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2D HYDRODYNAMIC MODELING IN THE WATERS OF LAMPUNG BAY, LAMPUNG PROVINCE USING TELEMAC-MASCARET

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ABSTRACT

Lampung Province shares borders with the Indian Ocean, Java Sea, and Sunda Strait. Lampung Bay has an average depth of 25 meters, with depths ranging from 25 meters to 75 meters. The waters of Lampung Bay have a coastline extending 1,105 km, including several surrounding islands, comprising 69 islands (Wiryawan et al., 1999). Lampung Bay serves as a main gateway for sea transportation routes, both nationally and internationally. This makes the waters of Lampung Bay require special observation, as the bay is at high risk of hydro-oceanographic changes. This study conducts 2D hydrodynamic modeling using Telemac-Mascaret in Lampung Bay. The results of this study are the current patterns of Lampung Bay, current speeds in Lampung Bay, and surface water elevation in Lampung Bay. The results show that the waters of Lampung Bay have an average current speed of 0.95 m/s with a dominant flow direction to the north and an average elevation ranging from -0.600 meters to 0.770 meters. Based on these results, it can be seen that the waters of Lampung Bay are dominated by semi-diurnal or mixed mainly semi-diurnal tides, with water mass movements only entering and exiting the Bay.

KEYWORDS: 2D Hydrodynamics, Tides, Current Velocity, Telemac-Mascaret 2D.

INTRODUCTION

According to Manafi (2021), Indonesia is a sovereign country with an area of up to 2,300,000, with the majority being ocean, accounting for 77.11%, and comprising up to

17,504 islands. Based on these territorial data, Indonesia is the largest archipelagic country in the world. Of the total waters, there are straits and bays; one of the bays in Indonesia is the Lampung Bay. The waters of Lampung border directly on the Indian Ocean, the Java Sea, and the Sunda Strait. Lampung Bay is a shallow coastal bay that has a major port used as the primary gateway in transportation routes. This is demonstrated by the heavy traffic of large vessels transporting industrial materials and energy requirements, as well as fishing boats in operation. Given the density of vessel traffic, hydrodynamic observation is required to understand and analyze the pattern and velocity of currents in a body of water, which can be used to avoid and minimize the negative effects in the Lampung waters.

In the Lampung Bay area, there are three large river estuaries, and these river mouths serve as outlets/discharge points for river flow; because they are located at the downstream ends, the flow rate at the estuaries is greater than in the upstream river sections. In this bay, human activity and the condition of the coastal/marine environment are heavily influenced by hydro-oceanographic factors. The characteristics of the bay are determined by the energy of the tides, which greatly affects the flows in this bay as this energy occurs daily. Therefore, hydrodynamic modeling of ocean currents is needed to understand water circulation in Lampung Bay. The aim of this research is to develop a 2D Hydrodynamic Model of Lampung Bay Waters using Telemac-Mascaret software, with outputs including current velocity, current direction, and tidal elevation. The benefit of this modeling is as a reference for navigation and port development efforts in the Lampung Bay Waters region and to serve as a foundation for further 2D Hydrodynamic modeling studies in Lampung Bay. Once the 2D hydrodynamic model results have been validated, this information becomes valuable and can be used to support the economy and fisheries, as well as for navigation, planning of coastal infrastructure development, and as a basis for hydro-oceanographic forecasting in the Lampung Bay area. Furthermore, this modeling makes it easier to analyze water conditions and is more efficient in terms of time, cost, and labor.

MATERIALS AND METHODS

The research materials consist of secondary data, namely TPXO (TOPEX/Poseidon Global Ocean Tide Model) tidal data taken from the OSE website, tidal data from BIG (Geospatial Information Agency) for model validation, bathymetric data from Batnas (National Bathymetry System), shoreline data obtained from Google Earth, and current data from the Copernicus website for 31 days, from January 1, 2024 to January 31, 2024, collected in the waters of Lampung Bay.

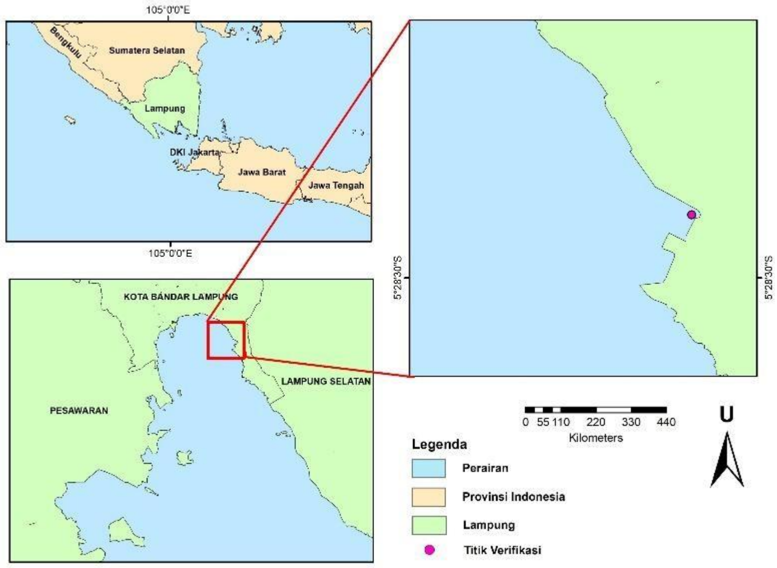

Figure 1. Research Location Map of Lampung Bay Waters.

This research was conducted to create a 2D hydrodynamic model using Telemac Mascaret 2D software. The modeling was carried out in the waters of Lampung Bay, Lampung, as shown in Figure 1.

Tidal Data Processing

Tidal data were obtained from the Indonesian Geospatial Reference System (SRGI), managed by the Geospatial Information Agency (BIG). The data used in this study cover the period from January 1, 2024 to January 31, 2024, or one full month. This data was collected and provided by BIG as part of national tidal monitoring.

This tidal data is used as supporting data in hydrodynamic modeling and is meant to provide an understanding that tides are the main factor influencing water circulation in Lampung Bay. The data obtained from BIG are highly accurate because they are collected from various permanent tidal stations distributed throughout Indonesia's coastal areas. The station name is Pel. Panjang located at Pelindo II Port, Bandar Lampung. The coordinates are 05° 28' 10.570 S and 105° 19' 13.370 E.

Coastline and Bathymetric Data Processing

This data was obtained from digitization using Google Earth Pro software. This is essential data used to support modeling and to create initial model features such as the coastline and mesh, prior to running simulations. The modeled area is located near Panjang Port, so the research location does not encompass all of Teluk Lampung. The bathymetric data was obtained from the Batnas website or Ina-Geoportal, which is a geospatial information platform managed by the Indonesian Geospatial Agency. This data is used to support modeling.

Processing Methods

The creation of the bay mesh is the first stage in conducting flow simulation/modeling using Telemac Mascaret 2D. The mesh itself is a collection of triangular grids that form a river. The software used in this mesh creation process is BlueKenue, which displays the developed layout. Steps in creating the bay mesh include digitizing the coastline boundary. The process of creating the bay mesh includes: delineating the bay boundary, creating the outline, generating meshes for small islands, performing bathymetric interpolation, and setting the boundary between the bay and open sea. The result of the mesh creation is a triangular grid, which is then interpolated to match the bay depths to actual conditions. Interpolation is done using BlueKenue software (a companion application to Telemac Mascaret 2D) with its features T3 Channel Masher and Map Object. Additionally, it is necessary to mesh the small islands around the bay as they can affect water currents. After interpolation, boundary conditions must be defined so that running can be performed in Telemac Mascaret2D. Boundary conditions are set in conlim (boundary condition). After that, selafin data is needed. Selafin is a geometry file containing information on the physical structure of the water body, consisting of water depths and contours. This selafin file is essential as a prerequisite for running the model. The file serves as a setting or control file containing the configuration and parameters used for running, including input of the geometry, boundary, fortran, and tpxo files. The function of this file is to control desired settings such as simulation time, time-step, run dates, etc. For the run, a period of 31 days was included, from January 1, 2024 to January 31, 2024, with a time-step of 5 seconds as the simulation is performed per second. The running process is straightforward because the required files already exist: by opening the Telemac Mascaret command prompt and the folder containing the necessary files, then typing "Telemac Mascaret2d.py Lampung.cas" (a command to run hydrodynamic modeling, where the file is the steering file). Information on the number of boundaries present in the .slf file indicates there are 19 boundaries, with 18 being small islands within the bay, and one boundary condition as the boundary with the open sea.

Model Verification

Verification is performed once the hydrodynamic modeling is completed and outputs are obtained, namely the 2D Hydrodynamic Model. The next step is verification using both verification data and the available model data to determine the degree of agreement between model results and observational data. Verification uses the RMSE (Root Mean Square Error) value. In addition to RMSE, model output verification also compares model data with verification data using a comparison graph, which allows for assessment of similarities/differences between results. This modeling verification graph compares tidal data from the model with BIG data, and current velocity and direction from the model are verified against data downloaded from the Copernicus website.

RESULTS

Physical Characteristics of Lampung Bay Waters

These physical characteristics make Lampung Bay a very relevant location for hydrodynamic modeling. Understanding water flow dynamics, particularly those influenced by tides, is vital for coastal planning and management, environmental risk mitigation, and to support economic activities such as fisheries and navigation.

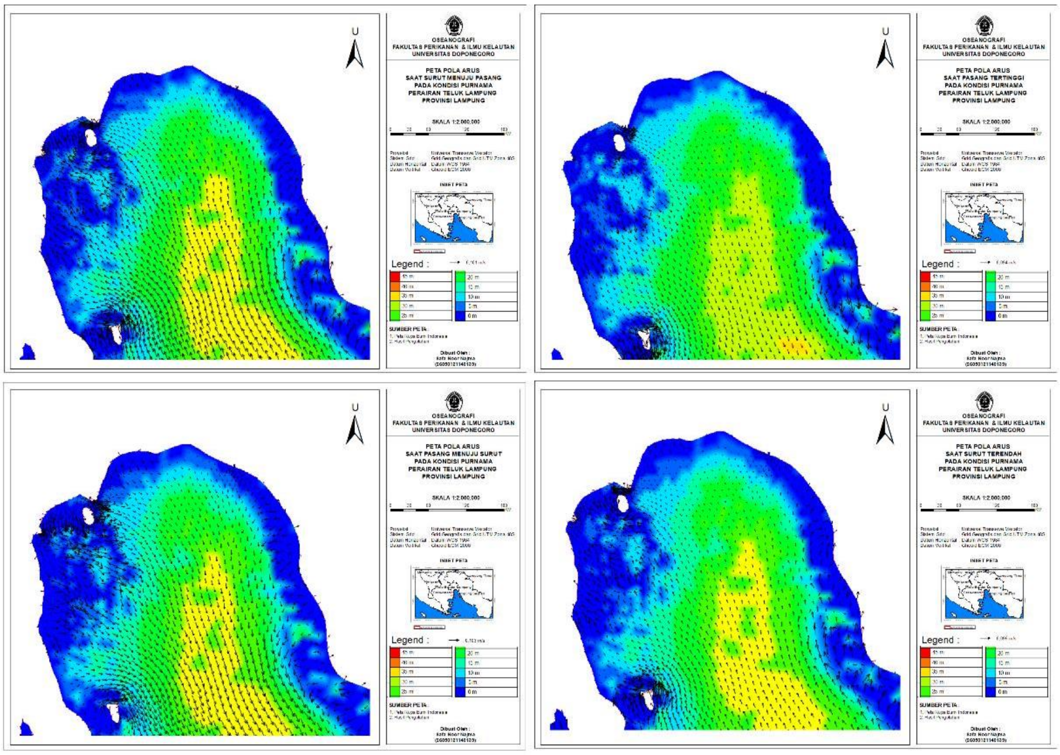

Figure 2. Current Patterns at (A) Low Tide to High Tide (B) Peak High Tide, (C) High Tide to Low Tide, (D) Minimum Low Tide at Full Moon Condition.

Based on the modeling results, the current pattern in Lampung Bay Waters is dominated by tidal currents moving from Sunda Strait to Lampung Bay during high tide, and vice versa, moving from Lampung Bay to Sunda Strait during low tide. The bay area is predominantly driven by tidal forces (Gross, 1990). Recorded current speeds vary depending on the prevailing tidal conditions. During periods of rising or falling tide, current speeds are higher compared to peak high tide or minimum low tide. The slack water phenomenon, where current speeds approach zero, occurs at peak high tide and minimum low tide. Slack water conditions arise when sea surface elevation reaches its maximum or minimum point. During full moon high tide, as the tide rises, water mass enters Lampung Bay at the bay's tip with speeds around 0.101 m/s. The current speed continues to decrease towards the northern part of Lampung Bay. This current speed is influenced by the prevailing tidal energy, which is relatively low during full moon tides, impacting both the currents and surface elevation. During full moon high tide at peak tide, the current speed at the bay's tip is around 0.094 m/s. This relatively high current speed results from the large amount of tidal energy during peak tides. The current speed continues to decrease northward in the bay, with flow direction oriented north or toward the bay's interior. During full moon high tide as the tide shifts to low, water mass flows out of the bay. The outbound current speed is not significantly different from the inbound speed, at about 0.103 m/s. However, the current direction differs, moving away from the bay or towards the south. During full moon high tide at minimum low tide, water mass exits the bay with a current speed at the tip of approximately 0.095 m/s, as shown in Figure 2. This scenario is similar to the one at peak high tide, where current speed also decreases. The current direction under this condition is southward, moving away from the bay.

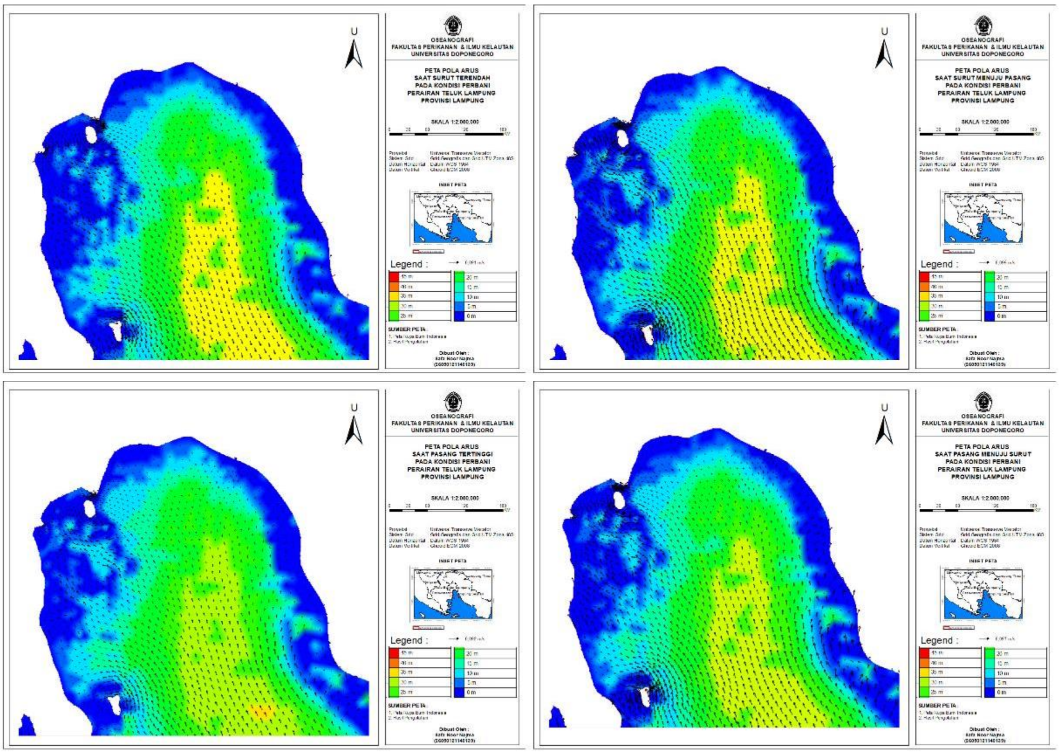

Figure 3. Current Patterns at (A) Lowest Low Tide, (B) Transition from Low to High Tide, (C) Highest High Tide, (D) Transition from High to Low Tide during Neap Tide Conditions.

During neap tide conditions at the lowest low tide, the water mass has a current speed of approximately 0.091 m/s. The current direction moves from the bay outward or towards the south. In the transition from low to high tide during neap tide conditions, the water mass has a speed of 0.095 m/s. At this speed, the current direction is towards the bay or northward. In neap tide conditions at the highest high tide, the water mass has a speed of 0.092 m/s. This speed indicates current dynamics moving into the bay. In neap tide conditions during the transition from high to low tide, the water mass has a speed of 0.097 m/s, with the current direction shown moving out of the bay as depicted in Figure 3.

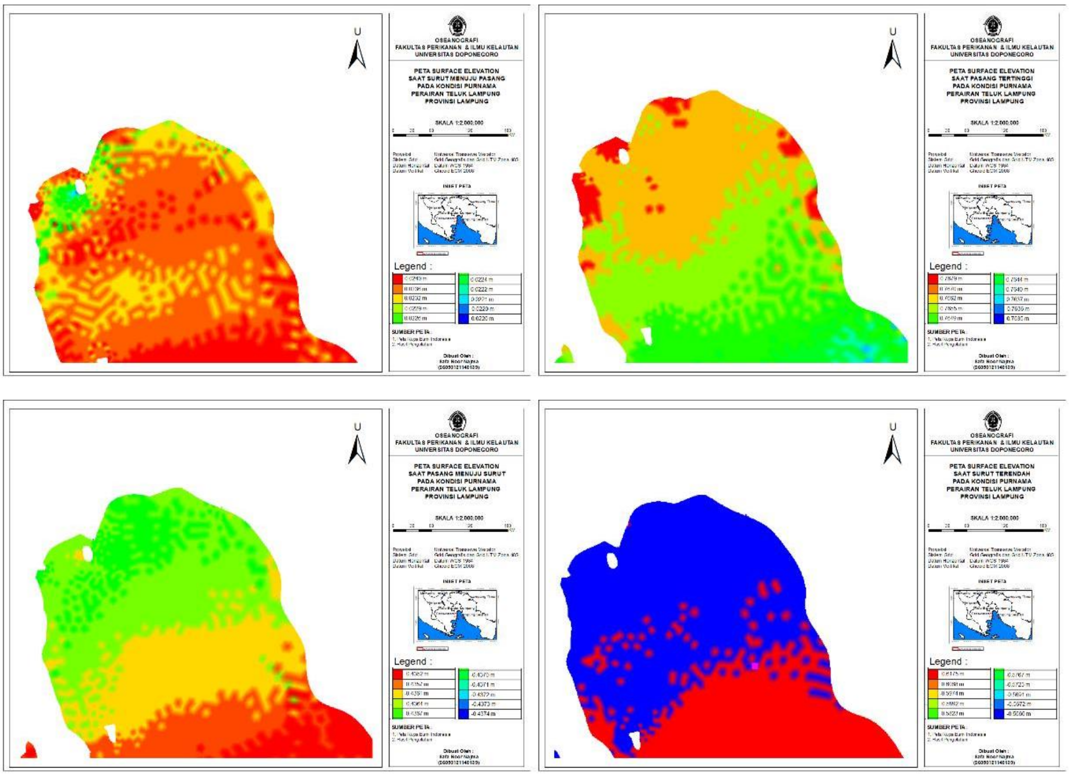

Figure 4. Surface Elevation at, (A) Ebb Tide Rising to Flood, (B) Highest Tide, (C) Flood Tide Falling to Ebb, (D) Lowest Ebb at Spring Tide.

Under spring tide conditions, the gravitational pull of the Moon and Sun are aligned, resulting in a very strong tidal force. Modeling results show that during the ebb-to-flood phase with an elevation of -0.20 m on January 12, 2024 at 09:00 WIB, the entry of seawater mass from the open ocean into the inner Bay of Lampung is observed. The dominant current direction is from south to north, with current velocity increasing rapidly as the tidal peak approaches. This phenomenon indicates that the hydrostatic pressure caused by increased water volume triggers a significant rise in horizontal current. On the same day at the tidal peak, with an elevation of 0.770 m at 14:00 WIB, current velocity decreases because the horizontal force due to water level differences is relatively small. However, the sea surface elevation reaches its maximum value, potentially causing inundation in the northern coastal areas of the bay, such as Telukbetung and Panjang. At this phase, the flow tends to spread (diverge) and turbulence begins to diminish. The flood-to-ebb phase with an elevation of -0.150 m at 18:00 WIB shows a reversal of current direction from the inside of the bay towards the open sea. Current velocity increases again, especially in narrow areas such as river mouths and near the bay entrance, due to differences in surface water pressure. Finally, at peak ebb with an elevation of -0.660 m at 21:00 WIB, the sea surface is at its lowest point, currents weaken again, and the shoreline shifts towards the sea as shown in Figure 4. This condition also increases the risk of seawater intrusion into the land via estuaries, especially if influenced by anthropogenic activities such as excessive groundwater extraction.

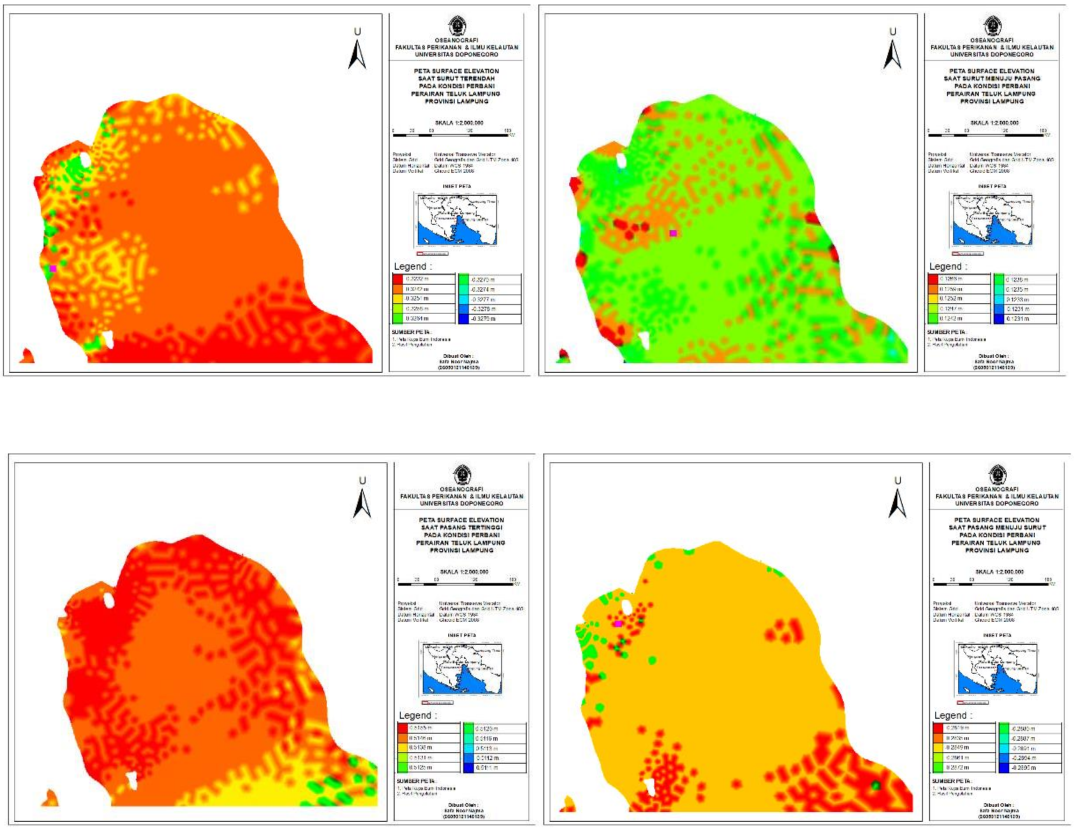

Figure 5. Surface Elevation During, (A) Lowest Low Tide, (B) Transition from Low to High Tide, (C) Highest High Tide, (D) Transition from High to Low Tide During Neap Tide

Conversely, under neap tide conditions, the moon and sun form a right angle to the earth, resulting in gravitational forces that counteract each other. As a result, the tidal amplitude is smaller, and the changes in water surface elevation are not as pronounced as during the full moon. Model results show that during the transition from low to high tide with an elevation of -0.350 m on January 20, 2024, at 04:00 WIB), currents begin to enter the bay but at a lower speed. This indicates a more stable water circulation with minimal turbulence. At the peak high tide with an elevation of 0.540 m at 08:00 WIB, sea level reaches its highest point during the neap cycle, but still remains below the full moon level. The current speed is nearly stagnant, so the residence time of seawater in the bay tends to be longer. This could have a positive effect on marine aquaculture as nutrient distribution becomes more even. Entering the phase from high to low tide with an elevation of -0.280 at 15:00 WIB, the current flows out again at a moderate speed. Then, at peak low tide with an elevation of -0.350 at 01:00

WIB, as shown in Figure 5, this condition is almost the same as during the full moon when the current is very slow, and the changes in water surface elevation are relatively small as seen on Figure 5.

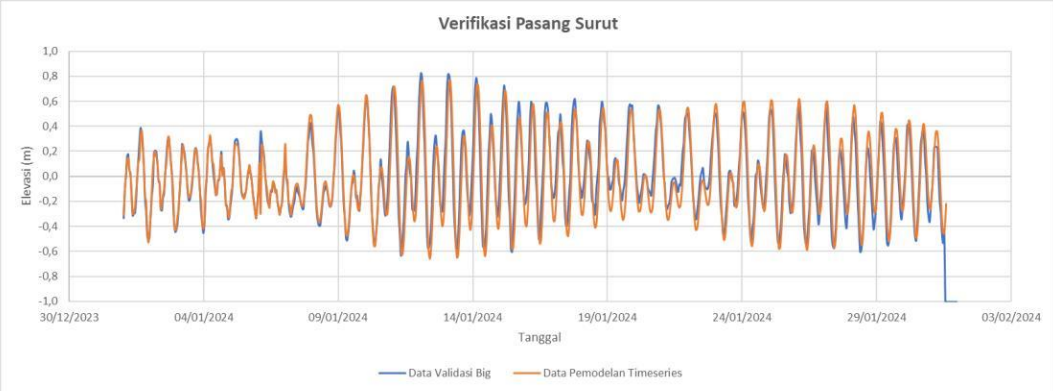

Figure 6. Tidal Verification from Model Data Compared with BIG Data.

Based on data obtained from the Indonesian Geospatial Reference System (SRGI) and analyzed using Telemac Mascaret-Mascaret, tides in the Lampung Bay Waters display a mixed pattern tending toward semidiurnal type. This means there are two high tides and two low tides each day, with varying amplitudes as depicted in Figure 6, which shows the tidal graph.

Sea surface elevation data obtained indicates that the maximum high tide at the study location from the BIG verification data ranges around 0.82 meters, while the minimum low tide elevation is around -0.63 meters. In comparison, model results at the same location show approximately 0.77 meters at maximum high tide and -0.77 at minimum low tide. These changes are influenced by the gravitational effects of the moon and the sun, as well as the morphology of the seabed.

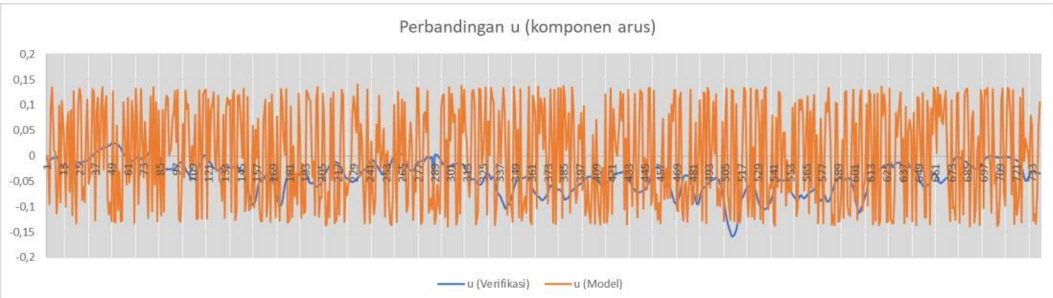

Figure 7. Validation of the Current Component (u) from Copernicus data and Model Results Image.

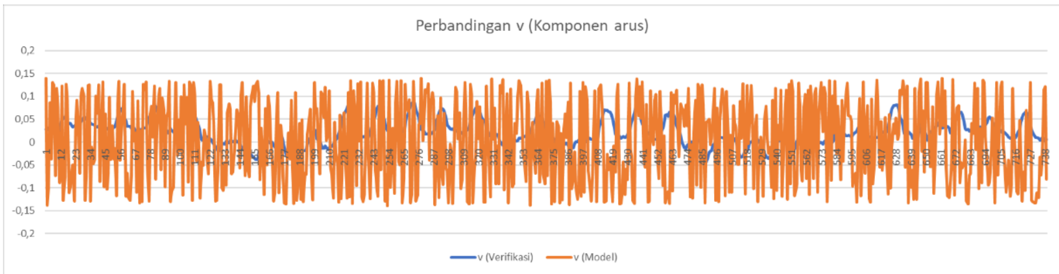

Figure 8. Validation of the Current Component (v) from Copernicus data and Model Results.

The zonal current movement (U component, East-West direction) shows an irregular pattern with an average velocity in the East-West (u) direction of 0.001 m/s, while validated data show an average (u) velocity of -0.039 m/s. This indicates that zonal current movement is more dominant towards Teluk Lampung, as presented in Figure 7 which details (u) current component validation. The dominance of the much stronger meridional velocity component forms the current pattern similar to the total surface current velocity. In general, both components follow a tidal pattern where, during spring tide, the daily maximum meridional current velocity tends to be very high. In contrast, during neap tide, the daily maximum meridional current velocity tends to be quite low. The distribution of total surface current separating the harmonic (tidal) and non-harmonic (residual) current components reveals the stronger dominance of the harmonic current component in influencing the current pattern in Teluk Lampung. Meanwhile, the comparison of the (v) current component in the north-south direction shows an average of 0.002 m/s, and the validated (v) current component data show an average of 0.02 m/s, as displayed in Figure 8, which presents the verification graph comparing the (v) current component.

DISCUSSION

Bathymetry is one of the important factors in hydrodynamic modeling. Bathymetry is related to current speed and direction, tides, and sediment. Moreover, the bathymetric shape also influences model results as base resistance, which is also used as model input. The deepest depths of Teluk Lampung are found at the mouth of the bay, with depths around ±28 m, and the depth decreases further northward in the bay's waters.

The waters of Teluk Lampung have a mixed tide type with double tidal dominance (Ongkosongo, 1989). Mixed tides, prevailing semi-diurnal, are tides that occur twice high and twice low in one day, with differing heights and times; these occur along the southern coast of

Java and eastern Indonesia (Wrytki, 1961). Based on model results, during the transition from low to high tide, the water mass moves into Teluk Lampung. The movement of water mass into and out of the bay can occur during both low to high tide transitions and at the highest tide, where the movement in and out of the bay causes changes in elevation for each tidal condition. The highest elevation occurs during the highest tide at spring tide and is much greater compared to elevation at neap tide. Gross and Kohn (1990) stated that in bay areas, the dominant generating force is the tide, consistent with the results showing that the current pattern in Teluk Lampung waters is dominated by tidal currents flowing out of the bay during low tide conditions. According to Nurhayati and Suyarso. (2020), the area is also dominated by tidal influence. Previous analytical studies of currents in these waters have shown that the tides and seasons of Teluk Lampung, as yielded by the model, demonstrate that the maximum current speed is achieved at spring tide, ranging from 0.093 m/s to 0.103 m/s—a higher speed than during neap tide, which ranges from 0.092 m/s to 0.097 m/s. Current speed also affects the surface elevation in Teluk Lampung; the exchange of mass during neap tide results in a maximum elevation change of 0.770 meters and -0.600 meters during spring tide. Meanwhile, for neap tide, surface elevations are 0.540 meters and -0.350 meters. Such current patterns and velocities—compounded by the accumulation of residential and household waste discarded and settling at the bottom of Teluk Lampung—will, over time, cause shallowing of Teluk Lampung's waters. In addition, the dense activity at Panjang Port has also led to changes within Teluk Lampung.

CONCLUSION

The ocean currents in Lampung Bay have an average speed of 0.13 m/s. The current movement pattern follows the tidal movement pattern, with a mixed tide predominantly semi-diurnal type. During high tide, the current moves from the Sunda Strait northward, entering Lampung Bay in a northwest direction with a maximum speed of 0.103 m/s, whereas during low tide the current reverses direction, flowing out of Lampung Bay to the south towards the Sunda Strait with the lowest current speed of 0.092 m/s. The waters of Lampung Bay are a mixed type dominated by semi-diurnal tides, in which the conditions during neap tide and spring tide differ. Elevation during spring tide is higher compared to neap tide, namely 0.777 meters and -0.600 meters versus 0.540 meters and -0.350 meters.

During spring tide, water mass movement tends to be dominated by inflow into the bay, whereas during neap tide the movement of water mass is predominantly outward from Lampung Bay.

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