collect some information of research location.
   b. Collecting numerous references or literature review from both related sources of books and research journals.
   c. Sampling, measuring river flow, and testing BOD and DO concentration parameter, as well as testing secondary data from the site of study.
   d. Processing data to achieve the desired research objectives.

2. Draft Report Stage
   This stage includes:
   a. Analyzing the data obtained as the main stage, so that a conclusion based on actual findings from the site of study is obtained.
   b. Research report drafting process.
   c. Preparing tools and materials to be used for water sampling in the sampling points.
   d. Implementation Stage

3. This stage includes:
   a. Primary data collection (water sampling at the sampling points)
   b. Research report writing process.
3. Results and discussions

This study took place along Jajar River which was divided into three segments. The site of this study was in Kebonagung, Dempet, Wonosalam, Demak, and Bonang Districts with the total length of 19.84 kilometers.

![Figure 4. Map of sampling points and segments](image)

The water samples were taken to the laboratory for DO and BOD tests, while pH and temperature parameter were tested in situ. Though, DO parameter was also tested in situ using DO meter. In situ test means a test conducted directly in the sampling locations to gain accurate results. Other secondary data such as flow velocity, water depth, and river width were also measured. The results are presented in table 1.

| No | Sampling points | Distance between sampling points (m) | \( \bar{v} \) (m/s) | Temperature (°C) | pH | Water depth (m) | \( L \) (m) |
|----|----------------|-------------------------------------|---------------------|-----------------|----|----------------|----------|
| 1. | T1             | 0                                   | 0.26                | 26.4            | 7.53 | 2              | 2         |
| 2. | T2             | 4717                                 | 0.20                | 27.0            | 7.55 | 2.6            | 2.7       |
| 3. | T3             | 5330                                 | 0.20                | 27.5            | 7.53 | 3.6            | 4.0       |
| 4. | T4             | 9810                                 | 0.22                | 27.8            | 7.79 | 1.2            | 1.4       |

The observation and measurement along the sampling points showed some variation in flow velocity with the lowest speed of 0.20 m/s and the highest speed of 0.26 m/s. It is slightly different from the pH parameter which indicated normal condition in the range of 7.53 to 7.79. Moreover, water temperature also showed normal condition in the range of 26.4 °C to 27.8 °C. Salmin (2005) [5] recommends using laboratory titration method to get more accurate results for determining dissolved oxygen level or DO,
compared to DO meter on site measurement. Thus, DO data from laboratory testing were utilized for the analysis and calculations in this study.

| No. | Sampling Point | DO (laboratory test) (mg/L) | DO (site measurement) (mg/L) | BOD (mg/L) |
|-----|----------------|-----------------------------|-------------------------------|------------|
| 1.  | T1             | 6.8                         | 5.9                           | 10         |
| 2.  | T2             | 6.28                        | 3.6                           | 11         |
| 3.  | T3             | 6.04                        | 7.2                           | 12         |
| 4.  | T4             | 6.04                        | 7.5                           | 5.3        |

There was no significant difference of DO concentration values between each sampling point from the comparison chart of distance against BOD and DO concentration. At point 1, DO concentration was found to be as much as 6.8 mg/l then it dropped 0.52 mg/l to 6.28 mg/l at the next point. DO concentration value decreased to 6.04 mg/l at point 3 and stayed in a stable value of 6.04 mg/l at point 4. In contrast, BOD concentration values fluctuated in certain sampling points. At point 1, BOD value was found 10 mg/l. It then increased to 12 mg/l at point 3 and later droped to 5.3 mg/l at point 4. High BOD concentration value indicates higher pollutant in the water body [3].

| Parameter | Unit | Grade II Quality Standard | Concentration |
|-----------|------|----------------------------|---------------|
|           |      |                            | Point 1 | Point 2 | Point 3 | Point 4 |
| Ph        |      | 6 – 9                      | 7.53    | 7.55    | 7.53    | 7.79    |
| Temperature | °C  | Deviasi 3                  | 26.4    | 27.0    | 27.5    | 27.8    |
| DO        | m g/l | 4                          | 6.8     | 6.28    | 6.04    | 6.04    |
| BOD       | m g/l | 2                          | 10      | 11      | 12      | 5.3     |

Note:

- Exceeds Grade II Quality Standard

pH, temperature, and DO concentrations on table 3 exceed the minimum value of Grade II Quality Standard. As for BOD parameters, each sampling point showed concentration level of significantly greater than 2 mg/l, which exceeded the water quality standard regulations. If the dissolved oxygen (DO) level of a water body was higher than 5 mg/l, it had good water quality with low contamination level. Meaning, water body is in a good quality to meet its designated uses if the DO level from laboratory test is in accordance with the quality standard [3].

However, if the BOD parameter shows higher value than 10 mg/l, the water body is considered as polluted [3]. Laboratory test results presented that BOD parameter in each sampling point exceeded quality standard for grade II designated uses. Streeter-Phelps model is limited to two phenomena; reduction of dissolved oxygen (deoxygenation) due to microorganisms activity of degrading organic materials in water and increase of dissolved oxygen (reaeration) caused by turbulence in river flow.
Deoxygenation and reaeration rates are affected by speed of the water flow, distance between each point, and travel time of water with organic substances in it [7]. With Streeter-Phelps equation, it is possible to obtain the concentration of dissolved oxygen by calculating deoxygenation and reaeration rates. These rates illustrate oxygen reduction variation towards the distance as oxygen reduction curve (oxygen sag curve).

Segment 1 was 4.7 km in length, lay in two sampling points with DO value of 6.8 mg/l in sampling point 1 and 6.28 mg/l in sampling point 2. Flow velocity in sampling point 1 was 0.26 m/s. Self-purification capacity can be calculated using Streeter-Phelps method if the value of dissolved oxygen concentration is perceived. The result indicated that DO deficit value reached critical point at distance of 15.92 km from sampling point 1 with critical DO deficit of 3.69 mg/l. The concentration then increased up at the distance of 30 km. This condition might occur if there was no pollutant input along river body in the specific distance. DO value at the critical point was 4.0 mg/l. Deoxygenation constant in this sampling point was 0.31 per day and reaeration constant was 3.41 per day. However, the data meant to show that there was no natural purification process nor critical DO deficit reached in segment 1 with the farthest distance of 4.7 km.

![Figure 5](image-url) Oxygen Sag Curve in Segment I based on Streeter-Phelps Equation

Segment 2 was 5.3 km in length, lay between sampling point 2 and 3 with DO value of 6.28 mg/l in sampling point 2 and 6.04 mg/l in point 3. Flow velocity in point 2 was 0.20 m/s. From Streeter-Phelps calculation method, it was found that critical DO deficit value reached the critical point at the distance of 11 km from sampling point 2 with critical DO deficit of 3.87 mg/l. This condition happened if there was no pollutant input along river body in specific distance. DO value in the critical point was 3.9 mg/l with deoxygenation constant of 0.32 per day and reaeration constant of 3.42 per day. Thus, there had not been a natural purification process happened or critical DO deficit reached in segment 2 with the furthest distance of 5.3 km from point 2.
Figure 6. Oxygen sag curve in segment ii based on Streeter-Phelps equation

Segment 3 was 9.7 in length, lay between two sampling points with DO value of 6.04 mg/l in sampling point 3 and 6.04 mg/l in sampling point 4. Self-purification capacity could be calculated using Streeter-Phelps method if the value of dissolved oxygen concentration was perceived.

Figure 7. Oxygen sag curve in segment iii based on Streeter-Phelps equation

The chart shows that DO concentration value decreases between sampling point 3 and 4, it indicates that there is no natural purification process happened in the distance of 9.8 km from point 3. In all segments of this study, the land was mostly used for agricultural activities. In other word, self-purification capacity on the three segments fluctuate in the DO and BDO concentration value.
Figure 8. The Fluctuation of DO Concentration in each segments

DO concentration in figure 8 shows a decrease value of concentration after waste input detected in point 1. Before self-purification process took place in segment 1, agricultural and domestic wastes entered the water body at point 2. As a result, the self-purification process which had been started in point 1 was terminated. After agricultural and domestic wastes entered the water at point 2, concentration value between point 2 and 3 gradually decreased. Between point 2 and 3 (segment 2), self-purification process did not happen due to waste input at point 2. The river inability to purify itself was characterized by the unreached critical deficit value until point 3. Besides, agricultural and domestic wastes input entered the water once more, at point 3. There was a decreased value of concentration at point 3 in the distance of 9.8 km. However, critical deficit value which indicates self-purification process has not been achieved.

Figure 9. Fluctuation of BOD concentration in each segment

At the same time, the agricultural and domestic wastes input in each segment also affected the fluctuation in BOD value. The decrease in BOD concentration at each segment means the concentration which has already decreased got some additions from agricultural and domestic wastes input. Self-purification process of the river had not been optimal. It is possibly caused by suspended solids in waste water from domestic wastes which hinder the purification process. Suspended solids in water could obstruct the penetration of light into water. Turbulent flow is necessary to improve self-purification capacity of water body. One of the ways to creat the turbulent flow is by creating stone wall breaker on riverbank. Stone wall breaker is created at every turn to create turbulence resulted in
diffusion of oxygen. Another alternative to create turbulent flow is by placing large stones and plants on river with shallower depth.

4. Conclusion
The result of water sample test at each sampling point of Jajar River flow area, Demak and Grobogan Regency indicated that the water quality for DO (Dissolved Oxygen) parameter met the quality standard referring to grade II designated use of Government Regulation No 82 of 2001. The water sample result showed that the water quality for BOD (Biological Oxygen Demand) parameter at each sampling point exceeded the limit of Grade II Quality Standard referring to Government Regulation No 82 of 2001. In this study, natural purification did not happen in Jajar River due to waste input at each segment. Water sample test at each sampling point for DO and BOD parameter showed unsuitable result. This result indicated the existence of waste input. In this condition, the ecosystem of Jajar River had not been able to decompose BOD in the water. It happened because DO concentration was unable to get back to aerobic river ideal condition due to waste input in the extended segments.

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