Water Quality Modeling Distribution at Bali Strait in the Western Monsoon and Its Impact for Ecosystems

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Abstract: The Bali Strait is geographically located between Java and Bali Island, with a total area approximately 900 square miles. It has a high potential of fish produces an average of 100 tons/year. The types of fishes there are tongkol, layang, and lemuru with high economic values. Bali Strait affected by the oceanographic phenomenon of upwelling in the Indian Ocean and has shallow and narrow bathymetry conditions made high currents speeds. The abundance of nutrients in Bali Straits made the ocean water fertile and rich in fish give an advantage for anglers. The nutrient is present in Bali Strait caused by water flow from land. These conditions is become triggers for an explosion of phytoplankton populations or called booming algae. The shrimp waste from companies disposing of the waste to Bali Strait consists of parameter DO, BOD, COD, TSS, Phosphate, and Nitrate. Research on the distribution of water quality in Bali Strait in the Western Monsoon has to research, where previous researchers have researched in the Eastern Monsoon. The purpose of this research is to find out the distribution of water quality parameters in the Bali Strait using MIKE 21 Ecolab [1]. The result of this research shown the maximum distribution exceed water quality parameter and influence for the biota are BOD = 83.031 mg/L, Nitrate = 0.924 mg/L, Phosphate = 0.176 mg/L and TSS = 27.574 mg/L. The BOD makes the water polluted, Nitrate and Phosphate is the trigger for booming algae, and TSS is not suitable for coral and sea grass.

1. Introduction
The Strait of Bali is geographically located between Java and Bali Island, with a total area of water approximately 900 square miles [2]. It has a high potential of fish produces an average of 100 tons/years. The types of fish there are tongkol, layang and lemuru with high economic values. Bali Strait affected by the oceanographic phenomenon of upwelling in the Indian Ocean and shallow and narrow bathymetry conditions that made high-speed currents speeds when entering or out from Bali’s Strait. The abundance of nutrients in Bali Straits made the ocean water fertile and rich in fish give an advantage for anglers. The nutrients caused by very much water flow from land, this condition will instead of an explosion of phytoplankton populations or called booming algae [3].

PT. 1368 is a shrimp processing company that was a research review. The shrimp waste from companies disposing to the ocean water of Bali Strait. The shrimp waste consist of each parameter are TSS and Nutrient [4], and consist of DO, Ammonia, Nitrate, Phosphate [5]. Fish and shrimp processing effluents are
very high in biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), fat-oil-grease (FOG), pathogenic and other micro flora, organic matters, and nutrients [6]. Water quality parameters can indicate environmental conditions and have evaluated water quality parameters with monthly and seasonal variations with the results obtained are a significant difference in each season [7]. The entry of organic and inorganic pollutants into coastal water bodies can cause the water quality to experience degradation of biological functions [8].

Hydrodynamic modeling and water quality distribution using MIKE 21 software, with hydrodynamic and Ecolab modules used to calculate and determine the dispersion of DO, BOD, COD Phosphate and Nitrate [9]-[13]. This research is study about the distribution of water quality in the Bali Strait in the Western Season, where previous researchers have researched in the Eastern Season. The purpose of this research is to find out the distribution of water quality parameters in the Bali Strait using MIKE 21 Ecolab.

2. Theoretical Concepts

2.1 Hydrodynamics

Hydrodynamic model as a numerical modeling system for water surface modeling and current two dimensions in a one layer fluidal assumed as vertically homogeneous. The equation from mass conservation and momentum, which is vertically integrated, also describes the current variation with water level fluctuation shown as follows:

\[
\frac{\partial \zeta}{\partial t} + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = \frac{\partial d}{\partial t} \tag{1}
\]

Momentum Equation at x-axis:

\[
\frac{\partial u}{\partial t} + \frac{\partial}{\partial x} \left( u^2 + \frac{\partial \zeta}{\partial y} \right) + \frac{\partial}{\partial y} \left( uv \right) + gh \frac{\partial \zeta}{\partial x} + \frac{g u v^2}{C^2 h^2} \cdot \frac{1}{\rho_w} \left[ \frac{\partial}{\partial x} (\hat{\tau}_{xx}) + \frac{\partial}{\partial y} (\hat{\tau}_{xy}) \right] \cdot \Omega_v - f V V_x = 0 
\]

Momentum Equation at y-axis:

\[
\frac{\partial v}{\partial t} + \frac{\partial}{\partial x} \left( uv \right) + \frac{\partial}{\partial y} \left( v^2 + \frac{\partial \zeta}{\partial x} \right) + gh \frac{\partial \zeta}{\partial y} + \frac{g u v^2}{C^2 h^2} \cdot \frac{1}{\rho_w} \left[ \frac{\partial}{\partial x} (\hat{\tau}_{xx}) + \frac{\partial}{\partial y} (\hat{\tau}_{xy}) \right] \cdot \Omega_v - f V V_y = 0 
\]

2.2 ECO Lab

The biological and chemical transformation processes affecting state variable in an ecosystem (also called the ECO Lab equation) specified for each ECO Lab state variable expressed by an ordinary differential equation [1] as follows:

\[
P_c = \frac{dc}{dt} = \sum_{i=1}^{n} \text{proses}_i 
\]

The dynamics of adventive ECO Lab state variable expressed by a set transport equation, which in neoconservative form written as:

\[
\frac{\partial \hat{c}}{\partial t} + u \frac{\partial \hat{c}}{\partial x} + v \frac{\partial \hat{c}}{\partial y} + w \frac{\partial \hat{c}}{\partial z} = D_x \frac{\partial^2 \hat{c}}{\partial x^2} + D_y \frac{\partial^2 \hat{c}}{\partial y^2} + D_z \frac{\partial^2 \hat{c}}{\partial z^2} + S_c + P_c 
\]

(5)
The transport equation written as:

$$\frac{dc}{dt} = ADc + Pc \quad (6)$$

Where the term ADc represents the rate of change in concentration due to advection (transport based on hydrodynamics), and dispersion including source and sinks.

3. Method

This research located at Bali Strait with four sampling locations, there are:

a. Station 1 : at 8°11' 3.14"S ; 114°23'13.68"E.

b. Station 2 : at 8°11'4.28"S ; 114°23'16.76"E.

c. Station 3 : at 8°11'9.12"S ; 114°23'28.92"E.

d. Station 4 : at 8°11'15.19"S ; 114°23'44.11"E.

The research used water quality as primary data. Secondary data consists of tides, currents, wind, waste discharge, and bathymetry. Hydrodynamics and ECO Lab modules used in this research, with input parameters are bathymetry, waste discharge, and wind speed and wind direction. The boundary conditions consist of three boundary conditions (Figure. 3), there are the sea, discharge, and land. Model simulations was carried out for 31 days (743 hours) with the time step interval = 3600s, number of time steps = 743h.
Measurement and validation data:
Measurement data had shown in Table 1. In addition, modeling data had shown in Table 2. Data collection carried out on January 4, 2019 at 11.00 am at time steps 83. The validation data had taken from the model and measurement, with the same day and hour, shown in Table 3.

### Table 1. Measurement Data of Water Quality

| Sta | BOD (mg/L) | DO (mg/L) | Nitrate (mg/L) | Phosphate (mg/L) | COD (mg/L) | TSS (mg/L) |
|-----|------------|-----------|----------------|------------------|------------|------------|
| 1   | 23.51      | 6.78      | 0.992          | 0.187            | 140.32     | 46.78      |
| 2   | 15.67      | 5.22      | 0.925          | 0.173            | 116.982    | 35.64      |
| 3   | 6.24       | 3.42      | 0.892          | 0.144            | 105.295    | 17.88      |
| 4   | 5.72       | 3.10      | 0.692          | 0.138            | 90.688     | 15.37      |

### Table 2. Modeling Data of Water Quality

| Sta | BOD (mg/L) | DO (mg/L) | Nitrate (mg/L) | Phosphate (mg/L) | COD (mg/L) | TSS (mg/L) |
|-----|------------|-----------|----------------|------------------|------------|------------|
| 1   | 17.505     | 4.749     | 0.872          | 0.155            | 122.608    | 40.359     |
| 2   | 12.365     | 3.682     | 0.812          | 0.155            | 96.982     | 28.319     |
| 3   | 4.485      | 2.398     | 0.674          | 0.126            | 75.295     | 12.605     |
| 4   | 4.020      | 2.244     | 0.579          | 0.102            | 64.688     | 10.993     |

The data on water quality measurement validated with data from modeling MIKE 21 results. The validation of the method uses the MAPE (Mean Absolute Percentage Error) method, from the validation results the average data error is approximately less than 30% and the data stated is reasonable, shown in Table 3.

### Table 3. Model Validation with MAPE (Mean Absolute Percentage Error)

| Sta | BOD (mg/L) | DO (mg/L) | Nitrate (mg/L) | Phosphate (mg/L) | COD (mg/L) | TSS (mg/L) |
|-----|------------|-----------|----------------|------------------|------------|------------|
| 1   | 25.54%     | 29.96%    | 12.10%         | 17.11%           | 12.62%     | 13.73%     |
| 2   | 21.09%     | 29.46%    | 12.22%         | 10.40%           | 17.10%     | 20.54%     |
| 3   | 28.13%     | 29.88%    | 24.44%         | 12.50%           | 28.49%     | 29.50%     |
| 4   | 29.72%     | 27.61%    | 16.33%         | 26.09%           | 28.67%     | 28.48%     |

3.1. Hydrodynamics Simulation Results
Figure 4. Graphic of Tide

Figure 5. Surface Elevation of Tide

Figure 6. Surface Elevation of Ebb

In Figure 4, the maximum tide high is 2.25 meter in 25 January 2019, at 12:00 pm at time steps 588 with current speed at 1.79 m/s. The minimum tide high is 0.38 meters on 13 January 2019, at 06:00 am at time steps 294 with current velocity at Ebb are 1.74 m/s, and the current flow from South to North.

3.2. The Distribution Pattern of Water Quality Parameter Based on Measurement data and Numerical Modelling Results

Distribution of water quality based on the modeling results with MIKE 21 ECO Lab module, it can be seen the distribution pattern at the waste disposal site, as shown in the Figure below:

Figure 7. BOD at Tide

Figure 8. BOD at Ebb
Figure 9. DO at Tide

Figure 10. DO Ebb

Figure 11. COD at Tide

Figure 12. COD at Ebb

Figure 13. TSS at Tide

Figure 14. TSS at Ebb
Figure 15. Phosphate at Tide

Figure 16. Phosphate at Ebb

Figure 17. Nitrate at Tide

Figure 18. Nitrate at Ebb

The value of quality standard limits for water quality parameters refer to the Minister of Environment Decree Number 15 of 2014 and other related references. The Results of MIKE 21 Ecolab modeling according to the sample location show the distribution of each concentration. The BOD concentration is 0.939 mg/L at time steps 588 at the highest tide and 2.437 mg/L at time steps 294 at the lowest ebb. The DO concentration is 1.174 mg/L at time steps 588 at the highest tide and 3.380 mg/L at time steps 294 at the lowest ebb. The COD concentration is 2.880 mg/L at time steps 588 at the highest tide and 8.860 mg/L at time steps 294 at the lowest ebb. The TSS concentration is 2.329 mg/L at time steps 588 at the highest tide and 8.213 mg/L at time steps 294 at the lowest ebb. The Nitrate concentration is 0.221 mg/L at time steps 588 at the highest tide and 0.389 mg/L at time steps 294 at the lowest ebb. The Phosphate concentration is 0.002 mg/L at time steps 588 at the highest tide and 0.005 mg/L at time steps 294 at the lowest ebb.
Table 3. Modeling Data of Maximum Water Quality

| Sta | BOD (mg/L) | DO (mg/L) | Nitrate (mg/L) | Phosphate (mg/L) | COD (mg/L) | TSS (mg/L) |
|-----|------------|-----------|----------------|------------------|------------|------------|
| 1   | 83.031     | 7.845     | 0.924          | 0.176            | 152.621    | 63.365     |
| 2   | 30.552     | 6.908     | 0.997          | 0.185            | 139.581    | 56.764     |
| 3   | 22.374     | 6.344     | 0.997          | 0.184            | 137.365    | 58.191     |
| 4   | 18.625     | 5.779     | 0.997          | 0.153            | 130.605    | 51.864     |

a. The modeling of water quality distribution in Bali Strait show the maximum values of each parameters (Table 3) for analytical for biota ecosystems, there are 83.031 mg/L for BOD, 7.845 mg/L for DO, 0.924 mg/L for nitrate, 0.176 mg/L for phosphate, 152.621 mg/L for COD and 63.365 mg/L for TSS.

b. The modeling shows that station 1 has a highest value because it is very close to the waste source and the distribution of waste decrease at stations 2, 3 and 4.

c. The BOD value is more than its water quality parameter and its much-polluted category > 10 mg/L [10].

d. The DO value is more than its water quality parameter its much-polluted category > 3 mg/L, so that crabs, shell, fishes, and estuary fish can still live in that area [14].

e. The Nitrate value is sufficiently for biota existence (0.9 – 3.5 mg/L) [12].

f. The phosphate value is more than its parameter (> 0.101 mg/L) so that the water is very fertile for biota [10].

g. COD value is under its water quality parameter (200 mg/L) so that biota is secure [15].

h. TSS value is and dangerous for coral and sea grass [15].

4. Conclusion

a. According to MIKE 21 Eco Lab modeling, the pollution influence for biota extent approximately 1.000 meters from its source.

b. Pollution occurs in the Bali Strait due to a company that did shrimp processing.

c. BOD, Nitrate, Phosphate and TSS are the pollutant that influences for biota.

d. Nitrate and phosphate value is not required for water quality for biota. It made seawater fertile and will cause the rapid growth of phytoplankton and become *booming algae*. 
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