Three Dimensional Numerical Modeling of Current and Temperature Distribution in the Estuary of Palu River

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Abstract. Three dimensional numerical model of current and temperature distribution in the estuary of Palu river was discussed in this article. The simulation was conducted using estuary coastal ocean model and sediment transport (ECOMSED) and geographical information system (GIS). The first simulation was conducted by assuming no discharge and the second simulation using combination of tidal and river discharge. The first simulation runs smoothly, where the results revealed that the tidal current velocity on the horizontal and vertical cross sections for one tidal cycle ranged from 0 m/s to 0.03 m/s. Whereas a run time error occurred during the second simulation due to the calculation of nonlinear advection term parameter in momentum equation. The error problem could be solved by imposing a low river discharge data into the model. The visual appearance of current circulation at the river mouth, calculated surface elevation, and temperature distribution on the horizontal and vertical cross sections revealed a good agreement with the primary and secondary data.

1. Introduction

The estuary of Palu river is a place for fishermen to earn a living. Industrial developments along the river banks have triggered waste disposal activities into the aquatic environment. The problem that frequently occurs is that during the rainy season water in the river overflows, it has led the pollutant enters the houses of some residents near such area. Therefore, an integrated environmental management is needed. An approach to solve this environmental problem is by collecting information that can show the pattern of pollutants dispersion through the current circulation prediction in the estuary. This information can be obtained through continuous monitoring activities. However, this activity requires a high cost, therefore, numerical model is one of solutions that can be used to solve this problem.

A predicting of hydrodynamics in coastal zone due to hydrometeorological activity using numerical model is also important for monitoring water quality and early warning system related to the water crisis in Palu city [1, 2]. Therefore, current circulation and temperature distribution model is needed to be made. One of the three-dimensional numerical models that can be applied to analyze the dynamics of the estuary physical oceanography in the region is the estuary coastal ocean model and sediment transport (ECOMSED) [3]. This model has been used by several researchers to simulate hydrometeorology phenomena in the estuary [4], tide current in the bay [5], a typhoon storm surge [6], inundation [7], three dimensional hydrodynamic over bed forms in open channels [8], etc. Where the
simulation results revealed that there is no significant difference with the observed data and theoretical model.

Numerical calculation in the estuary of Palu river became unstable due to the water depth rapidly change from nearshore to the open sea based on the previous researches [9, 10], where bathymetry data obtained based on the contours analysis of the sea map of the Palu bay and general bathymetric chart of the oceans (GEBCO) digital atlas [11]. Modification of bathymetry data will change the current velocity on the steep area and vicinity, therefore, in this article, the simulations were conducted without changing bathymetry data which is obtained from interpolation.

This research aims to make the current circulation and temperature distribution model in the estuary of Palu river. The results are expected to provide information to anticipate the pollution, so that losses can be prevented before a disaster occurs.

2. Methods

Three dimensional model for current and temperature distribution which is generated by tide and river discharge are simulated separately to reveal the dynamics of current and temperature in the estuary of Palu river.

Topography map, IKONOS image, and google earth image are used as reference points for geometric correction in simulation area. The more reference points, the error during geometric correction can be reduced, so that the model domain has a high level of precision and accuracy.

Figure 1. Map of simulation area based on the satellite image of (a) IKONOS and (b) google earth

The simulation area is divided into 125 x 125 grids horizontally and 11 layers vertically with the different thickness. The parameter settings are as follows: \( \Delta x = 25 \text{m} \), \( \Delta y = 25 \text{m} \), \( \Delta t = 1 \text{s} \), the simulation was running 360 hours continuously, constant temperature value of 28\( ^0 \text{C} \) at the upstream (river) and 29\( ^0 \text{C} \) at the downstream (sea), constant salinity value of 0 psu at the upstream and 34 psu at the downstream, river depth obtained from the Department of Public Works of Palu City in year 2008, bathymetry data obtained from interpolation of the sea map of Palu bay, and six tidal harmonic constants obtained from hydro oceanographic office (DISHIDROS) [12].

The first simulation was conducted by assuming no discharge to reveal the current velocity due to the tidal effect. Second simulation were conducted for the river discharge of 36 m\(^3\)/s and 2 m\(^3\)/s. in order to see clearly the current and temperature distributions at the delta and vicinity, the simulation results were displayed in high resolution.
Verification of model was conducted by comparing the simulation results to the secondary data from DISHIDROS) for water elevation and field observation of temperature distribution was carried out at the same locations with simulation area on the vertical cross section.

3. Results and Discussions

3.1. Depth interpolation
The interpolation was conducted using Arcgis and Tecplot based on the sea map of the Palu bay. The water depth of the Palu bay shown in Fig. 2 was obtained by digitizing the map and then creating interpolation using the kriging interpolation method. The result shows that the river depth ranging from 1.5 m to 3 m and the bathymetry ranging from 0 m to 167.83 m, where the depth rapidly change in the eastern part of the sea.

![Depth interpolation of simulation area](image)

Figure 2. Depth interpolation of simulation area

3.2. Run time error
Run time error occurred during second simulation with discharge of 36 m$^3$/s due to the calculation of nonlinear advection term parameter in momentum equation. The problem could be solved by turning off convective acceleration. It means that the analytical solution can be obtained by solving the differential equation using techniques of integration for elementary functions [13, 14]. However, the simulation results will be unrealistic to describe the nonlinear phenomena, therefore, the error problem was solved by imposing the river discharge of 2 m$^3$/s as input data into ECOMSED. The instability of numerical calculation due to the river discharge of 36 m$^3$/s could be solved by reducing the gradient of the depth slope of bathymetry on steep areas [9]. However, the current velocity will change because of the velocity dependent on the rate of depth change.

Many numerical calculations have generally the computational stability condition. In the ECOMSED, the Courant-Friedrichs-Levy (CFL) stability condition should be satisfied as one of stability criterion. According to the CFL condition, numerical stability is dependent on water depth and maximum flow velocity. Therefore, numerical calculation become unstable when water discharge is larger. Other, numerical instability is dependent on the rate of depth change and velocity change. When maximum depth is 168.33, CFL conditions are internal mode time step (DTI) < 8.9s and external mode time step (DTE) < 0.22s.
3.3. Tidal current and surface current

Tidal current simulation was conducted for the first simulation by assuming no discharge to test the stability of ECOMSED and to reveal the current velocity that is only generated by tidal, so that the effect of tidal and river discharge at the estuary can be revealed. The simulation was carried out by imposing the tidal harmonic constants as a generated force on the open sea boundary was extracted from harmonic analysis, where the simulation runs smoothly without any error.

**Figure 3. Tidal current simulation on the vertical cross section for one tidal cycle**

**Figure 4. Surface current simulation for one tidal cycle**
Fig. 3 shows that the current pattern reverses during low slack water and high slack water conditions, it flows alternately in approximately opposite directions. At low slack water, the current pattern moves from downstream to upstream, whereas at high slack water flows from upstream to downstream. The current velocity in this conditions varies from 0 m/s to 0.03 m/s. The current velocity at ebb condition begins to slow down and reach the minimum velocity at the flood condition with the velocity varies from 0 m/s to 0.008 m/s.

The direction of current will change dynamically depend on the position and geometry of delta at the river mouth. The visual appearance of Fig. 4 shows the direction of current movement based on the simulation results has similar patterns with the google earth image in Fig 1(b), where the surface current velocity in the estuary varies from 0 m/s to 0.54 m/s.

### 3.4. Temperature distribution

Fig. 5 depicts the high resolution of simulation area around the delta and vicinity. The surface temperature distribution on the horizontal cross section from the upstream to downstream varies from 28°C to 29°C. This is caused by a constant input data of surface temperature in ECOMSED, where in upstream and downstream are 28°C and 29°C respectively. It can be seen in Fig. 5, that surface temperature distribution follows the patterns of surface current from the river.

![Temperature distribution](image)

**Figure 5.** Temperature distribution on the horizontal cross section for one tidal cycle.

### 3.5. Verification of temperature distribution

Fig. 6 depicts the temperature distribution on the vertical cross section from the river to the sea. The boundary between the fresh water from the river and saline water from the sea can be seen clearly, where the fresh water that has higher temperature lies above the saline water that has lower temperature due to the different salinity between fresh water and saline water. The lower salinity of the fresh water corresponds to the lower density, so that it lies above the layer of saline water from the sea that has higher density. These conditions in line with a theoretical model, where the water temperature decreases with the depth. At ebb and flood conditions, the difference of water temperature between the near-surface and near-bottom rarely exceeded 1°C [15].
The observation was conducted on three observation stations on the vertical cross section from the bottom to the surface around the delta, water temperature at low slack water, ebb, and high slack water condition was 28°C from bottom to surface. It reveals a uniform condition from the lowest layer to the surface. At flood condition, water temperature was 29°C at the lowest layer. This condition similar to the simulation results in Fig. 6, where the temperature distribution varies from 28°C at the surface and 28.8°C at the bottom.

![Temperature distribution on the vertical cross section for one tidal cycle.](image1)

3.6. Verification of water elevation

Verification was conducted by comparing secondary data on the tidal area of the Palu bay from DISHIDROS and ECOMSED. The simulation was running for 360 hours continuously. According to Fig. 7, comparison of water elevation between ECOMSED and DISHIDROS shows a good agreement, where there exist a similar patterns for both results. According to the tidal harmonic constants, the Formzahl value is 0.29. It means that the type of tide in Palu bay included of the mixed tide prevailing semidiurnal, where on one day, ebb and flood conditions occurred twice with the different amplitude and period.

![Comparison of water elevation between ECOMSED and DISHIDROS](image2)
4. Conclusions
The first simulation revealed that the tidal current velocity on the vertical cross sections varies from 0 m/s to 0.03 m/s. Run time error occurred during second simulation due to nonlinear advection term parameter in momentum equation, the problem could be solved by imposing a low river discharge into the ECOMSED. The visual appearance of current circulation at the river mouth and vicinity, calculated surface elevation, and temperature distribution on the horizontal and vertical cross sections revealed a good agreement with the image satellite obtained from google earth, temperature observation, and water elevation obtained from DISHIDROS.

The results are expected to predict the spread of pollutants and sea surface temperature with a low river discharge during ENSO. This model can be used for a large river discharge by reducing the gradient of the depth slope of bathymetry on steep area and increasing the resolution of space and time near such area. The next research topic will be conducted using nesting model for a better resolution. The current patterns and temperature distribution are strongly influenced by several parameters such as discharge and water elevation. Nevertheless, a comprehensive simulation need to be conducted by considering the effects of wind and wave. In order to see clearly the dynamics of the shoreline moving over tidal flat, then the wet and drying scheme (moving boundary) need to be applied into the numerical model.

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