STUDY OF DEBRIS MOVEMENT IN SOUTH AND WEST COAST OF SUMATRA AND JAVA AND ITS IMPACT ON BALI STRAIT DURING WESTERN MONSOON

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Abstract. Bali Strait is one of the most unique and important water areas, especially for the coastal communities of Banyuwangi and Jembrana up to Badung Regency. The Bali Strait has Sardinella lemuru fish resources where it is widely exploited and is the main livelihood income of the coastal communities. In recent years, the quality of Sardinella lemuru fish has begun to decline due to contamination of microscopic plastic debris in the Bali Strait during western monsoon. Many previous researches have carried out the movement of debris in the Bali Strait using numerical model to find out the source and location of the marine debris, however it only carried out local simulations within the Bali Strait. This study aims to determine the movement of debris that reaches the Bali Strait assuming debris originates from coastal areas on south and west coast of Sumatra Island to Java Island during the western monsoon (December 2018 - February 2019). The Finite Volume Coastal Ocean Model (FVCOM) model is used to obtain circulation of current patterns and debris particles movement patterns using the Lagrangian Particle Tracking module. The verification result of the model current pattern and field data using the Root Mean Square Error (RMSE) equation. In the u velocity component the RMSE value is 0.014 m/s with a correlation of 0.968 and the v velocity component is 0.011 m/s with a correlation of 0.945. In general, the current pattern in the waters of southern of Sumatra Island to Java Island in the dominant western monsoon moves eastward due to the influence of western monsoon. The simulation results show particles that reached the Bali Strait as much as 3.47% originating only from the coastal waters of East Java.

Keywords: Bali Strait; FVCOM; lagrange; marine debris

1. Introduction

Bali Strait is one of the unique and important water areas, especially for the coastal communities of Banyuwangi Regency, East Java and Jembrana Regency to Badung Regency, Bali. Bali Strait has abundant lemuru (Sardinella lemuru) fish resources, so it is widely exploited and has become the main livelihood of coastal communities[1]. The coastal area of the Bali Strait also presents the beauty of nature, thus there are many tourist areas located around the coast of the Bali Strait.

In the last few years, the Bali Strait have been threatened due to indications of debris contamination, especially plastic debris. Based on a research conducted by Bagaskara[2] the spread of microscopic-sized plastic debris in the Bali Strait has polluted some potential fishing areas during the western monsoon. As a result of contamination of plastic debris in the Bali Strait, the quality of lemuru fish begin to decline. In addition of affecting fisheries activities, debris also has an impact on tourism activities on the coast that are directly bordering the Bali Strait. One example is a build up of debris volume in the coast of

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Badung regency, Bali. The average landfill dumped reaches ± 30 tons/day and the peak occurs in January 2014 which reaches ± 1,700 tons\textsuperscript{[3]}.

Based on the debris data at the coast of Badung regency, average high debris occurs during the western Monsoon\textsuperscript{[3]}. The high amount of debris in the Bali Strait during western monsoon is thought to occur due to the high rainfall, making debris transportation from the watershed which empties into the sea to increased\textsuperscript{[4]}. Debris originating from the watershed is then carried by waves to the shore, with an average of 5 tons/day with a peak reaching 50 tons, dominated by wood and plastic debris\textsuperscript{[5]}. During the western monsoon, the dominant wind moves from Asia to Australia, causing surface currents to move eastward in the waters of Southern Java\textsuperscript{[6]}. Based on the research from Fadika\textsuperscript{[6]} there are indications that the source of debris that empties into the Bali Strait can also originate from the waters of the Southern Java Sea.

With the indication of debris originating from the waters of Southern Java in western monsoon, this study aims to determine the movement of debris that reaches the Bali Strait assuming debris originates from coastal areas on south and west coast of Sumatra and Java during the western monsoon (Desember 2018 – Februari 2019).

2. Material and Methods

2.1. Model Design

The domain model used in this study is located in the Southern Waters of Sumatra Island to the Southern of Bali Island (Figure 1). The used grid is a triangular unstructured grid consisting of two boundaries, namely open boundaries and closed boundaries with a spatial resolution of 10 to 50 km. The simulation is carried out for 90 days during the western monsoon period (December 2018 - February 2019) with a 1 second time step and uses the stability requirements of Courant Friedeich Levy (CFL). This model consists of the four sigma layer divided by uniform layer conditions, using components of tidal elevation totaling 4 which are of S2, M2, K1, and O1.

Figure 1. Research location and large model grid

In the verification of the results of the model, a smaller scale simulation model was carried out with a suitable location in the Bali Strait (Figure 2) with a higher spatial resolution. The small model is made because of the lower spatial resolution used in the large model, so the results of the model assessment are smaller on the coastal area and areas that have complex bathymetry, such as the Bali Strait. The grid used is an unstructured triangle lattice with a spatial resolution of 500 up to 1000 m. The simulation is carried out for 20 days from 16 January 2019 to 5 February 2019 with a 1 second time step.
2.2. Hydrodynamic Model

The hydrodynamic model simulation is used to obtain current movement patterns using the Finite Volume Coastal Ocean Model (FVCOM). FVCOM consists of two modes (external and internal) which are calculated separately. The constructing equation in the FVCOM model consists of momentum and continuity equations (1 to 3), temperature (4), salinity (5), density (6) and tidal elevation (7) which are continuity and momentum equations.

\begin{align*}
\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} - fv &= -\frac{1}{\rho} \frac{\partial P}{\partial x} + \frac{\partial}{\partial z} \left( K_u \frac{\partial u}{\partial z} \right) + F_t \quad (1) \\
\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} + fu &= -\frac{1}{\rho} \frac{\partial P}{\partial y} + \frac{\partial}{\partial z} \left( K_v \frac{\partial v}{\partial z} \right) + F_t \quad (2) \\
\frac{\partial v}{\partial t} &= -\rho g \quad (3) \\
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} &= 0 \quad (4) \\
\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z} &= \frac{\partial}{\partial z} \left( K_T \frac{\partial T}{\partial z} \right) + F_T \quad (5) \\
\frac{\partial S}{\partial t} + u\frac{\partial S}{\partial x} + v\frac{\partial S}{\partial y} + w\frac{\partial S}{\partial z} &= \frac{\partial}{\partial z} \left( K_S \frac{\partial S}{\partial z} \right) + F_S \quad (6) \\
\zeta_0 &= \zeta_0 + \sum_{i=1}^{N} \xi_i \cos (\omega t - \theta_i) \quad (7)
\end{align*}

Where \( x, y \) and \( z \) are the east, north, and vertical axes in the Cartesian coordinate system; \( u, v \) and \( w \) are the \( x, y \) and \( z \) velocity components (m/s); \( T \) is the temperature (°C); \( S \) is the salinity (ppt); \( \rho \) is the density (Pa); \( P \) is the pressure; \( f \) is the coriolis parameter variable (°); \( g \) is the gravitational acceleration (m/s); \( K_u \) is the vertical eddy viscosity coefficient (m²/s); \( K_v \) is the thermal vertical eddy diffusion coefficient (m²/s); \( F_u, F_v, F_T, \) and \( F_S \) represent the horizontal momentum, thermal, and salt diffusion terms (N); \( \zeta \) is the height of the free surface (m), \( \zeta_0 \) is the average elevation relative to water level (m); \( \zeta_i, \omega_i, \) and \( \theta_i \) represent the amplitude (m), frequency (s), phase of the tides formed (°); and \( t \) is the time (s).

Figure 2. Research location and small model grid
2.3. Model Lagrangian Partikel Tracking

The simulation of the Lagrangian Particle Tracking model uses the assumption that debris originates from the coast in the southern island of Sumatra to Java. The location of particle released is 10 km to 16 km from the coastline, while the distance between particles is 5 km (Figure 3). The particle is released discontinuously at the first time on the model simulation. Mathematically, tracing the particle trace with the Lagrange method on FVCOM is solved by ordinary differential equations in non-linear systems using equation (8)[8].

\[
\frac{dx}{dt} = v(x(t), t)
\]

(8)

Where \( x \) is the position of the particle at time \( t \), \( \frac{df}{dt} \) is a change in the position of the particle with time and \( v \) is a velocity field in 3-dimensional \((x, y, z)\) generated from the hydrodynamic model.

Figure 3. Release location of particles

2.4. Data Sources and Model Results Verification

This study uses primary and secondary data as input and to validate the results of model simulations. The primary data used in this study is the current movement data using a davis drifter which was carried out on February 3, 2019. The davis drifter was placed for 6 hours from 8.21 AM at a location point far from the coastline to avoid the influences of longshore current (Figure 4).

Figure 4. Observation location for the davis drifter
The secondary data used in this study are data from the General Bathymetric Chart of the Oceans (GEBCO), the average wind data for 5 years obtained from the European Center for Medium-Range Weather Forecasts (ECMWF) with a resolution of 0.125°, average water temperature and salinity data obtained from the World Ocean Atlas (WOA), and tidal elevation data using tidal elevations developed by the Ocean Research Institute (ORI), University of Tokyo (ORI-Tide)\(^9\).

Current velocity and direction of the model are verified with field observation data obtained from primary data using Davis drifter. Verification of the model results is done using correlation analysis with equation 9 and RSME (Root Mean Square Error) in equation 10.

\[
\begin{align*}
  r & = \frac{\sum_{i=1}^n xy - (\sum_{i=1}^n x)(\sum_{i=1}^n y)}{\sqrt{\left(\sum_{i=1}^n x^2 - \left(\sum_{i=1}^n x\right)^2\right)\left(\sum_{i=1}^n y^2 - \left(\sum_{i=1}^n y\right)^2\right)}} \quad (9) \\
  \text{RMSE} & = \sqrt{\frac{\sum_{i=1}^n \left( X_{\text{insitu},i} - X_{\text{model},i} \right)^2}{n}} \quad (10)
\end{align*}
\]

where \( x \) is the value of the observations in the field, \( y \) is the value obtained from the model results, and \( n \) is the amount of data.

### 3. Result

#### 3.1. Verification of the Hydrodynamic Model

Verification of the hydrodynamic model is done by comparing between the components of the current velocity \( u \) and \( v \) and the results of the simulation model and the observation data (Figure 5). In the \( u \) velocity component, the RMSE value is 0.014 m/s with a correlation of 0.968 and the \( v \) velocity component is 0.011 m/s with a correlation of 0.945. In general, the difference in value between the simulation model and field observation is not much different. In component \( v \), it has a different current speed pattern starting at 2 hours. This difference occurs due to changes in tidal current speed in the observation data, whereas in the simulation model only uses 4 tidal components so that some conditions of tidal current speed changes are not calculated at model. But in general based on correlation and RMSE values and flow velocity graphs, the simulation model is sufficient to illustrate current patterns in the field.

![Figure 5. East-west component (u) and north-south component (v) validation graph](image)

#### 3.2. Residual Current

Movement of currents can cause movement of particles in the waters. In the model simulation, dominant current is generated by tides and winds. Average current speed at high tide is 0.06 m/s, ebb tide is 0.08 m/s, low tide is 0.05 m/s and flood tide is 0.09 m/s. To simplify the analysis of current movements that affect particle movements, residual currents are used. The residual current is the average flow pattern
During model simulations in the western monsoon. The movement pattern of residual currents can show the dominant current movements in the water, therefore it can show the pattern of movement of debris particles. The patterns of residual current movements show that during the western monsoon, the dominant current moves eastward with an average speed of 0.0422 m/s (Figure 6). Western monsoon winds are very influential in the movement of the dominant currents to the east due to the western monsoon movements from the Asia to the Australia in the December, January and February periods. In the southern part of the Bali Strait, there is a northward wind with an average speed of 0.028 m/s, where it can carry water mass from the southern waters of East Java to the Bali Strait.

3.3. Movements of Particles
Simulation of the Lagrangian Particle Tracking model on the model domain for 90 days shows the pattern of particle movements generated by currents. The particles released in the southern coastal region of Sumatra Island to Java Island are assumed as debris originating from the coast. Based on the simulation results of the model (Figure 7), the average particle displacement is 58,235 km with an average speed of 0.0074 m/s and the maximum displacement is 247,344 km. Particles released in the Sunda Strait have faster particle movements which reached 0.0318 m/s with the direction of movement towards the south. The rapid movements of these particles occur due to high residual currents (Figure 6).

![Figure 6. Pattern of residual currents in western monsoon](image)

The particles that reached the Bali Strait for 90 days had displacements ranging from 24,506 km to 61,797 km. Based on these results, the movement of particles toward the Bali Strait is relatively short within 90 days. This displacement occurs because of the low velocity of the residual currents therefore decreasing the movement of the water mass that carries debris particles.
Of all the particles released in the model domain, only particles from the southern coastal waters of East Java reached the Bali Strait (Figure 8). Of all the particles released from the southern coastal waters of East Java, only 3.47% of the particles reached the Bali Strait. The movement of particles from East Java to the Bali Strait caused by 2 events. first, the currents in the south of Java are dominantly moving eastward following the west monsoon winds, so particles originating from eastern Java tend to move towards to Bali island. secondly, in the southern part of the Bali Strait there is a current that moves north towards to Bali Strait with an average speed of 0.028 m/s, so that it can move particles into the Bali Strait. The number of particles that arrived was indeed quite low, but in the long term the debris particles originating from the southern coast of East Java had contributed to the accumulation of debris in the Bali Strait.

4. Conclusion
Based on the obtained results, it can be concluded that the waters of Southern East Java contribute as much as 3.47% of the total debris particles released from the waters of the Southern coast of East Java.
West monsoon winds are very influential in the movement of debris particles towards the east in the southern waters of the island of Sumatra to Java, to the Bali Strait.

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