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## Research Article

# Assessment of Surabaya River (Karang Pilang-Gunung Sari Segment) Water Quality by Streeter-Phelps Model

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## Abstract

**Background and Objective:** Surabaya river has been polluted by many industries, which is located along the river and by sewage from human activities. Wastewater effluent, which has not met the established quality standards has been discharged into water bodies. Surabaya river is the main source water for clean water and drinking water consumption. The aim of this study are to identify water quality of Surabaya river along Karang Pilang-Gunung Sari segment and to assess organic parameters of river water quality with Streeter-Phelps model to predict its quality for further monitoring. **Materials and Methods:** Organic parameters such as; Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD) were analyzed in addition of pH and temperature parameters. Sample was taken in Surabaya river between Karang Pilang-Gunung Sari Segment during wet season. Streeter-Phelps model was used to apply the data modelling and chi-square was applied to validate the data statistically. **Results:** The results show that along the segment has low DO concentration averagely ($2.7\pm0.1$ mg $L^{-1}$), even DO<0.5 mg $L^{-1}$ has been detected. Low DO indicated a high BOD concentration ($50.5\pm1.5$ mg $L^{-1}$). For the purification process itself, the deoxygenation value (K1) is 0.34-0.36/min, while the reaeration value (K2) is 0.80-1.1/min. **Conclusion:** Comparison between organic parameters measurement and modelling indicated that Streeter-Phelps model could be applied to monitor water quality of Surabaya river. The validation (sig = 90%, $X_i^2 \leq X^2$) shows chi-square value 1.39$\leq$7.79 for BOD and 2.96$\leq$7.79 for DO concentration.

Key words: River water quality, organic, streeter-phelps model, self purification

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

## INTRODUCTION

River water quality is very easy to change both naturally and as a result of human action. Declination of water quality will affects the environment and has an impact on social and economic factors that are detrimental to the surrounding communities. Currently, polluted water bodies is a problem that requires a good management of river water quality mapping to solve these problems[1]. Part of the river area used as the object of this research is the Karang Pilang-Gunung Sari river, which is a river segment that passes through densely populated areas and industries. Various land use activities along this segment, such as; settlements and industries are predicted to affect the water quality of Surabaya river[2]. Study around Surabaya river found that production of different actions was occurring at the same time with reproduction of actions is present, which becomes more visible in the long term. For example, waste burning is a reconducting action every afternoon. However, the reduction of single-use plastics is an evolved state. Surabaya river is an important river in the relations and could serve as a suitable location for such activities. Lack of communication, information and facilities have been identified as the most important issues. People are needed to be motivated and supported for concerning the environmental issue around Surabaya river. Otherwise, it will cause a divide of social tensions in the community. Various industries in modern industrial areas discharged their wastewater to Surabaya river[3]. Environmental pollution in the upper site of the Surabaya river can be identified from the community's behavior such as; dumping trash directly into the river, which causing in the accumulation of garbage and river water pollution by domestic and industrial waste and decrease of land conservation areas issues often happen in the upper site of Surabaya river.

Modeling is a process that attempts to approach and forecast recent status based on real conditions in a very complex field. The result of a modeling is the prediction of states at different conditions and times. Mathematical modeling have been using to predict water quality as well. Water quality models are having an important role in predicting the present and future status of water quality due to pollution issues and due to the changing of environmental scenario. Numbers of water quality models have been developed for almost a century and developed countries have regulated the models to simulate surface water quality[4]. Water quality models, such as; QUAL 2K model[5], Water Quality Analysis Simulation Program (WASP) model[6], Quality Simulation Along River System (QUASAR) model[7], Soil and Water Assessment Tools (SWAT) model[8] have been developed in different countries for monitoring surface water quality. Previous studies by Visser[2] has identified water quality status in Surabaya river, for example Surabaya river was classified as second class of water with 49.44% contamination status according to STORET method. While, Pollution Index method indicated that Surabaya river water quality status is medium status with 100% index value[9,10]. Another model is the application of Streeter-Phelps model, which is presented in the form of graphs and equations to calculate BOD decline and oxygen deficit. Streeter-Phelps model is determined by hydrodynamics conditions, loading effects and parameter assumptions that are capable of producing a suitability between DO-BOD responses in the field[11,12]. A study of estimation water environment capacity in the Cau river Basin Vietnam has shown that Streeter-Phelps modeling is useful tools that could help managers and authorities to set better objectives for different hydrological periods, especially in areas dominated by pollutant sources. Streeter-Phelps could provide information based on input data to deal with the environmental issues regarding the Cau River Basin[13]. Streeter and Phelps concern on oxygen balance and one-order decay of BOD and it is one-dimensional steady-state model[14].

According to current status of high polluted Surabaya river and high loading pollution capacity from industrial wastewater effluent to Surabaya river, then this research determine the Surabaya river quality by using Streeter-Phelps modeling. The objective of this study is to identify the distribution of water quality pollution of Surabaya river and to determine the application of Streeter-Phelps model for Surabaya river. Water quality determination is conducted by the analysis of each parameter specified. In addition, monitoring of parameters that have been determined on the model, e.g., BOD and DO pollution by taking and analyzing samples of river water.

## MATERIALS AND METHODS

Experiment was conducted in several stages, firstly was determine river segmentation. Segmentation was arranged based on sources of contaminants in the area. Sample was taken from 15 segments starting from Karang Pilang to Gunung Sari with river length 6.980 km as shown in Fig. 1. Sampling period is April-May, 2018. Secondly, sample was analyzed for BOD (HQ30D portable DO meter, Hach USA), while DO (HQ30D portable DO meter, Hach USA), pH (HQ11D portable, Hach USA) and temperature (Hach USA) were measured on-site[15]. Data was applied for Streeter-Phelps model, in order to predict deficit oxygen in the river in term of before and after received wastewater. Model was validated by


Fig. 1: Research area and its sampling point
Source: Google earth

using chi-square method, the purpose of model validation is to measure the extent to which model results are approaching the real condition. The closer the model is to the field data, the more valid the model is to illustrate its field conditions Government Regulation of Republic of Indonesia No: 82/2001 about Water Quality Management and Water Pollution Control were applied as a guideline for water quality standard.

**Data analysis:** Streeter-Phelps model was used to apply the data modeling and chi-square was applied to validate the data statistically.

## RESULTS

**Water quality of Surabaya river with BOD and DO value:** Figure 2 and 3 describes water quality in term of BOD and DO in 15 segments along Karang Pilang and Gunung Sari district. Figure 2 explains BOD and DO value on the first week sampling time. The results shows that DO concentration at point 1 to point 15 is below the specified standard of reference, which is 0.9 mg $L^{-1}$ DO as the lowest value at point 3 and 3.8 mg $L^{-1}$ DO as the highest value at point 13. While BOD parameter indicates that all sampling points have a concentration greater than 30 mg $L^{-1}$ as determined for the applicable class I water quality standard. Figure 3 explains BOD and DO value on the second week sampling time. The results shows that DO concentration at point 1 to point 15 is

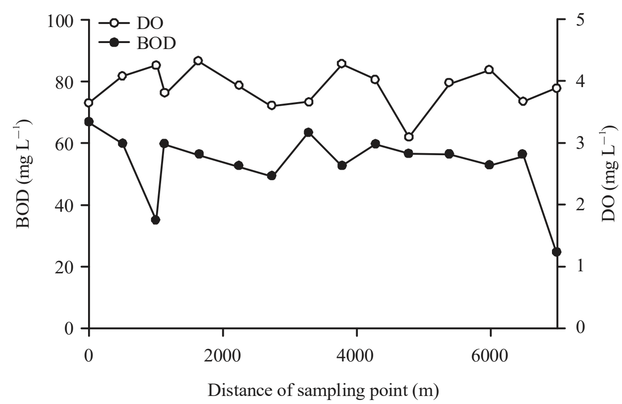


Fig. 2: BOD and DO concentration between Karang Pilang and Gunung Sari segment during first week measurement

below the specified standard of reference, which is 1.2 mg $L^{-1}$ DO as the lowest value at point 15 and 3.5 mg $L^{-1}$ DO as the highest value at point 1. While BOD parameter indicates that all sampling points have a concentration greater than 30 mg $L^{-1}$ as determined for the applicable class I water quality standard.

**Water quality modelling of Surabaya river:** Figure 4 and 5 describes the comparison between BOD and DO concentration from observation and BOD and DO concentration from Streeter-Phelps model. According to water

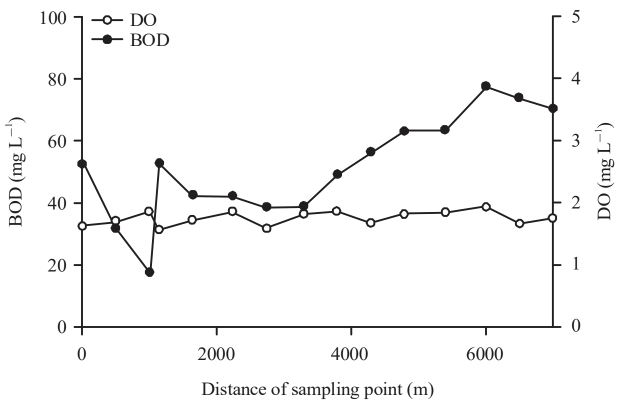


Fig. 3: BOD and DO concentration between Karang Pilang and Gunung Sari segment during second week measurement

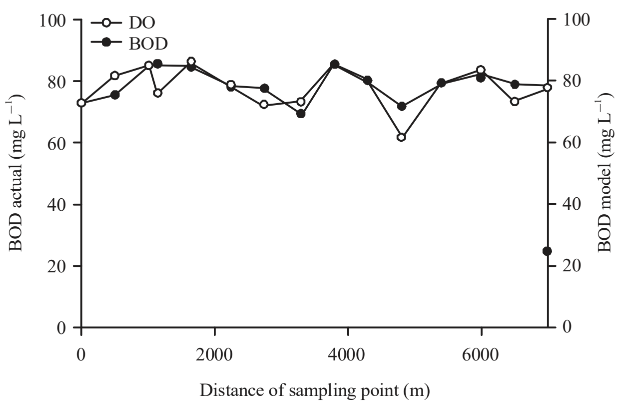


Fig. 4: Comparison between BOD actual from BOD sampling and BOD model from Streeter-Phelps model

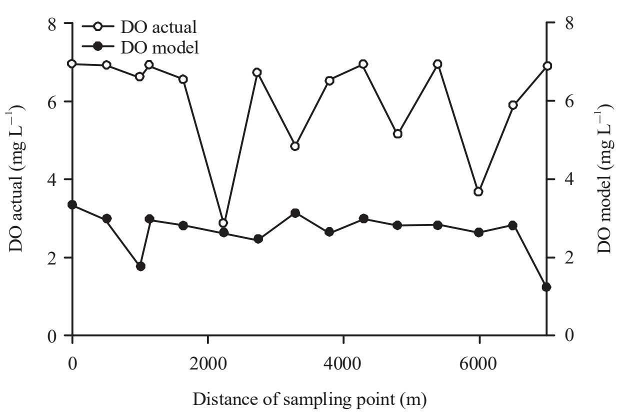


Fig. 5: Comparison between DO actual from DO sampling and DO model from Streeter-Phelps model

quality modelling by Streeter-Phelps, it shows an insignificant difference between BOD measurement and BOD observation as shown small gap between those data. It can be considered to indicate the condition of BOD pollutant quality on the river body. At first point sampling, BOD concentration has the same value between the actual and theoretical BOD. However, about 500-6.98 m, there was a fluctuation of BOD rate.

Figure 5 showed a huge gap between DO actual from DO sampling and DO model from Streeter-Phelps model.

Table 1: Chi-Square table value to validate water quality of Surabaya river

| Data | $X_i^2$ | $X_0^2$ | Result | Validation status |
|---|---|---|---|---|
| BOD (1st week) | 1.39 | 7.79 | $X_i^2 \leq X_0^2$ | Valid |
| BOD (2nd week) | 1.96 | 7.79 | $X_i^2 \leq X_0^2$ | Valid |
| DO (1st week) | 8.24 | 7.79 | $X_i^2 \geq X_0^2$ | Invalid |
| DO (2nd week) | 2.96 | 7.79 | $X_i^2 \leq X_0^2$ | Valid |

**Validation water quality modelling of Surabaya river:** The chi-square method is used to provide a clear limitation on model validity. In order for model results to be accepted, the value of chi-square must meet the following requirements $X_i^2 \leq X^2$, with the confidence range $\alpha = 90\%$, $X^2 = 7.79$ which states the value for the n-1 freedom based on the number of research data (n = 15) and confidence span of $\alpha = 90\% = 0.9$ as shown in Table 1. The first week BOD calculation uses $X_i = 1.39$. This value is lower than chi-square table value ($1.39 \leq 7.79$). While, the second week BOD calculation also has a lower value than $X_i^2$, $1.96 \leq 7.79$. Therefore, it can be concluded that BOD model with Streeter-Phelps method in Surabaya river in Karang Pilang-Gunung Sari segment is declared valid with level of significance 90%. For the DO model validation results in the first and second week shows that DO calculation uses $X_i^2 = 8.24$. This value is lower than the chi-square table value ($8.24 \geq 7.79$). While, the second week DO calculation results have a lower value than $2.96 \leq 7.79$. Therefore, it can be concluded that the DO model with Streeter-Phelps method in Surabaya river along Karang Pilang-Gunung Sari segment is declared invalid.

## DISCUSSION

Comparison of water quality in Karang Pilang to Gunung Sari segment between first sampling and second sampling showed that second week has better DO value than first week, while first week has a lower BOD value than second week value. The dissolved oxygen levels at point 1 to point 3 are not self purification because the DO rate decreases. At point 4, DO increase because of the temperature factor which is also increasing. At point 5 to point 8, the DO value decreased from 2.1 mg L$^{-1}$, 2.1 g L$^{-1}$, 1.93 and 1.93 mg L$^{-1}$ without any re-oxygenation in the body to increase oxygen content. There is no purification because of the physical factor that is the presence of garbage and algae that can block the process of photosynthesis on the biota in the water. Another possibility is other high parameters, then the micro-organisms located at point 5 to point 8 only degrade major components, which is able to be degraded. Discharged wastewater from other industries at points 5-8 causing the volume of wastewater to be reduced, it becomes deeper and the oxygen diffusion process into the body becomes obstructed. Along the segment, BOD and DO value were changing, it is probably due to effect of self-purification in the river[12]. Self-purification capacity of river water is an important parameter for an unpolluted river. Various organic and inorganic pollutants which is generated from non-point sources and point sources, in most streams were found beyond the river self-purification capacity and it caused a decreasing river water quality[9]. River as ecosystem for biotic has ability to purify its environment because river has various factors including; physical, chemical and biological factors. The deoxygenity and reaeration rates are influenced by the velocity of flow, the distance between points, the hydrodynamics condition and the travel time required by the water containing organic matter in it[8,10]. Increasing value have occurred again at point 9 to point 13, at this point the river undergoes self purification due to the deoxygenation process when micro-organism requires oxygen to decompose organic compounds[11,14].

It could be caused by many natural factors in the river, which are not taken into account in some of the systematic models existed. Under these conditions the influence of non-pollutant inputs, organic content types and disperse pollutant is negligible, therefore different values may occur. Figure 5 described the comparison between the actual DO concentration and theoretical DO concentration based on the Streeter-Phelps equation used. The results seems almost similar with the BOD analysis. There is a fluctuating concentration difference value for actual DO parameters and DO theoretical. The difference is probably due to calculations of K constant, DO saturation and velocity on river bodies[5,12]. The value showed the proportion of deoxygenate rate proportional to the amount of oxidized organic matter and the reaeration rate value to the oxygen deficit value. In reality, the value of the constant is strongly influenced by temperature, area and river cross section model[11]. The condition of biological life around the location of the river, the presence of water turbulence in the river, even the sediment found on the river, as well as the river morphology[16]. However, the difference between the theoretical and actual concentration of concentrations showed a very significant result in the segment of Karang Pilang-Gunung Sari. K constant varies with temperature, in addition microbial metabolism, concentration and composition of the organic matter in the polluted river will give influence to K constant. Different deoxygenation rates conjecturing that the interpretation of DO and BOD data probably connected to the principle of deoxygenation ratio and therefore the rate of oxidation of the organic compound[6].

Invalid DO model with observation DO in the first week is likely because the concentration value of DO observation of the 3rd point has very low value compared with concentration value at other point. In addition, because many of the natural factors inside the river are not taken into account in this mathematical model[2,17]. Under these conditions, the influence of non-polluting load sources, organic content and decomposing bacteria is negligible. As well as ignore the consequences of photosynthesis and respiration. In hydrogeometric parameters (depth, width, flow and stream flow) and physicochemical parameters (DO, BOD, pH and temperature) and coefficients (reagent coefficient, deoxygenation coefficient, longitudinal dispersion coefficient and DO saturation) estimated the calculation of the natural purification mathematical model in the Surabaya river[11,18]. The value of the K1 constant (deoxygenation velocity) of river can indicated the rate of oxygen consumption for biochemical processes such as; decomposition of organic matter. The greater the value of K1 will be the greater the ability of the river to decompose, oxidize and purify scientifically[19]. Therefore, deoxygenation will cause a decrease in oxygen content in water. This change of constants, in addition to the effects of changes in physical conditions and river flow speeds, is also influenced by environmental fats such as; changes in wind speed, temperature change, changes in DO and river water BOD concentrations[12,13]. The deoxygenation coefficient is a constant of oxygen solubility decline in the water, then the present value indicated the quality of the waters. K1 value is evaluated from $T = 20°C$ based on 0.05-0.23/day. Typical values commonly used are 0.23/day for polluted water[5]. The value of the reagent coefficient (K2) showed an oxygen-transfer process coming from the air to the body of water[8]. The displacement affected by these events, affects the small amount of dissolved oxygen derived from the air. Flow velocity, turbulence, wind speed, depth and stratification is another factors that could affects as well[16].

## CONCLUSION

Water quality of Surabaya river along Karang Pilang-Gunung Sari segment showed a fluctuating pattern tendency, according to parameter BOD, DO, pH and temperature. Decreasing the concentration of DO parameters and increasing concentration on the parameters BOD at the early sampling point. Additionally, from two parameters related to the self purification (pH and temperature) supporting factors have stagnant concentration patterns at middle to the end of sampling point.

## SIGNIFICANCE STATEMENT

This study discover the possibility of using Streeter-Phelps model to predict water quality of Surabaya river, that can be beneficial for monitoring water quality of Surabaya river and to support regulation for water quality standard. This study will help the researcher to uncover the critical areas of Streeter-Phelps model for implementing water quality monitoring in Surabaya river and typical river in Indonesia that many researchers were not able to explore. Thus, a new theory on relation of the pattern of DO and BOD concentration along Surabaya river may be arrived at.

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