Modelling Water Quality in Welang River Estuary, Pasuruan

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Abstract: Land use activities for agriculture, plantations, industrial areas, fishponds and settlements in the Welang watershed can affect water quality in the Welang estuary. Waste disposal from these activities into the river can reduce water quality. The purpose of this study is to apply a numerical model to assess the water quality in the Welang estuary in accordance with permitted water quality standards in the coastal water. 2D numerical model with Hydrodynamic and Ecolab module is used to simulate the distribution of DO and pH as water quality parameters. Result of the hydrodynamic model showed that the current velocity flows into upstream at the tide, whereas at the ebb the current flows into downstream. The water quality modelling results show the minimum value of DO is 1.80 mg/l, and pH between 7.74 -7.87, while, the DO quality standard must be more than 3 mg/l, and pH is 6-9. Modelling results show that water quality in the Welang estuary is lightly polluted, because DO values are not in accordance with the water quality standards for class III based on government regulation number 82/2001.

1 INTRODUCTION

Welang River is one of the major rivers in East Java that crosses Malang Regency, Pasuruan Regency, and Pasuruan City. The upstream river is located at Lawang, Malang Regency and estuary in the Madura Strait in Kraton Regency, west of Pasuruan City. The Welang watershed from upstream to estuary has an area of 518 km^2 with the main river length of 36 km and an average width of 25 m (Public Works and Water Resources Pasuruan, 2019). Upstream of the Welang river is agriculture, plantation, industrial and residential area. Midstream of the Welang river is residential area and agriculture. The downstream is an agricultural area, fishpond, and industrial area. Various land-use activities in the Welang watershed can affect the river water quality. Organic and inorganic waste generated from these activities directly or indirectly enter the river will accumulate in the estuary causing the water quality in the estuary to decrease.

Previous research by Suntoyo et al. (2015) aims to determine the condition of water quality in the Porong river estuary due to mud disposal in Sidoarjo. The parameters used in modelling are chemical demand (COD), total suspended solid (TSS), phosphate and nitrate. The results showed that the water quality in Porong estuary still within safe criteria, because the water quality parameters none of which exceed the quality standard based on government regulation number 82/2001. Another research was carried out by Gopal et al. (2018) to find out the water quality at the mouth of the Uppanar river. This river is an agricultural area, settlement and fishing port downstream, barren land and industrial centre in the upstream and middle. The results showed that the values of nitrate, phosphate, iron and lead exceed the permissible limit of WHO drinking water guidelines.

Research about water quality at the Welang estuary has never been done before. Therefore, research is needed to assess whether water quality in the Welang estuary in accordance with permitted water quality standards. The parameters used to assess water quality are dissolved oxygen (DO) and power of hydrogen (pH). DO is a very important parameter for knowing water quality (Thomann and Mueller, 1987).

2 STUDY AREA

The study area is located in the Welang Estuary, Pasuruan East Java Province (Figure 1). Geographically located between 7.57-7.60 south latitude and 112.86-112.89 east longitude.

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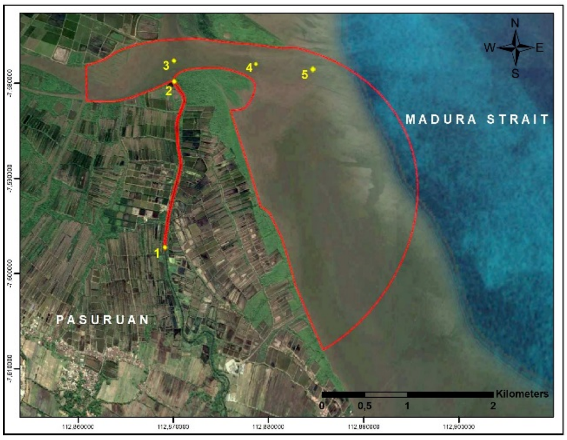

Figure 1: Study area in Welang estuary.

3 MATERIAL AND METHOD

3.1 Data Collection

Water quality measurements were performed at 5 points in the surface (Figure 1). The measurement point is along the river to the coastal. Measurement of water quality parameters are DO and pH.

3.2 Method

Modelling simulation was done with input bathymetry, river flow discharge, tides, and water quality parameters. River flow discharge data is used as boundary conditions in rivers, while tides are used as boundary conditions at sea. The simulation was carried out for 30 days with the time step interval is 3600s, number of steps is 720. The boundary condition shown in Figure 2. The hydrodynamic model is use for water surface and currents 2D modelling. The continuity equation and the momentum equation used for hydrodynamic modelling as follows:

Continuity equation:

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

Momentum equation:

- Axis – x

$$\frac{\partial u}{\partial t} + \frac{\partial}{\partial x}\left(\frac{u^2}{h}\right) + \frac{\partial}{\partial y}\left(\frac{uv}{h}\right) + gh\frac{\partial \zeta}{\partial x} + \frac{gu\sqrt{u^2+v^2}}{C^2h^2} - \frac{1}{\rho_w}\left[\frac{\partial}{\partial x}(h\tau_{xx}) + \frac{\partial}{\partial y}(h\tau_{xy})\right] - \Omega_v - fVV_x + \frac{h}{\rho_w}\frac{\partial}{\partial x}(p_a) = 0 \tag{2}$$

- Axis – y

$$\frac{\partial v}{\partial t} + \frac{\partial}{\partial y}\left(\frac{v^2}{h}\right) + \frac{\partial}{\partial x}\left(\frac{uv}{h}\right) + gh\frac{\partial \zeta}{\partial y} + \frac{gu\sqrt{u^2+v^2}}{C^2h^2} - \frac{1}{\rho_w}\left[\frac{\partial}{\partial y}(h\tau_{yy}) + \frac{\partial}{\partial x}(h\tau_{xy})\right] - \Omega_u - fVV_y + \frac{h}{\rho_w}\frac{\partial}{\partial xy}(p_a) = 0 \tag{3}$$

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Where ζ = water surface (m), t = time (s). g = gravitation acceleration (m/s^2), x dan y = space coordinat (m), u dan v = flux density in direction of x and y (m^3/s/m), $f(V)$ = wind friction factor, P_a = atmospheric pressure (kg/m/s^2), ρ_w= water density (kg/m^3), Ω= parameter of Coriolis, h = water depth (m), d = water depth varied with time (m), C = resistance coefficient Chezy (m/s), $\tau_{xx}, \tau_{xy}, \tau_{yy}$ = component of effective shear stress, V, V_x, V_y = wind velocity in direction of x and y (m/s).

ECO Lab equation used to simulate the DO and pH distribution pattern in a given time is shown as follows:

$$P_c = \frac{dc}{dt} = \sum_{i=1}^{n} process_i \tag{4}$$

Where P_c = ECO Lab process, c = the concentration of the ECO Lab state variable, n = number of processes involved for specific state variable, $process$ = user specified expression containing argument such as mathematical function, build in function, number, forcing, constants, and state variable.

The calibration of the hydrodynamic model and water quality was conducted by comparing the data of modelling results with the measurement data. The calibration of hydrodynamic modelling uses the root mean square error (RMSE) and mean absolute percentage error (MAPE) methods, whereas for ECO Lab modelling only uses MAPE. The RMSE equation as follows (Wei, 2006):

$$RMSE = \sqrt{\frac{1}{M}\sum_{l=1}^{M} e_l^2} \tag{4}$$

Where, M is amount of data and e_l is obtained from the following equation:

$$e_l = Z_{n+l} - \hat{Z}_n(l) \tag{5}$$

Where, Z_{n+l} is measurement data and $\hat{Z}_n(l)$ is modeling data. The equation for calculating MAPE as follows:

$$MAPE = \left(\frac{1}{M}\sum_{l=1}^{M}\left|\frac{e_l}{Z_{n+l}}\right|\right)100\% \tag{6}$$

Figure 2: Boundary condition of modelling.

4 RESULTS AND DISCUSSION

4.1 Bathymetry

Bathymetry modelling in the Welang estuary is shown in Figure 3. The depth at the Welang estuary ranges from 0-5.5 meters.

4.2 Model Validation

The calibration of the hydrodynamic model was conducted by comparing simulation results at point 3 with the measurement data. For the hydrodynamic model, the root mean square error (RMSE) value is 0.01 and the mean absolute percentage error (MAPE) value is 0.64%.

Table 1 shows the measurement data at point 3 and the results of the water quality modelling. The difference in value is relatively small. DO value of the field measurement result is 4.08 mg/l, while the modelling result is 4.75 mg/l. pH value of the field measurement result is 7.87, while the modelling result is 7.84. MAPE value for DO is 16.42% and for pH is 0.38%. It can be concluded that the results of water quality modelling give good results.

Table 1: Validation of modelling results with measurement data at point 3.

Water Quality Parameters	Field measurements	Modelling Result	MAPE (%)
DO	4.08 mg/l	4.75 mg/l	16.42
pH	7.87	7.84	0.38

4.3 Hydrodynamic Simulation

The types of tides that occur at the Welang estuary is mixed tide prevailing semidiurnal. The water surface elevation at the highest tide reaches 2.8 m in the simulation step of 35. While at the lowest tide, water surface elevation is 0.5 m in the simulation step of 42. Figure 4 shows the tidal graph at the Welang estuary.

Current speed at high tide between 0-0.06 m/s, whereas at low ebb 0.0-0.28 m/s. Current flow into upstream at the highest tide, while at the lowest ebb the current flow into downstream. Currents flow to upstream or towards river mouths during high tide conditions with the maximum current speed of 0.13 m/s (Figure 5a). During the low ebb, current flow into downstream or toward the coastal. Maximum current speed is 0.30 m/s (Figure 5b).

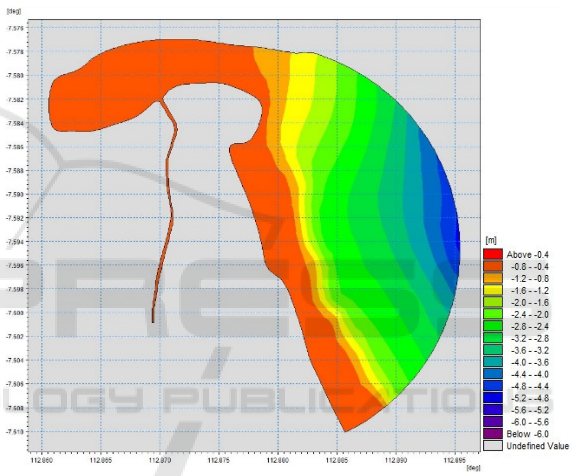

Figure 3: Bathymetry in Welang estuary.

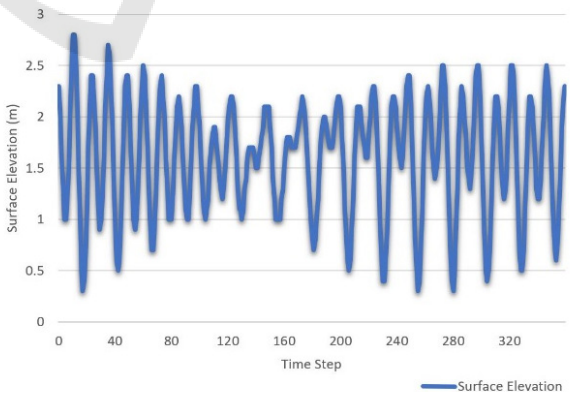

Figure 4: Water Surface Elevation.

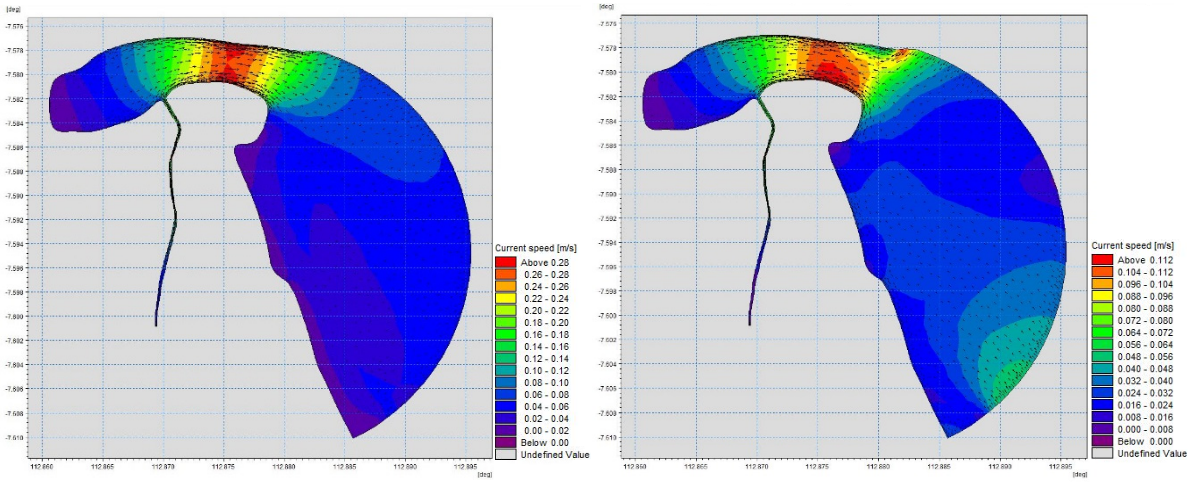

Figure 5: Current distribution at highest tide (a) and lowest ebb (b).

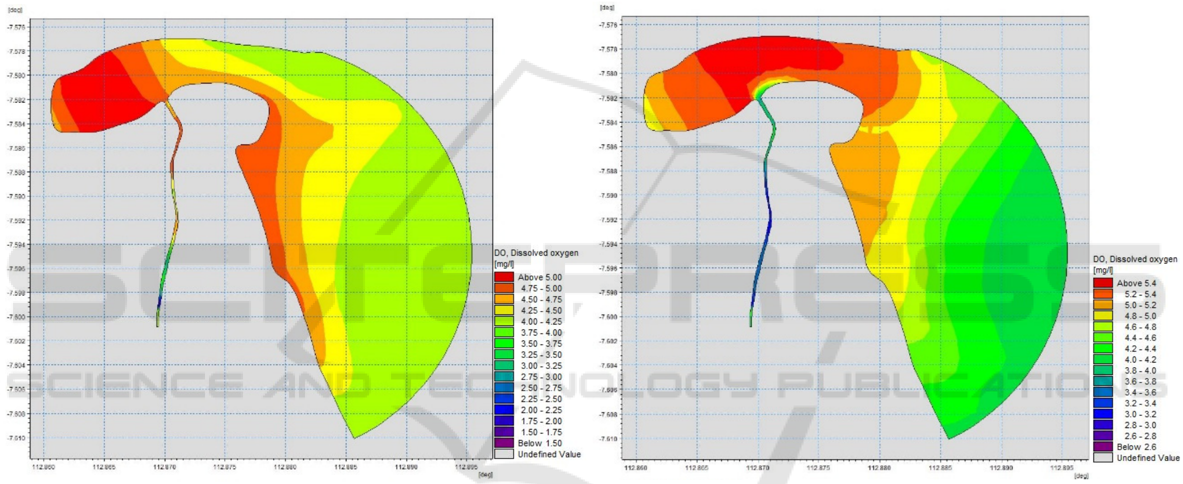

Figure 6: Distribution of DO during tide condition (a), and during ebb condition (b).

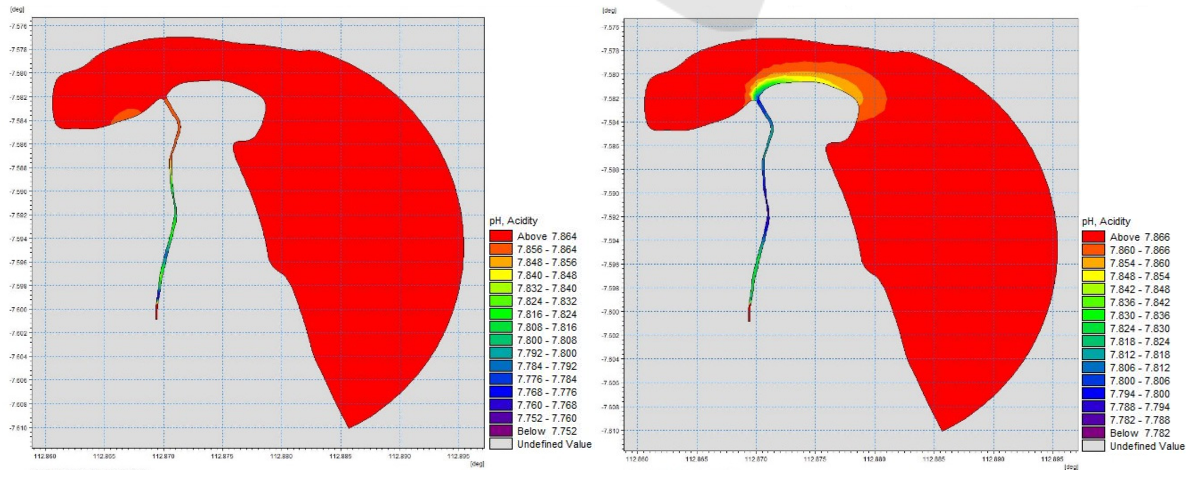

Figure 7: Distribution of pH during tide condition (a), and during ebb condition (b).

4.4 Water Quality Parameters

Water quality measurements have been conducted for 5 points in the study area (Figure 1), where measurement data are given in Table 2. The highest concentration of DO at station 3 reaching 4.08 mg/l, while the lowest at station 1 with a value of 1.07 mg/l. The highest pH at station 5 reached 7.941, while the lowest at station 1 with a value of 7.735.

The modelling results of DO shown in figure 6. DO concentration at tide is lower than at ebb. DO distribution varies between 1.80-5.24 mg/l in the river body to the coastal at tide (Figure 6a). DO concentrations in river bodies are smaller than in river mouth and coastal area. At the river bodies, maximum DO concentration is 4.97 mg/l, the minimum DO concentration is 1.80 mg/l. In the estuary, concentration of DO maximum value is 5.24 mg/l and minimum is 4.01 mg/l. When at the ebb, the spreading of DO does not vary much with at tide. Concentration of DO ranged from 3.01-5.46 mg/l (Figure 6b). The highest DO concentration is 5.46 mg/l around the estuary. The maximum DO concentration in the river is 4.23 mg/l, while the smallest concentration is 3.01 mg/l. In the estuary, concentration of DO maximum value is 5.46 mg/l and a minimum of 3.7 mg/l. DO concentrations at the river mouth of and coastal area are greater than in river bodies during tide and ebb.

Figure 7 shows the distribution of the pH in for tide and ebb condition, it was indicated that the value of pH in the river body and estuary are not much different with range 7.741-7.864 (Figure 7a). The value of pH in the river body is lower than in the estuary and coastal area. At high tide, the maximum value of pH at the coastal area which is 7.860, while maximum value at the river is 7.743. At ebb, the distribution of pH also has the same tendency as the current tidal conditions (Figure 7b). The maximum value of pH is 7.866 at estuary and the minimum value is 7.866 at river body.

Table 2: Water quality measurement data.

Station	DO (mg/l)	pH
1	1.07	7.735
2	1.18	7.778
3	4.08	7.876
4	3.43	7.93
5	3.14	7.941

4.5 Water Quality of Welang River Estuary based on Quality Standard

Water quality in Welang estuary analysed under the government regulation number 82/2001 on the management of water quality and water pollution control. Classification of Welang estuary included in water quality class III. The modelling result of water quality parameter compared with the value of the water quality standard provided in the regulation (Table 3). Table 3 shows the DO value is less than the water quality standard. Based on government regulations, the DO quality standard must be more than 3 mg/l, while the modelling results show the lowest DO value is 1.80 mg/l. pH value of the modelling result showed still relatively safe. Water quality standards of pH are 6-9, while modelling results show the values between 7.743-7.87.

Table 3: Water quality in Welang estuary.

Water Quality Parameters	Water Quality Standard (Water class III)	Value of modelling Result
DO	>3 mg/l	1.12 - 6.93 mg/l
pH	6 - 9	7.743 - 7.87

5 CONCLUSIONS

The modelling results show the minimum value of DO is 1.80 mg/l, and pH between 7.743-7.87, while, the DO quality standard must be more than 3 mg/l, and pH is 6-9. Modelling results show that water quality in the Welang estuary is lightly polluted, because DO values are not in accordance with the water quality standards for class III based on government regulation number 82/2001.

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