

Cohesive sediment transport modeling: Application to the Madura Strait, Indonesia

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ABSTRACT

Madura Strait is located in East Java province, about 800 km east of Jakarta, the capital city of Indonesia. The Madura Strait is subject to ocean waves of less than 1 m height due to its position in semi-enclosed Java Sea in Indonesian archipelago. There are 2 major rivers that carry sediment to Madura strait namely Bengawan Solo River and Brantas River. In the last years sediment transport from Brantas river has been increasing significantly through one of its branch namely Porong River. The development of Suramadu Bridge between Surabaya (at Java Island) and Bangkalan (at Madura Island) contributed to sedimentation pattern in Madura Strait. The shallow bathymetries in major part of Madura Strait threat an environmental problem in the area. Therefore sedimentation model is necessary on attempt to anticipate serious environmental problem in Madura Strait. This study is about mud transport simulation in Madura Strait due to increasing sediment discharge from Porong River.

The analysis was carried out by using MIKE-21 model software developed by DHI Water and Environment. In hydrodynamic simulation, water level boundary conditions were generated using global tide model from MIKE21 Toolbox at the boundary. The simulated water level and velocity were compared with observed data at calibration stations. In the calibration, the bed roughness parameter was adjusted by trial and error until the most satisfactory results were obtained. The root mean square error between computed and observed parameters in calibration was satisfied.

In mud transport simulation, sediment concentration boundary conditions were generated using observation data. The simulated suspended sediment concentration was compared with observed data at calibration stations. Calibration parameters (critical shear stress for deposition, critical shear stress for erosion and erosion coefficient) were adjusted to get satisfaction results. After the calibrated mud transport model was achieved, simulation of several scenarios was applied to predict future behavior of sedimentation in Madura Strait.

I. INTRODUCTION

River cohesive sediment discharge to river mouth plays a significant effect in estuary condition. Especially when waves and tidal in estuary area is not dominant. In many cases river sediment discharge created river mouth sedimentation and later will developed a river mouth. In other cases when estuary hydrodynamic, that is effected by tidal and waves, is relatively active, cohesive sediment discharge will spreaded over the estuary area.

Estuary that is located in a strait, generally get affected by strait hydrodynamic condition which is active, especially by tidal. When some activities are presence, such as harbor, bridge, fishing port, etc, on that strait, sediment transport will also contribute a signifant effect to those activities.

1.1 Background and Description of Study Area

Madura Strait is located in East Java province, about 1,000 km east of Jakarta (Figure 1), the capital city of Indonesia. The Madura Strait is subject to ocean waves of less than 1 m height due to its position in semi-enclosed Java Sea in Indonesian archipelago. There are 2 major rivers that carry sediment to Madura strait namely Bengawan Solo River and Brantas River. In the last years sediment transport from Brantas river has been increasing significantly through one of its branch namely Porong River.

The development of Suramadu Bridge between Surabaya (at Java Island) and Bangkalan (at Madura Island) contributed to sedimentation pattern in Madura Strait. The shallow bathymetries in major part of Madura Strait threat an environmental problem in the area. Therefore sedimentation model is necessary on attempt to anticipate serious environmental problem in Madura Strait. This study is about mud transport simulation in Madura Strait due to increasing sediment discharge from Porong River.

The importance of sedimentation study in this area could be viewed by two reasons. Under the presence of harbour activities on Madura Strait, sedimentation in this area should be studied as the area is surrounded by structures such as turning basin, waterway, and bridge. Another reason is sediment discharge from Porong River that tends to be increased due to mudflow hazard in upstream area.

The Java Sea, where Madura Strait is located, as shown in **Figure 1**, is connected to other seas through the Sunda and Karimata Straits to the west, and Makassar and Flores Sea to the east. The sea is 1,400 km long in the east-west direction and about 400 km wide. The sea is under the influence of two monsoon conditions. In the northern summer months, monsoon winds develop due to airflow from Australia to Asia. The winds over Java Sea are generally northeasterly. This period is referred to as East Monsoon. During the northern winter period winds over Java Sea are generally northwesterly and somewhat stronger than in the east monsoon. The northwest winds period is referred to as the west monsoon and contains the period of high rainfall over Porong catchment and higher wave activity in Java Sea. This area is not subject to wind fetch in order of thousand, but rather hundreds kilometers. Accordingly under the action of monsoon winds, the north coast of Java is not subject to very large waves.



Figure 1
Study area in Java Sea, Indonesia

The study of cohesive sediment (mud) transport and morphology has been carried out since middle of 20th century, e.g Van Straaten and Kuenen (1958), Krone (1962), Waldrop and Farmer (1973). Since that time the process related

model to simulate the transport of cohesive sediment and morphology had been studied, e.g Waldrop and Farmer (1973), Christodoulou et.al (1974), Nicholson and O'Connor (1986), and Van Rijn (1987).

The publication of sediment transport and morphological simulation using process based models in river mouth areas is few comparing to similar applications in tidal areas, e.g Van Ledden (2003), Lumborg (2004), Ganasut (2005). The publication on river mouth modeling study using various methods was presented in Komar (1973), Frihy et.al (1991), Uda (1998), and Pruszek et al (2002).

In the present study, tidal dynamic process in Madura Strait and sediment pattern around Porong river mouth were analyzed using a mathematical model, MIKE21 HD and MT. In a large extent, the tidal hydrodynamic study of Madura Strait will be useful in management of coastal zone and hazard prevention around the area. The cohesive sediment and morphological simulation will be useful for future sedimentation study in Porong river mouth area and would be useful as a reference for similar studies at other locations.

The main objectives of this study were:

- a. Perform hydrodynamic and mud transport simulation in Madura Strait area using MIKE-21 HD MT model.
- b. Calibration and verification of the hydrodynamics model for water level, velocity and tidal constituents.
- c. Calibration and verification of the sediment transport model for suspended sediment concentration and deposition/erosion volume.

1.2 Methodology

Software package MIKE-21 was used in the modeling of Madura Strait. In general, the model were divided to 4 areas due to limited water level data in the boundaries especially in the offshore area, and limited number of stations with available observed suspended sediment concentration data for calibration and verification of mud transport model. As shown in **Figure 2**, there are two areas for hydrodynamic model (Large Area-HD and Medium Area-HD) and two areas for mud transport model (Medium Area-MT and Small Area-MT). The small area MT in mud transport model is a nested model area with 3 types of grid size.

The hydrodynamic simulation was done to provide water level boundary condition in sediment transport simulation in river mouth area. The hydrodynamic model was calibrated for water level and predicted flow velocity.

Given the water level boundaries, the next simulation was for cohesive sediment transport and morphological simulation. In this phase, the model results were compared with observed values of suspended sediment concentrations, bed levels and deposition volumes.

The sensitivity analysis was then performed. Several calibration parameters were varied to analyze the effect of each parameter. The significant parameters were identified and used in the analysis of model application results. The model was applied to simulate Porong river mouth development in 2009 - 2010. The observed and simulated deposition volumes were compared..

II. THEORETICAL CONCEPT

2.1 Hydrodynamics

Using MIKE-21, a software package of 2-Dimensional Horizontal process-based model developed by DHI (2002), the hydrodynamics simulation is done. The Hydrodynamic Module (MIKE-21 HD) is the basic module in the MIKE-21 package. MIKE-21HD Module simulates the water level variations and velocities in response to a variety of forcing functions in lakes, estuaries and coastal areas. The water levels and flows are resolved on rectangular grids covering the area of interest given the bathymetry, bed resistance coefficients, wind field, and hydrographic boundary conditions, etc.

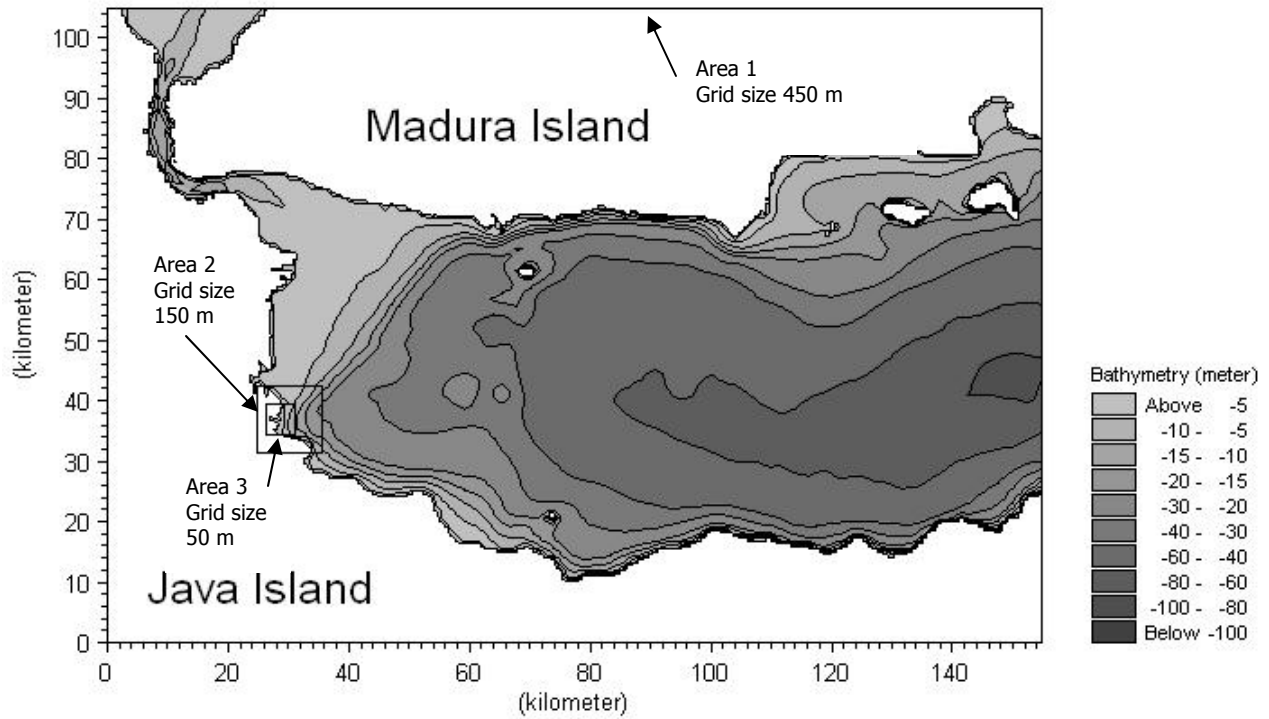


Figure 2

Numerical grid system, bathymetry map and boundaries of model simulation in study area

The hydrodynamic model in MIKE-21 HD is a general numerical modeling system for the simulation of water levels and flows in estuaries, bays and coastal areas. It simulates unsteady 2D flows in one-layer (vertically homogeneous) fluids. Basic principles are conservation of mass and conservation of momentum principles, which lead to continuity, momentum, and advection-dispersion equations. The following equations for the conservation of mass and momentum are integrated over the vertical to describe the flow and water level variations:

Continuity:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = 0 \quad (1)$$

x-Momentum

$$\frac{\partial p}{\partial t} + \frac{\partial}{\partial x} \left(\frac{p^2}{h} \right) + \frac{\partial}{\partial y} \left(\frac{pq}{h} \right) + gh \frac{\partial \zeta}{\partial x} + \frac{gp\sqrt{p^2+q^2}}{C^2 \cdot h^2} - \frac{1}{\rho_w} \left[\frac{\partial}{\partial x} (h\tau_{xx}) + \frac{\partial}{\partial y} (h\tau_{xy}) \right] - \Omega p - fV_x + \frac{h}{\rho_w} \frac{\partial}{\partial x} (p_a) = 0 \quad (2)$$

y-Momentum

$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial y} \left(\frac{q^2}{h} \right) + \frac{\partial}{\partial x} \left(\frac{pq}{h} \right) + gh \frac{\partial \zeta}{\partial y} + \frac{gq \sqrt{p^2 + q^2}}{C^2 \cdot h^2} - \frac{1}{\rho_w} \left[\frac{\partial}{\partial y} (h\tau_{yy}) + \frac{\partial}{\partial x} (h\tau_{xy}) \right] + \Omega p - fVV_y + \frac{h}{\rho_w} \frac{\partial}{\partial y} (p_a) = 0 \quad (3)$$

Let denote: x, y = space coordinates (m); t = time (s); $h(x,y,t)$ = water depth (m); $\zeta(x,y,t)$ = surface elevation (m); $p, q(x,y,t)$ = flux densities in x-, y-directions ($\text{m}^3 \text{s}^{-1} \text{m}^{-1}$); $p=uh, q=vh$; u and v are depth averaged velocities in x- and y-directions; g = acceleration due to gravity (m s^{-2}); $f(V)$ = wind friction factor; $V, V_x, V_y, V_y(x,y,t)$ = wind speed and components in x- and y-directions (m s^{-1}); $\Omega(x,y)$ = Coriolis parameter, latitude dependent (s^{-1}); $\Omega = 2\omega \sin(\varphi)$; ω is angular rotation velocity of the earth and φ is latitude of interested position; $p_a(x,y,t)$ = atmospheric pressure ($\text{kg m}^{-1} \text{s}^{-2}$); ρ_w = density of water (kg m^{-3}); $\tau_{xx}, \tau_{xy}, \tau_{yy}$ = components of effective shear stress due to turbulence and viscous effects.

2.2 Sediment Transport

Sediment transport formulations are built into advection-dispersion module, MIKE-21 AD. MIKE-21 solves the so-called advection-dispersion equation:

$$\frac{\partial \bar{c}}{\partial t} + u \frac{\partial \bar{c}}{\partial x} + v \frac{\partial \bar{c}}{\partial y} = \frac{1}{h} \frac{\partial}{\partial x} \left(hD_x \frac{\partial \bar{c}}{\partial x} \right) + \frac{1}{h} \frac{\partial}{\partial y} \left(hD_y \frac{\partial \bar{c}}{\partial y} \right) + Q_L C_L \frac{1}{h} - S \quad (4)$$

Where \bar{c} is depth averaged mass concentration (kg m^{-3}); u, v is depth averaged flow velocities (m s^{-1}); D_x, D_y is dispersion coefficients; h is water depth; S is deposition/erosion term ($\text{kg m}^{-3} \text{s}^{-1}$); Q_L is source discharge per unit horizontal area ($\text{m}^3 \text{s}^{-1} \text{m}^{-2}$); and C_L is concentration of source discharge (kg m^{-3}). The bottom shear stress τ_b (N m^{-2}) is calculated with respect to currents and waves using following equation:

$$\tau_c = \frac{1}{2} \rho f_w (U_b^2 + U_\delta^2 + 2U_b U_\delta \cos \beta) \quad (5)$$

where ρ is the density of water (kg m^{-3}), f_w is the wave friction factor, U_b is the horizontal mean wave orbital velocity at the bed (m s^{-1}), U_δ is the current velocity at top of water boundary layer (m s^{-1}), and β is the angle between the mean current direction and the direction of propagation (degree).

Formula for sediment deposition was originally proposed by Krone (1962)

$$S_D = w_s C_b p_d \quad (6)$$

Where S_D is deposition rate ($\text{kg m}^{-3} \text{s}^{-1}$), w_s is settling velocity (m s^{-1}), C_b is near bed concentration (kg m^{-3}), p_d is probability of deposition which is calculated by

$$p_d = 1 - \frac{\tau_b}{\tau_{cd}}, \tau_b \leq \tau_{cd} \quad (7)$$

τ_b is bed shear stress (N m^{-2}) and τ_{cd} is critical bed shear stress for deposition (N m^{-2}).

Settling velocity, w_s , described flocculation process. Flocculation is when the concentration of sediment is high enough for the sediment flocs to influence each other settling velocity. The modification of settling velocity also computed due to salinity variation.

$$w_{s,s} = w_s (1 - C_1 e^{S \cdot C_2}) \quad (8)$$

where $w_{s,s}$ is settling velocity due to salinity variation, C_1 and C_2 are calibration parameters and S is salinity. Erosion formula was described as soft partly consolidated sediment (Mehta et al, 1989).

$$S_E = E \exp \left[\alpha (\tau_b - \tau_{ce})^{1/2} \right], \tau_b > \tau_{ce} \quad (9)$$

Where S_E is the erosion rate (g m^{-2}), E is the erosion coefficient, ($\text{g m}^{-2} \text{s}^{-1}$), τ_{ce} is critical bed shear stress for erosion (N m^{-2}), and α is coefficient ($\text{m N}^{-0.5}$).

III Model Set-up

a. Computational grid and bathymetry

Bathymetrical data of study area was taken from bathymetry data produced by Department of Hydrographic – Indonesia Navy (2003). Bathymetry set-up of model area is shown in **Figure 2**. The largest area (Area 1), that was covered whole Madura Strait, consisted of 344 x 233 cells; each cell is 450 m x 450 m size. The medium-HD area (Area 2) composed by 72 x 72 cells, each cell was 150 m x 150 m size. And the smallest area (Area 3) that covered Porong river area composed by 99 x 99 cells, each cell was 50 m x 50 m.

b. Open sea boundary condition

The water level was prescribed along the open boundary for the model for flow computation. There were 2 open boundaries: Northern and Eastern (**Figure 2**). The Northern and Eastern boundaries were generated using Global Tide Model from MIKE21 Toolbox.

For concentration, the boundary condition, since lack of data it was assumed to be 0.0001 kg/m^3 (sea water). For the salinity boundary, the boundary condition was taken from MGI data they are equal to 4.0 Practical Salinity Unit

c. Input Source from river

The river discharge was based on the observed data from the Department of Public Work of Indonesia. The concentration was generated uniformly from MGI data (2007) 1.3 kg/m^3 . The salinity condition was taken from the data of MGI data it is equal to 0.3 Practical Salinity Unit.

d. Initial Condition

The initial water surface was equal to 0 m MSL. The initial concentration was equal to 0.0 kg m^{-3}

e. Parameter Setting

- Water Column Parameters. The settling velocity depends on flocculation condition with flocculation parameters. The concentration that mud starts flocculation was 0.01 kg m^{-3} . The concentration for hindered settling was 10 kg m^{-3} . The sediment density is 2650 kg m^{-3} .

- Calibration factors. The dispersion coefficient, the critical bed shear stress for deposition, the critical bed shear stress for erosion and the erosion coefficients were initially assumed and adjusted by trial and error. The values of the calibrated parameters are given in section 3.3.

IV Calibration

In this study, the simulation considers uniform bed resistance (Manning), In this case bed roughness, k_s , was calibrated in order to get good agreement between the computed and observed water levels and velocity at the calibration stations. The agreement between the computed and observed water level was presented by the error. Location of calibration stations is presented in Figure 3. There are 5 points namely Karang Jamuang, Surabaya, Karang Kleta, Kali Porong and Pulau Kambing. The best result is obtained in Surabaya station data, as presented in Figures 4 and 5 with error RMS 0.09.

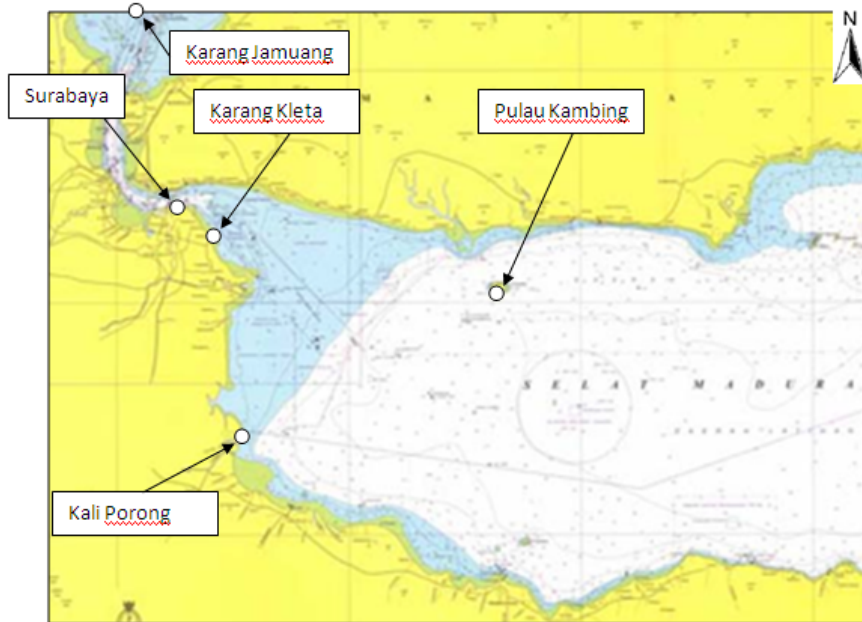


Figure 3
Location of calibration stations

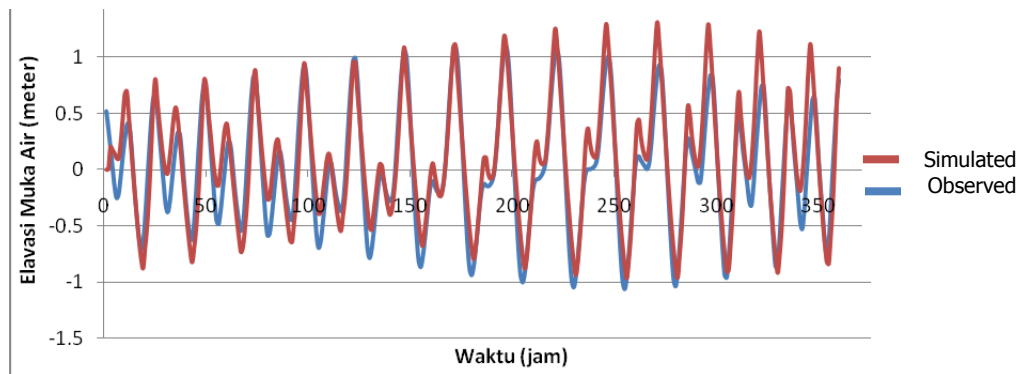


Figure 4
Comparison of observed and simulated water level at Surabaya station

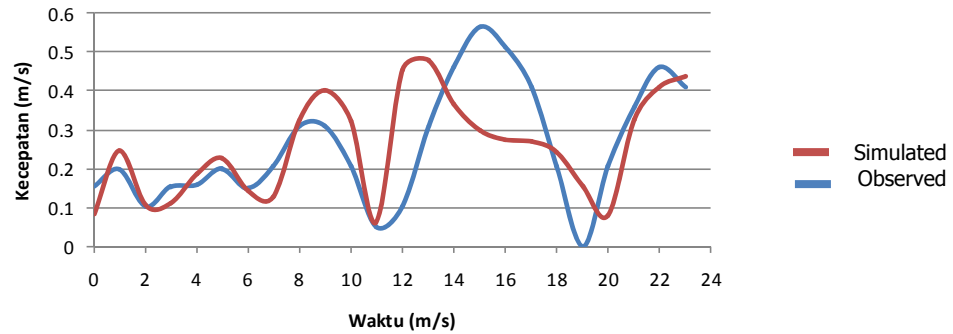


Figure 5
Comparison of observed and simulated flow velocity at Surabaya station

Calibrated model then used to simulate hydrodynamics and mud transport simulation in 1 year period, from July 2008 to July 2009. Results are presented in Figures 6 up to 8. Velocity distribution is presented in Figure 6, figure 6 a) presents velocity distribution for the larger area (area 1) and figure 6 b) presents velocity distribution in Porong river mouth. As presented in Figure 6a), There are 5 study points, P1 and P2 located at the western part of Madura Strait which commonly known as Surabaya Strait, P3 is located nearby Porong river mouth and P3 and P4 are located in the main part of Madura Strait. From visual observation and reference (Tanaka and Ishida, 1999), water movement in Madura Strait have different phase. This phenomenon is due to bathymetry and strait configuration. When water is high in the Java Sea, water enters Madura Strait from P1 and P5, and meet center of Strait, around P3. In this case, water movement is consistently different for western and eastern part of Madura Strait. The other aspect is, type of tidal at the Java Sea near P1 is mixed dominant to diurnal tide, while in the Madura strait mostly effected by semidiurnal tide. Hence the water level movement is unsimilar. To show this occurrence, computed water level for P1, P2, P3, P4 and P5 are presented in Figure 7 and 8.

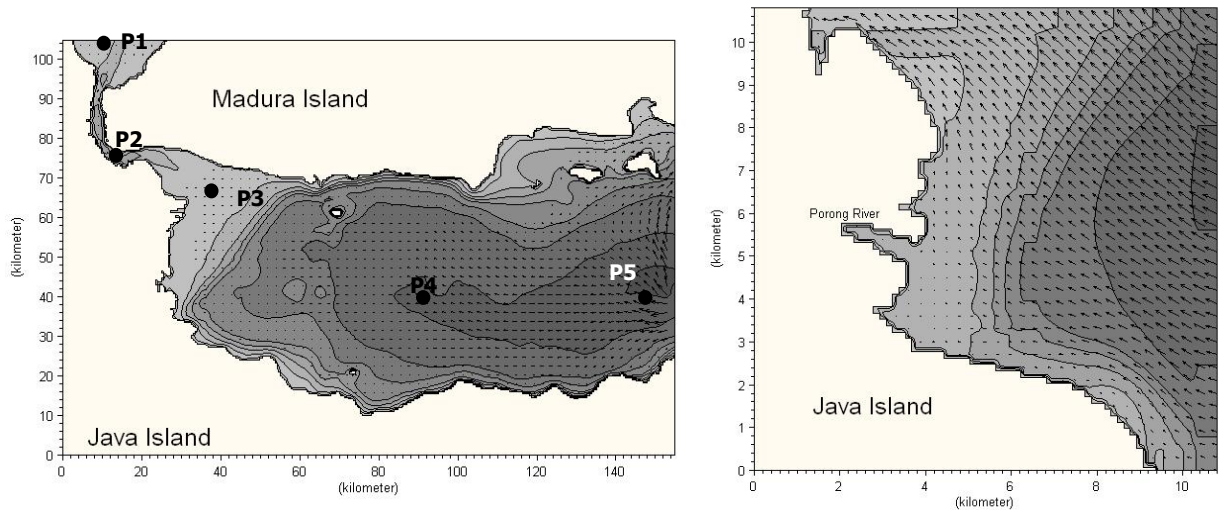


Figure 6

Velocity distribution a) At Madura Strait area 1 (coarse grid), b) At Porong river mouth, area 2 (finer grid)

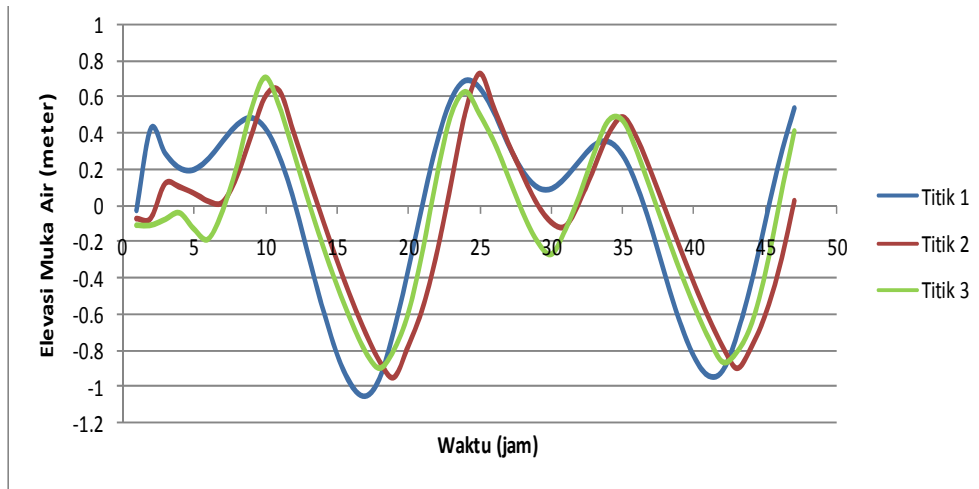


Figure 7

Computed water level at study points P1, P2 and P3

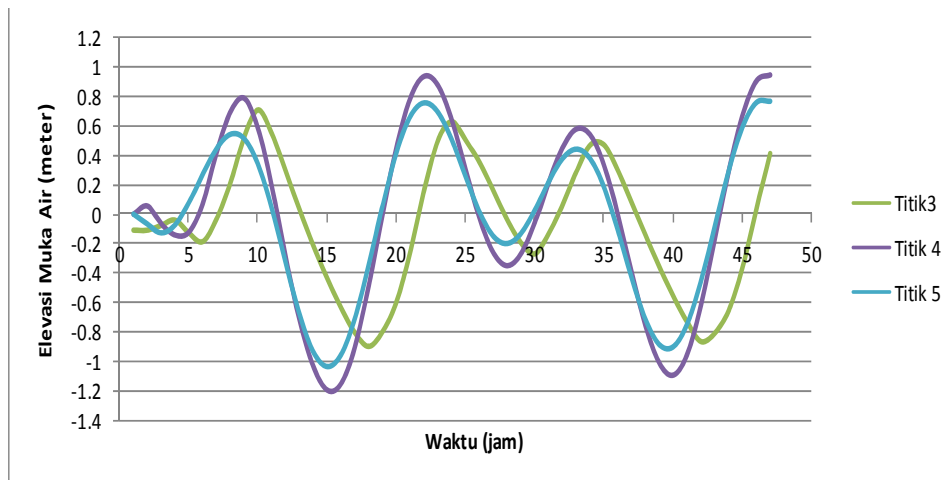


Figure 8

Computed water level at study points P3, P4 and P5

V Sensitivity Analysis

After model calibration step, sensitivity analysis was performed to analyze the sensitivity of several model parameters in particular to their effects on suspended sediment concentration distribution and changes of deposition volume. The period of analysis was 2 months 1 July – 1 September 2009. Results are presented in Figures 8, 9 and 10.

In sensitivity analysis, the following parameters were varied namely critical bed shear stress for deposition, critical bed shear stress for erosion, erosion coefficient, suspended sediment concentration at river boundary, suspended sediment concentration at sea boundary and initial suspended sediment concentration. The suspended sediment concentration distribution and volume of deposition were compared to analyze their changes. From the analysis, parameters that give significant changes are critical bed shear stress for deposition, critical bed shear stress for erosion and suspended sediment concentration at the river effluent boundary.

The use of different initial concentrations only gave significant effect in the early period of simulation (warming up period). After this period the computed suspended sediment concentration distribution was not changed with regards to initial concentration. The same result was valid for the deposition volume. The suspended sediment concentration at the sea boundary had no significant influence to distribution of sediment concentration especially in the river mouth region; it controlled the suspended sediment concentration only in the area near the sea boundaries.

Sensitivity analysis on the effects of critical bed shear stress for deposition was done considering $\tau_{cd} = 0.005 \text{ Nm}^{-2}$; $\tau_{cd} = 0.01 \text{ Nm}^{-2}$; $\tau_{cd} = 0.05 \text{ Nm}^{-2}$; and $\tau_{cd} = 0.1 \text{ Nm}^{-2}$. It was noted that the $\tau_{cd} = 0.05 \text{ Nm}^{-2}$ was the selected parameter value in the calibrated model. It was found that the critical bed shear stress for deposition had insignificant effect on the computed suspended sediment concentration but it had a significant effect on the deposition volume in the river river.

Sensitivity analysis on the effects of critical bed shear stress for erosion was done considering $\tau_{ce} = 0.0075 \text{ Nm}^{-2}$; $\tau_{ce} = 0.015 \text{ Nm}^{-2}$; $\tau_{ce} = 0.075 \text{ Nm}^{-2}$; and $\tau_{ce} = 0.15 \text{ Nm}^{-2}$. It was noted that the $\tau_{ce} = 0.15 \text{ Nm}^{-2}$ was the selected parameter value in the calibrated model. It is found that the critical bed shear stress of erosion had insignificant effects on the computed suspended sediment concentration but it had a significant effect on the deposition volume in the river river mouth.

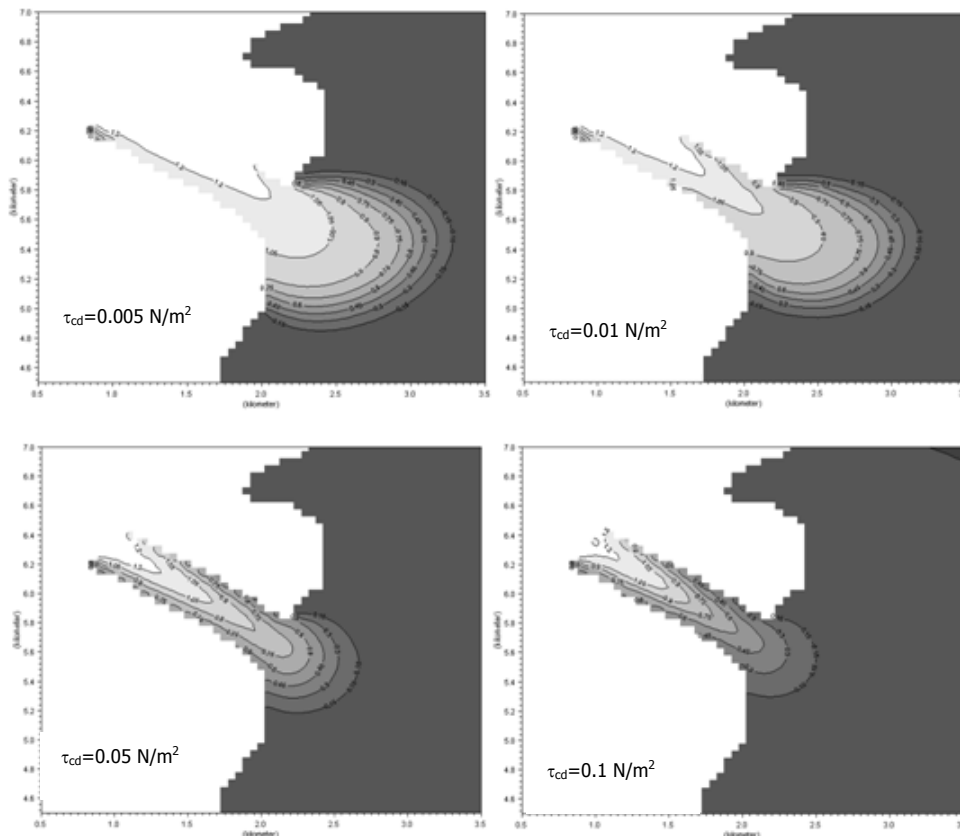


Figure 8

Sensitivity analysis by analyze volume of deposition with various number of critical shear stress of deposition

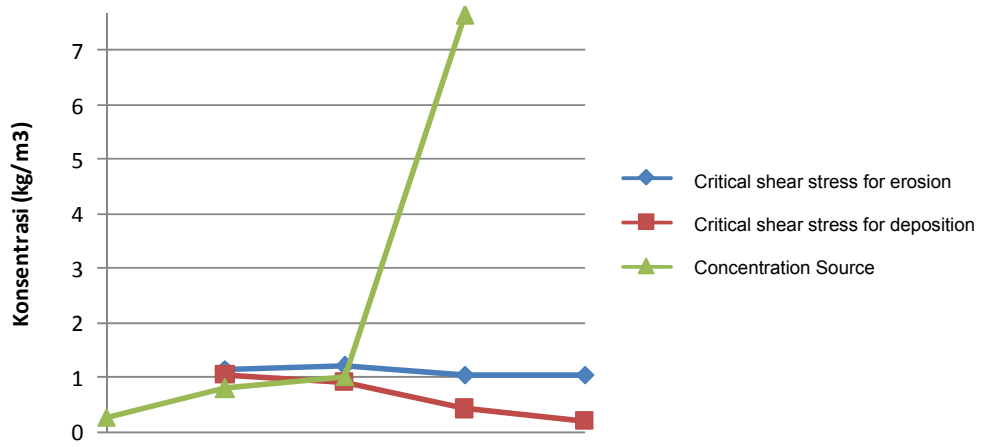


Figure 9

Sensitivity analysis of several model input/parameters to sediment concentration at river mouth

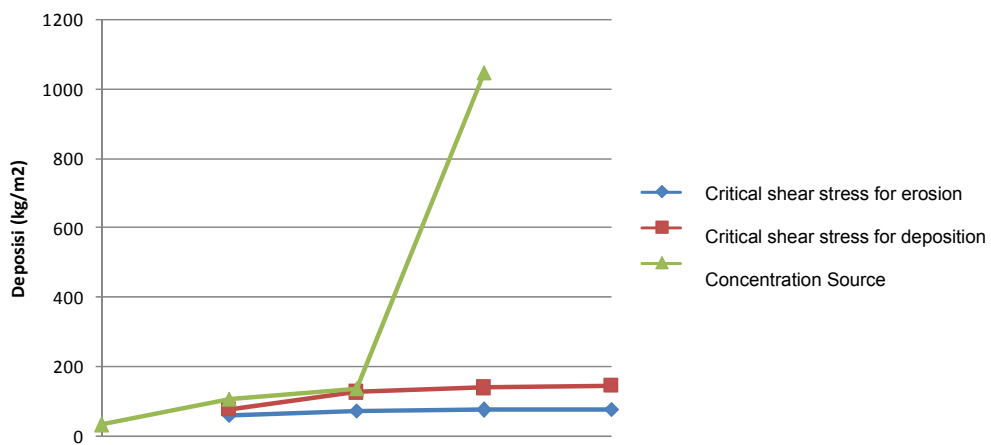


Figure 10

Sensitivity analysis of several model input/parameters to deposition volume at river mouth

From sensitivity analysis it was concluded that the most important input model is input from river, especially suspended sediment concentration. Important parameters of model are critical shear stress of deposition and critical shear stress of erosion.

VI. Results and Discussion

The calibrated model of hydrodynamic and mud transport was used to simulate flow and sediment pattern from July 2009 – July 2010. Results are presented in Figures 11 – 13.

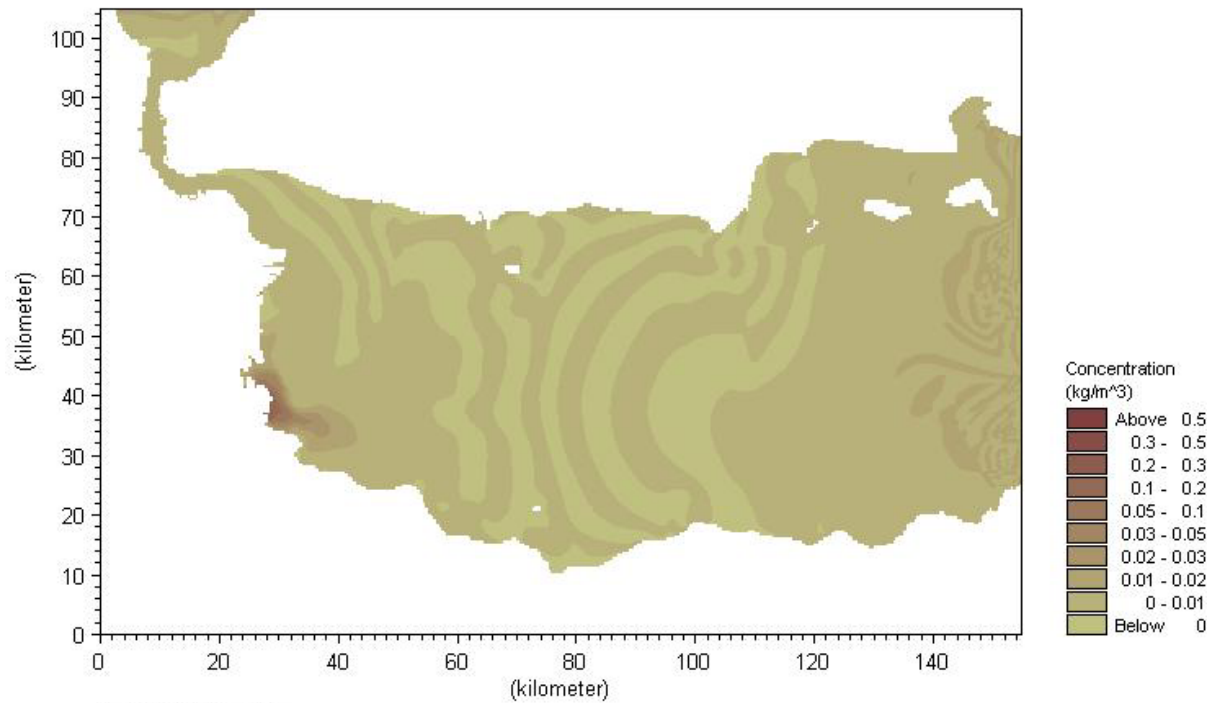


Figure 11

Computed sediment concentration on Madura Strait (area 1) after 1 year period simulation

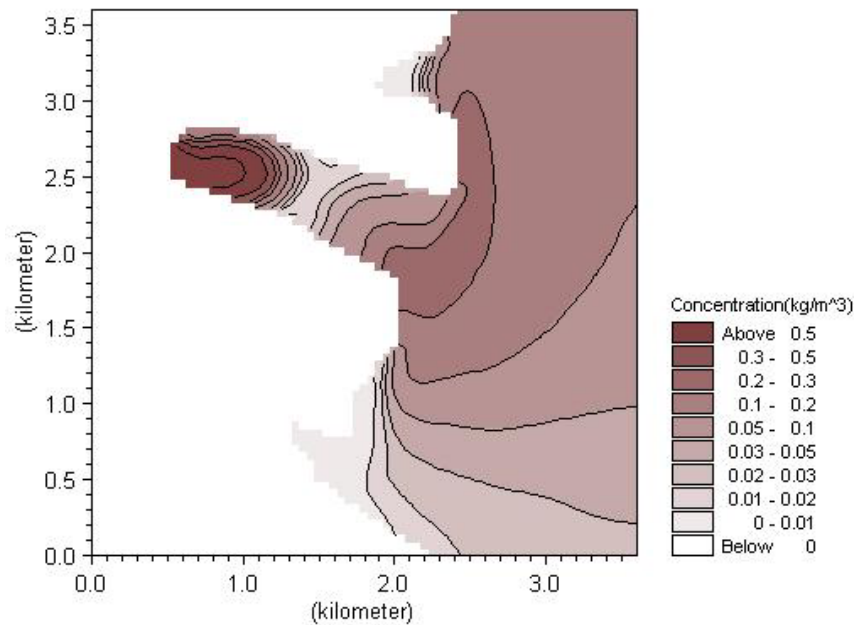


Figure 12

Computed sediment concentration on Porong river mouth after 1 year period simulation

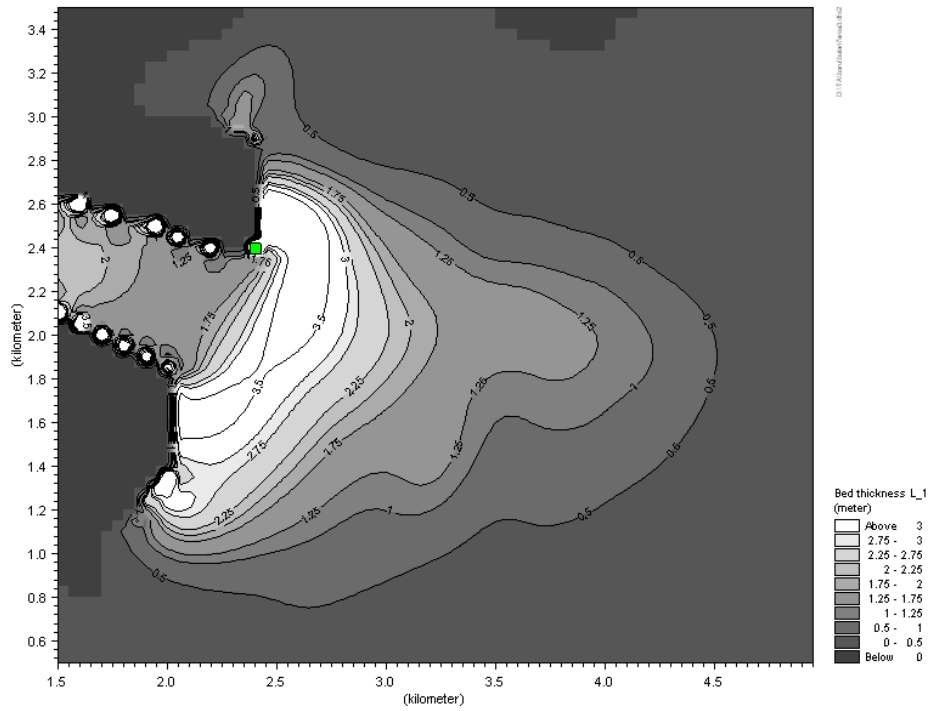


Figure 13

Computed bed thickness changes on Porong river mouth after 1 year period simulation

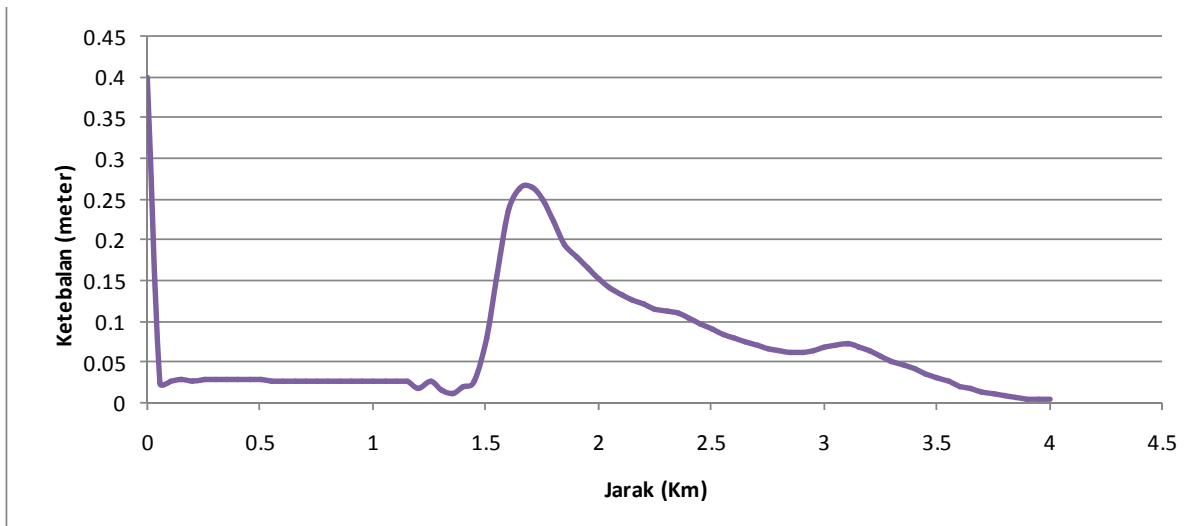


Figure 14

Profile series of bed thickness changes from river to river mouth

From the simulation, it was found that the amount of deposition and bed thickness was in relation with the value of sediment from river. Hence in time when the observed sediment source from the river was decreased or increased, the amount of deposition was also decreased or increased in the same order respectively. This result is consistent with the characteristic of river river mouths as described by Van Rijn (1998).

From the simulation it was showed that the deposition occurs in most of the river mouth area with small bed level changes of not more than 0.04 m.

From sensitivity analysis, the important parameters were found to be critical bed shear stress for deposition, critical bed shear stress for erosion and river input suspended sediment concentration. Hence the important calibration parameters for simulating river mouth development were critical bed shear stresses for deposition and for erosion. Critical bed shear stress for deposition is physically explained as initial shear stress at the beginning of deposition, this is very important as it is mainly related to deposition. The values of τ_{cd} were found to be in the range of 0.083- 0.11 Nm^{-2} for Bandon Harbour, Surat Thani, Thailand (Lee, 1974), while Mehta (1984) found the value of τ_{cd} for San Francisco Bay mud, USA and Maracaibo estuary mud, Venezuela to be 0.10 Nm^{-2} and 0.08 Nm^{-2} respectively. Winterwep et al. (1991) found the value of τ_{cd} were in the range of 0.03- 0.15 Nm^{-2} for various natural muds from lakes, rivers and estuaries in the Netherlands. Van Ledden (2003) performed the sand-mud simulation in the Friesche Zeegat, a tidal basin in Dutch Wadden Sea, Netherland and found τ_{cd} equal to 0.15 Nm^{-2} . Lumborg (2004) used values of τ_{cd} in the range of 0.02 – 0.04 Nm^{-2} in modeling cohesive sediment transport in Lister Dyb tidal area in Danish Wadden Sea, Denmark. Ganasut (2005) found the similar value with Winterwep et. al (1991) for mud transport simulation in Songkhla Lagoon, Thailand. The value of τ_{cd} in this study is found to be 0.05 Nm^{-2} .

The critical value of bed shear stress for erosion depends on the bed material characteristics such as mineral composition, organic materials, salinity, and density. Erosion of cohesive soil occurs whenever the bed shear stress induced by water flow over the bed is high enough to break the electrochemical inter-particle bonds. The surface erosion takes place by the removal of individual sediment particles. In contrast, mass erosion occurs more or less instantaneously by the removal or entrainment of relatively large pieces of soil, occurring when the flow induced shear stresses on the bed exceeds the soil bulk strength. In the studies covering erosion of natural muds from lakes, rivers and estuaries in the Netherlands, Winterwerp et al. (1991) found that a top layer was eroded by surface erosion at bed shear stresses in the range of 0.15 - 0.30 Nm^{-2} . Ravens (1999) found the value of τ_{ce} in the range of 0.1 ± 0.04 Nm^{-2} in Quincy Bay of Boston Harbor, Massachusetts, USA. Van Ledden (2003) did sand-mud simulation in the Friesche Zeegat, a tidal basin in Dutch Wadden Sea, Netherland and found τ_{ce} equal to 0.5 Nm^{-2} . Lumborg (2004) use values of τ_{cd} in the range of 0.1 – 0.7 Nm^{-2} in modeling cohesive sediment transport in Lister Dyb tidal area in Danish Wadden Sea, Denmark. Ganasut (2005) applied τ_{ce} , in a range of 0.1 to 0.3 Nm^{-2} .

Selection of critical bed shear stress for deposition and bed erosion is important task in sediment transport and morphological modeling. There was a range of critical bed shear stress for deposition and erosion values, which was sensitive in the study area. The bed shear stress distribution and sedimentation condition in the study area was strongly related to hydrodynamic condition e.g. boundary condition and the characteristics of the tides semidiurnal and diurnal.

In general, based on the simulation results, the model had successfully simulated sedimentation in the river mouth area. Sediment flux from river into the estuary is fluctuated due to tidal dynamics and river discharge. In the river area where tidal effect is small the sediment is transported as bed and suspended load. The velocity is decreased when the flow enters the estuary and it increases further with respect to tidal condition (from tidal boundary). Coarser sediment deposits near the river mouth when it just enters the estuary. Finer materials are formed in suspension; it may deposit during periods of neap water or transport in suspended form. With effect of salinity, suspended particles tend to bind each other and form heavier flocs particles, which may settle and deposit in the region of low flow velocity.

Based on this simulation, sediment discharge from Porong river to Madura Strait affected area about 4 km from river mouth.

V. CONCLUSIONS

The numerical model of river mouth development is a considered the most promising approach in river mouth area planning and management. The Porongriver river mouth was selected as a study case because the catastrophic phenomenon of mudflow from Lapindo area that was discharged to Porong river.

A study on hydrodynamics and morphological simulation in Madura Strait had been done with the main purpose to investigate the hydrodynamic condition in Porong river mouth area. Calibration of the hydrodynamic model namely the MIKE-21 HD had been done successfully. Sediment transport simulation was performed in the river mouth area using MIKE-21 Mud Transport module, which takes into account sediment flocculation and salinity variation. The model considered only suspended sediment transport, because of most of sediment load in the river that deposited to estuary is fine suspended load. Inputs from the river were discharge and suspended sediment concentration. Boundary conditions at the surrounding sea are water level, suspended sediment concentration and salinity. Sea water levels are generated using Admiralty method with astronomical constituents based on co-tidal chart in the river mouth area. Calibration and verification parameters were dispersion coefficient, critical bed shear stress for deposition, critical bed shear stress for erosion, and erosion coefficient. By comparing the computed suspended sediment concentration and deposition volume with the observed data, model calibration and verification had yielded satisfactory agreement results.

Sensitivity analysis was performed in which the considered parameters were critical bed shear stress for deposition, critical bed shear stress for erosion and input of suspended sediment concentration from river.

This study presents procedures in modeling sedimentation in river mouth using a 2-dimensional horizontal model that can be used to analyze sediment transport in river mouth areas and to predict morphological growth of river mouths.

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