HYDRODYNAMICS MODELING IN KENDARI BAY, SOUTHEAST SULAWESI, INDONESIA

Imalpen Imalpen[1], Tri Prartono[2], Rastina[3], Alan Frendy Koropitan[4], Amir Yarkhasy Yuliardi[5]
[1]Marine Science Postgraduate Program, Faculty of Fisheries and Marine Sciences, IPB University, Jl. Agatis, Dramaga, Bogor, 16680, Indonesia
[2,3,4]Department of Marine Science and Technology, Faculty of Fisheries and Marine Science, IPB University, Jl. Agatis, Dramaga, Bogor, 16680, Indonesia
[5]Marine Science Study Program, Faculty of Fisheries and Marine, Universitas PGRI Ronggolawe, Jl. Manunggal No. 61, Semanding, Tuban, 62381, Indonesia
e-mail: imalpengmtkdi@gmail.com

Received: 02-01-2024; Revised: 12-03-2024; Approved: 17-03-2024

Abstract. Kendari Bay in Southeast Sulawesi province is shaped like a pocket with a narrow mouth and there is the Wanggu river, which makes the dynamics of its waters very interesting to study. This study aims to examine the hydrodynamic conditions, mainly due to the existence of reclamation and the influence of the Wanggu River which has not been studied previously. This research method uses a 2D hydrodynamic model with a simulation time of 15 days in March 2020. The modeling results were then verified with PUSHIDROSAL tide data showing an RMSE of 0.07 indicating that that was good. The mixed tidal type with a tendency to double daily is the tidal type based on the Formzahl value of 0.51. The current pattern generally moves in and out from east to west and vice versa. The results of the hydrodynamic modeling show that the current velocity increases when passing through a narrow path. The existence of the reclamation area affects the changes in the velocity of the current and the direction of the current. Water circulation patterns play a role in the process of particle distribution and deposition, especially after reclamation. Furthermore, it can be used for sustainability of coastal ecosystem.

Keywords: *2D hydrodynamic model, current velocity, kendari bay, Reclamation, wanggu river*

1 INTRODUCTION

The waters of Kendari Bay, which is located in the center of the provincial capital of Southeast Sulawesi, are waters with an area of ± 19.05 km2 (Limi et al, 2017), which are semi-enclosed in the shape of a pocket with a narrow mouth. It contains a large river, namely the Wanggu river (Mustikasari et al, 2018) and there is a reclamation area on the west side. Reclamation development by the Regional Government is driven by the need for space for productive activities in the bay waters (Wibowo et al., 2022). This activity will affect the configuration of the coast which will then have an impact on its geomorphology due to the influence of tidal activity that occurs (Qomariyah & Yuwono, 2016). On a long time scale, it can trigger abrasion which will cause shoreline changes due to sediment transport by wave-generated currents (Oktiarini et al., 2015; Wisha et al., 2017; Nurjaya et al., 2019). This will also affect changes in hydrodynamic patterns that occur in the region (Rachmat & Purwanto, 2011; Hariyanto & Krisananda, 2019).

The existence of the Wanggu River estuary and the reclamation area in Kendari Bay waters is interesting to study because of their potential influence on changes in current patterns or hydrodynamic systems. The physical dynamics that occur in coastal waters have an important role in the distribution of marine pollution which is influenced by inputs from rivers (Koropitan et al., 2021). The Kendari Bay hydrodynamic study conducted by Ondara and Husrin (2017) without considering the input of the Wanggu river and the existence of a reclamation area using the Mike-DHI 21 software, shows that tides are the main driving force for water mass exchange. Widada (2015) studied changes in current patterns with a slower speed of 0.1 m/s due to reclamation development at Tanjung Emas Port in Semarang and Siagian et al (2013) in Makassar waters with an average speed of 8.64 cm/s. The shape of the topography of the seabed has become new due to reclamation compared to before. The topography of the seabed can then be seen from a bathymetric map which describes the waters and their depth (Effendi et al., 2015). Current flow can be influenced by several factors such as seabed topography, wind, density differences or thermohaline circulation (Tarhadi et al., 2014). Tidal currents, especially in coastal areas, are able to control the transportation of materials from one place to another and play a role in biological processes (Koropitan et al., 2006; Osawa et al., 2010).

Although many hydrodynamic modeling studies have been carried out, analysis of current patterns that occur after reclamation and taking into account the input from the Wanggu river using numerical modeling has never been carried out in this area. Therefore, in this study hydrodynamic modeling has been carried out to prove that there is a significant difference to the new coastal configuration in the form of reclamation which also includes the influence of input from the Wanggu river. This study aims to examine the hydrodynamic conditions of Kendari Bay, especially due to the existence of reclamation and the influence of the Wanggu river which has never been studied before. Based on this analysis, suggestions can be determined to overcome the existing problems.

2 MATERIALS AND METHODOLOGY

2.1 Location and Data

This research was conducted from October to December 2020 starting with data collection in the form of bathymetry data for Kendari Bay which will later be combined with direct measurements in previous research, discharge of the Wanggu River as input from land, tides for Kendari Bay as a driver of surface water masses, model simulations, and verification of model data using comparison data. The model simulated to support futher studies regarding the conditaion of Kendari Bay Waters in March. The research location is in the waters of Kendari Bay, Southeast Sulawesi, which is geographically located at $3^0$58'36.54'' south latitude and $122^0$33'35.90" east longitude as shown in (Figure 2-1). The geographical boundaries of Kendari Bay cover the western side bordering the lower reaches of the Wanggu River, residential and hospital activities, reclamation areas, and mangrove forest tourism areas. Bungkutoko Island and container port activity to the west. To the north there are ferry port activities (fast boats and ferries), entertainment activities and sports facilities as well as the Fish Ocean port to the south.

2.2 Model Configuration

Hydrodynamic conditions were simulated using the 2D Barotropic model, namely the depth was considered homogeneous using the MIKE 21 MZ25957 software. The model was simulated for 15 days (1 March – 15 March 2020) with the model configuration in table 1. The development of a two-dimensional hydrodynamic model for Kendari Bay in this paper is simulated based on secondary data sourced from PUSHIDROSAL in the form of a 2004 bathymetric map combined with bathymetric measurement data by Ondara and Husrin 2015, tidal data obtained from MIKE21 software through the outer boundary of the model (open boundary condition) using elevation from FES 2009 Topex 09 was run using FES 2009 (Finite Element System) which is a global tide forecasting with a resolution of 1/400 x 1/ 400) which is then predicted to produce high tides in the study area, as well as discharge of the Wanggu River sourced from Sarifuddin and Sudarmadji (2013). Several parameters and boundaries are used to produce a model that is close to the actual situation in the field

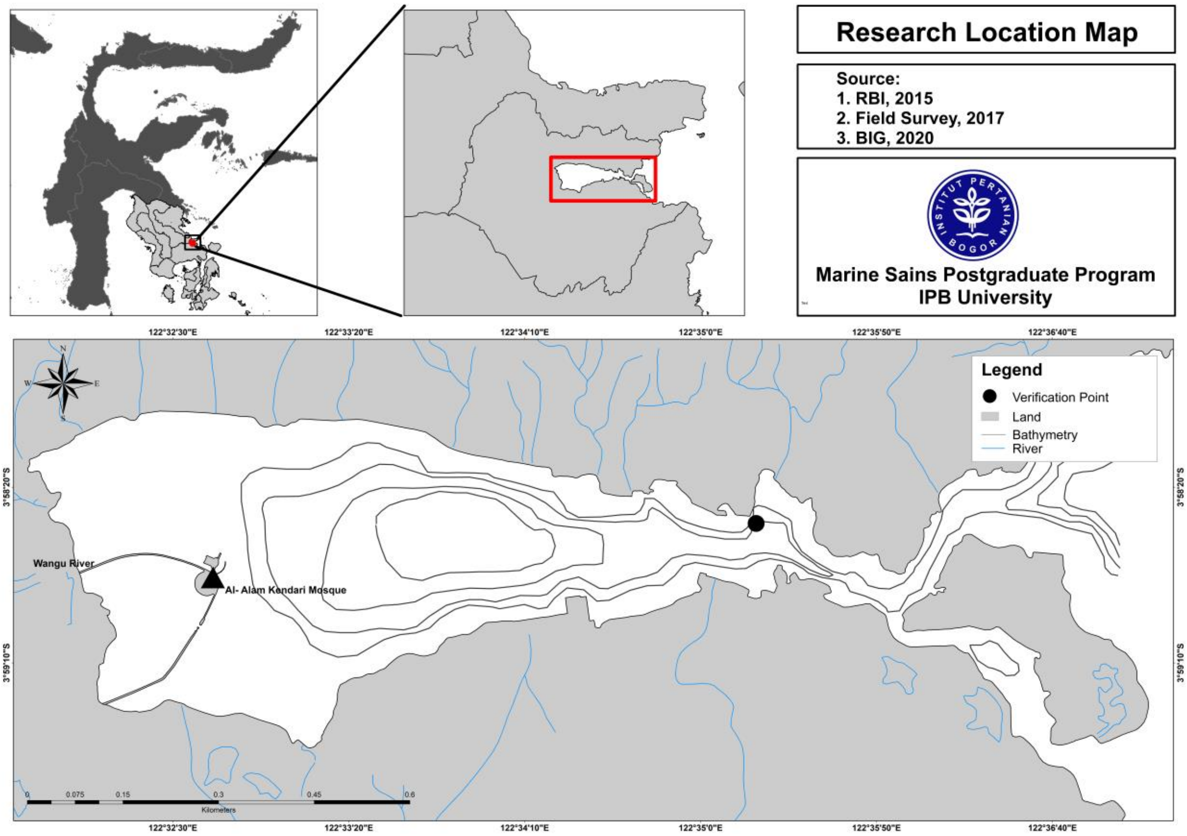

Figure 2-1: Locations and Verification Points of Research Models in Kendari Bay Waters, Southeast Sulawesi.

Tabel 2-1: Hydrodinamic model configuration

Parameter	Simulasi	
Model Characteristics		2D
Models Area	*Mesh*	Number of dots 4362 Number of Elements 6566
	Total Simulation Time	720
	Model Time Intervals	1800 /s
Simulation Time	Simulation Time	01/03/2020 – 15/03/2020 01:00:00 – 24:00:00
Area	*Maximum* element area	
Grid	*Angle mesh*	
Mesh Boundary	1. PUSHIDROSAL Bathymetry Data (2004) 2. Ondara and Husrin Bathymetry Data (2017) 3. MIKE 21 Tidal Data MZ25957	
River	Wanggu river (Sarifuddin and Sudarmadji, 2013) $hdry$=0.001 m $hflood$=0.5 m $hwet$=0.9 m	8.649 m^3/second (Constant)

The hydrodynamic model simulation is based on the continuity equation:

$$\frac{\partial u}{\partial v}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \ldots\ldots (1)$$

And the momentum equation for velocity in the form of Cartesian coordinates can be described below:

$$\frac{\partial u}{\partial t}+\frac{\partial(uu)}{\partial x}+\frac{\partial(uv)}{\partial y}+\frac{\partial(uw)}{\partial z}-fv$$
$$=-\frac{1}{\rho_0}\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}\left(v_H\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(v_H\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial z}\left(v_v\frac{\partial u}{\partial z}\right)\ldots\ldots(2)$$

$$\frac{\partial v}{\partial t}+\frac{\partial(uv)}{\partial x}+\frac{\partial(vv)}{\partial y}+\frac{\partial(vw)}{\partial z}-fu$$
$$=-\frac{1}{\rho_0}\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}\left(v_H\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(v_H\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(v_v\frac{\partial v}{\partial z}\right)\ldots\ldots(3)$$

Where u, v, and w are the velocity components in x, y, z, f are the Coriolis parameters, vH, and vv are the velocity in the vertical and horizontal directions, p is the pressure. The vertical equation for hydrostatic pressure momentum is described below:

$$\frac{\partial \rho}{\partial z}+\rho g=0\ldots\ldots(4)$$

2.3 Statistic analysis

The 2D hydrodynamic model data was simulated using DHI-MIKE Software and then verified using the Rot-mean squared error (RMSE) verification. The RMSE formula is as follows:

$$RMSE=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(o-pi)^2}\ldots\ldots(5)$$

Where:
n = number of validated data
o = model result data
pi = field measurement data.

3 RESULTS AND DISCUSSION

3.1 Bathymetry of Study Area

The bathymetry conditions of the Kendari Bay waters are visualized through the depth contours of various colors towards purple, ranging from 0 to 30 m (Figure 3-1). Based on the bathymetry contours, the depth of the sea in Kendari Bay changes gradually getting deeper out of the bay (to the east) towards the open sea (Ondara and Husrin, 2017). In the western part of the bay there is the mouth of the Wanggu River with a depth of 2.5 m. Towards the east the water depth increases between 5 and 15 m. The highest depth in the waters of the bay is in the eastern part of the outermost area of the bay, which reaches 27 m to 30 m. Depth variability from the mouth into the bay to the exit of the bay can be possible to produce spatially different current velocities. In shallow locations, a relatively greater current velocity will occur compared to deeper locations (Putra et al., 2021).

The bathymetric slope and surface area of the Kendari Bay waters differ between the western and eastern parts. The bathymetric slope in the western part of the bay is more sloping compared to the eastern part which appears relatively steep. In addition, the water surface area of the western part of the bay is wider than the eastern part, which is getting narrower. One of the reasons for the narrowing of the bay waters in the eastern part is the existence of Bungkutoko Island which is located right in front of the mouth of the bay. The complex morphology and bathymetry of Kendari Bay will affect tidal dynamics such as the magnitude of elevation, currents and tidal asymmetry, namely the difference in the length of high tide and low tide time (Nidzieko, 2010; Putra et al., 2021) in these waters. In addition, in Kendari Bay there are also several large and small rivers that flow into Kendari Bay (Asriana et al., 2009), these rivers carry suspended solids from the mainland (Alwi, 2016).

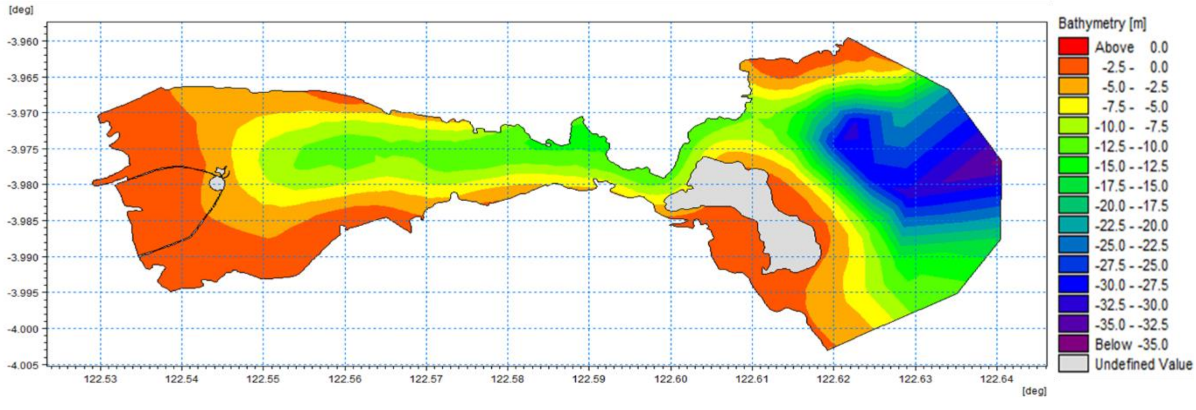

Figure 3-1: Bathymetric Condition of Kendari Bay Study Area.

3.2 Hydrodynamic Modeling

The hydrodynamic modeling results were validated by comparing the data at the coordinates 3058'24.794" South Latitude and 122035'0.625" East Longitude, which are the position of the tidal station in Kendari Bay and the location of the tidal data from PUSHIDROSAL Kendari city with model output data. The validation results based on the RMSE value produce a value of 0.07. This shows that the data is at a fairly good level. Wilks (2006) stated that the results of the model with RMSE values adequately illustrate the similarity of conditions in the study areas. The mixed type of tide with a double diurnal inclination is a type of tide in Kendari Bay (Suprapti, 2015; Ondara and Husrin, 2017) based on a formzahl number value of 0.5, slightly different from research by Saputri et al., (2021) which stated 0.525. Variations in the range of tidal elevations resulting from the model under bank conditions of 1.21 m and at full moon conditions of 1.75 m (Figure 3-2). Full moon tides are when the earth, moon and sun are in a straight line. Then nepal tides occur when the earth, moon and sun form a right angle and only occur on 1/4 and 3/4 months (Gumelar et al., 2016).

The results of this study indicate that the hydrodynamic process of Kendari Bay which is classified as shallow and semi-enclosed and so complex is due to the inflow of water masses from the Wanggu River and the mass flow of seawater. The hydrodynamic conditions at the mouth of the Wanggu River during high tide and low tide conditions during the full moon are so dynamic and strengthen when passing through narrow gaps as well as in the mouth of the bay. The influence of tides clearly dominates this process, in line with Noya et al (2016) that the process of mass exchange of water in shallow waters is influenced by tidal phenomena.

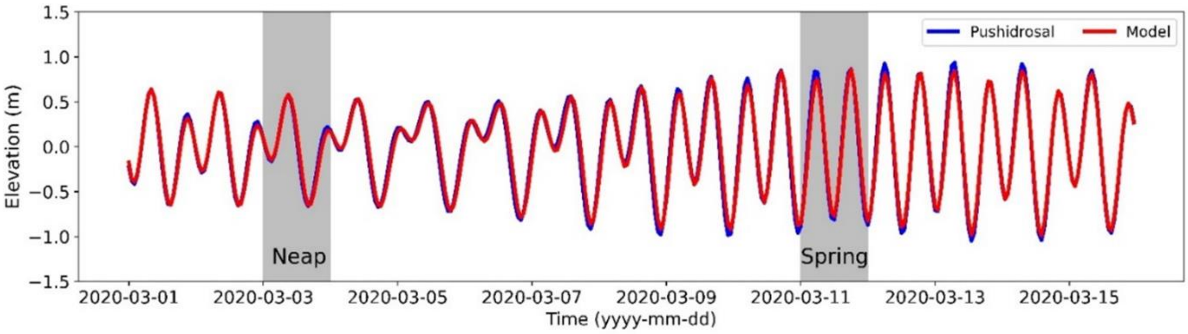

Figure 3-2: Comparison of sea level elevation in Kendari Bay from PUSHIDROSAL data (Blue Line) and Model Results (Red Line).

Sampling model results focusing on full moon conditions at high tide and low tide are shown in Figures 3-3 and 3-4. The propagation of the surface elevation of Kendari Bay from the modeling results in Figure 3-3 shows the mass of water entering the bay waters during the low tide phase (Figure 3-3a). The outermost area of the bay which is the western part of Bungkutoko Island has a range of elevation values above -0.025 m. The mouth of the bay and the western part of Bungkutoko Island have elevation values ranging from -0.075 m to -0.050 m. The area within the bay has an elevation range of -0.125 m to -0.100 m. The reclamation area has surface elevation values ranging from -0.275 m to -0.250 m. In the Wanggu River area, the elevation starts from the open boundary area, in the middle, to the mouth of the Wanggu River, with successive surface elevation values ranging from below -0.025 m; -0.050 m to -0.075 m.

Wave propagation from the south enters the bay waters from high tide to low tide (Figure 3-3b). The outer area of the bay values range from -0.48 to -0.44 m. Towards the western part of Bungkutoko Island and the bay mouth area has elevation values ranging below -0.36 m. The area in the bay is quite diverse, covering the middle of the bay ranging from -0.36 m to -0.32 m and the inner part of the elevation reclamation ranging from -0.12 m to -0.08 m. While the Wanggu River area is divided into open boundary areas with elevations ranging from -0.04 m to 0.00 m, the middle part ranging from -0.12 m to -0.08 m, and the area at the mouth of the river to entering the bay area ranging from -0.24 m to -0.20 m. Differences in surface elevation will cause the movement of large amounts of water masses, the amount of sediment will increase at low tide because the sediment carried at high tide will settle to the bottom of the water (Catrin et al., 2014; Wibowo et al., 2020; Karbela et al., 2021).

The tidal flow of a water area produces a constant value of the harmonics so that it describes the type of tide in the water area (Oktavia 2011). Fatoni (2011) states that the tidal characteristics of East Indonesian waters are dominated by mixed tidal types as a result of the propagation of tidal generating forces from the Pacific Ocean and the Indian Ocean. The results of the Kendari Bay waters hydrodynamic model produce a K1 harmonic component with an amplitude of 0.1957 cm forming a single tidal type and M2 forming a double tidal type with an amplitude of 0.5091 cm, so that the tidal type describes two times the highest tides and two lowest tides with different periods. different. In line with Ondara and Semeldi (2017) that the K1 constant forms a single tidal type and the M2 harmonic constant forms a double tidal type in Kendari Bay.

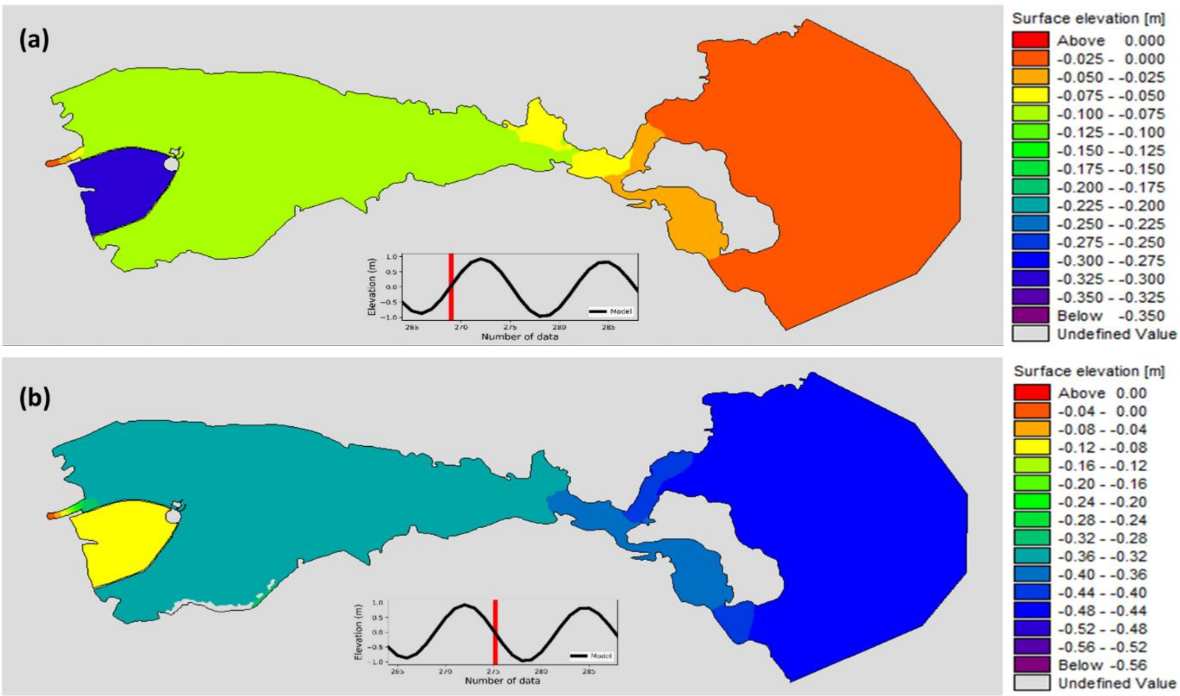

Figure 3-3: Sea level elevation (a) low tide conditions, (b) low tide to high tide conditions, (c) high tide conditions, and high tide to low tide conditions (d) when spring tide in Kendari Bay

Current conditions in the bay at low tide to high tide (Figure 3-4a) the direction of the current to the west dominates almost the entire bay and experiences an increase in current velocity in the area of the bay mouth with a range of 0.36 m/s to 0.42 m/s. Entering the Wanggu River area has speeds ranging from 0.18 m/s to 0.24 m/s and continues to increase until the open boundary ranges from 0.48 m/s to 0.78 m/s. The tidal conditions towards the ebb (Figure 5b) the current towards the east passes through a narrow gap with an increasing current speed where the current velocity of the Wanggu River ranges from 0.24 m/s to 0.32 m/s and the mouth of the bay area ranges from 0.48 m/s to 0.56 m/~~s .~~s. In narrow gaps, the bathymetry is quite deep, while the surrounding areas are gradually getting shallower. This makes it possible for sedimentation processes to occur which are transported by currents. Current speed will affect the processes of transportation, deposition and distribution of sediments that occur in the aquatic environment (Nugroho and Basit, 2014).

The current circulation model results show an alternating direction from east to west at high tide and vice versa at low tide, where there is an amplification of the mass flow of water at several points in the bay area which is suspected to be due to narrow gaps. The tide conditions tend to the current direction to the west because it is influenced by the propagation of the Pacific Ocean which moves in through the bay. While the receding conditions tend to move in a reverse direction to the east due to the decreasing thrust of the water mass from the Pacific Ocean, plus the thrust of the Wanggu River water mass moving into the bay waters. The amplification of the water mass occurs in a narrow gap around Bungkutoko Island which is located at the mouth of the bay and the mouth of the Wanggu River which is indicated by an increase in water mass. This is in line with Siagian et al (2013) who wrote that narrow gaps affect the increase in mass circulation of water. The circulation that occurs has a different response in each coastal configuration, such as in the bay (Noya et al., 2019).

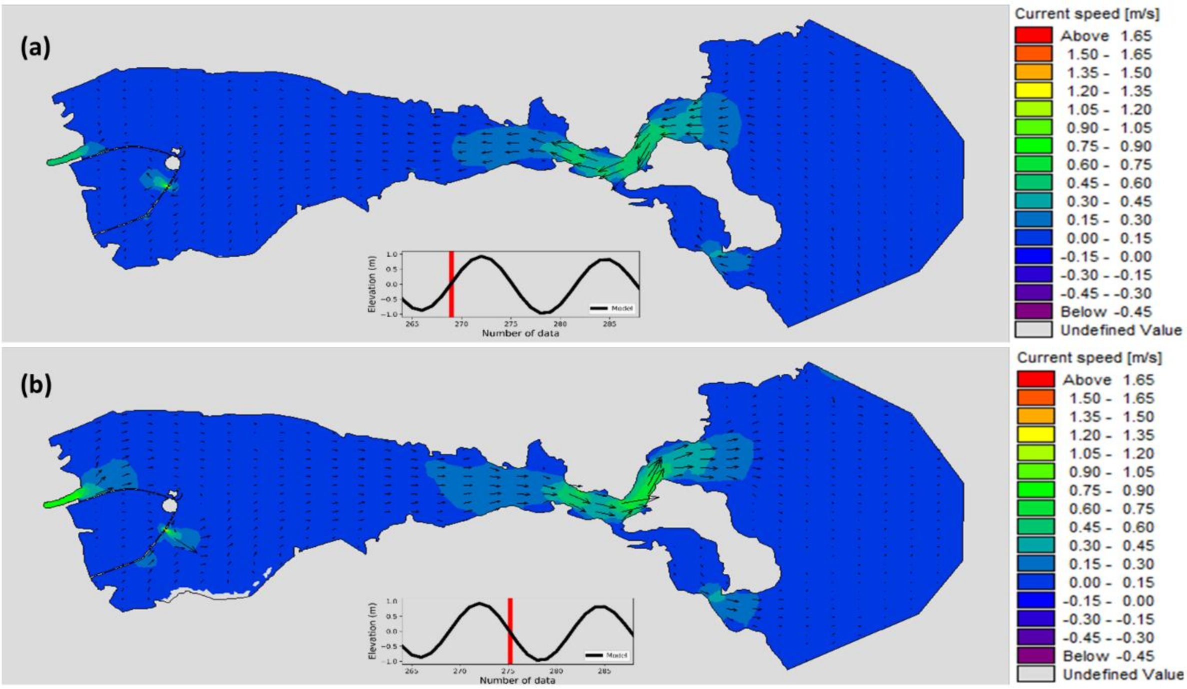

Figure 3-4: Current speed (a) low tide to high tide conditions and high tide to low tide conditions (b) when spring tide in Kendari Bay.

3.2 Hydrodynamics of the Reclamation Area

The construction of a reclamation area at the mouth of the Wanggu River in the Kendari Bay area as a consideration in this research shows a change in current patterns where there is a diversion and an increase in current speed. This is when compared to the previous study by Ondara and Husrin (2017) simulating the hydrodynamic conditions of Kendari Bay waters without considering the existence of a reclamation area at the mouth of the Wanggu River. The increase in current velocity during tidal conditions due to reclamation has been studied by Jing et al (2015) in the Xinghua Bay water area of 0.18 m/s at low tide and 0.44 m/s at high tide. Hendrawan et al. (2005) modeled the condition of the current pattern in Benoa Bay-Bali Island to experience a decrease in speed in both high and low tide conditions due to port construction and reclamation. Furthermore, Ajiwibowo and Pratama (2018) modeled the pattern of water currents in the Jakarta Bay showing a decrease in speed due to the influence of reclamation.

The reclamation area is in the upper reaches of the Wanggu River which is divided into 5 parts as shown in Figure 3-5 representing the condition of the waters at full moon. The sampling of the model results represents the tidal phase including ebb to high tide (Figure 3-6a) and high tide to low tide (Figure 3-6b). The condition of the waters receding towards high tide (Figure 3-6a) shows that the current direction is dominated to the west with a speed of -0.15 m/s to 0.00 m/s. The Wanggu River area with a current velocity entering the bay area of 0.45 m/s decreased to 0.00 m/s. The direction of the current which partially traces the outskirts of the reclamation area towards the southeast turns to the northeast. The current with a speed of -0.15 m/s to 0.00 m/s which was originally heading west turned to the southeast in the Al-Alam Mosque area following its reclamation form. Entering the mouth of the reclamation area, the current speed increases from 0.45 m/s to 1.65 m/s from the northeast turning towards the east entering the mouth gap which slowly decreases when entering the area under reclamation with a speed of 1.65 m/s to 1.30 m/s from east to west sea and east trace the form of reclamation. The current speed is -0.15 m/s to 0.00 m/s with various current directions from the east and southeast turning to follow the shape of the reclamation to the southwest and south within the reclamation area. Following the shape of the reclamation the current speed is -0.15 m/s to 0.00 m/s with a northeast direction turning towards the southwest and west in the area outside the reclamation.

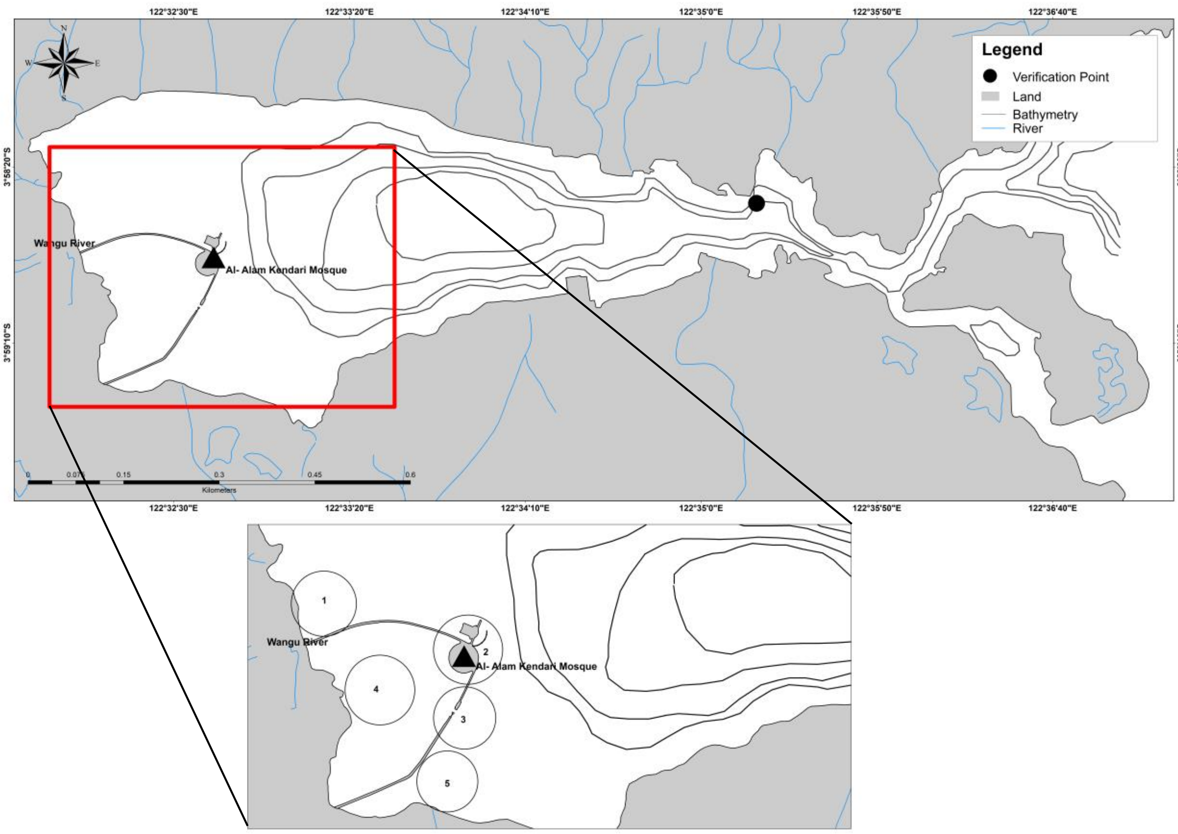

Figure 3-5: Reclamation area 1. Wanggu River, 2. Al-Alam Mosque area, 3. Reclamation mouth, 4. Reclamation area, 5. Outside reclamation area in the waters in Kendari Bay in Kendari Bay water.

The tidal water conditions shown in Figure 3-6b show a current pattern dominated towards the east with almost the same speed although there is an increase in current velocity in the mouth of the Wanggu River and reclamation which then decreases when entering the bay area. The Wanggu River area has a current speed of 0.75 m/s, decreasing to 0.45 m/s with the current direction continuing to the east and turning towards the northeast following the shape of the bay. The current speed is -0.15 m/s to 0.00 m/s in an eastward direction then turns towards the southwest following the reclamation form in the Al-Alam Mosque area. The speed increases at the mouth of the reclamation gap by 1.50 m/s to 1.65 m/s then decreases to 0.30 m/s entering the bay area with a southeast direction turning east and northeast. The area within the reclamation has a current speed of -0.15 m/s to 0.00 m/s to the east and the outer area has the same speed with the current direction towards the northeast following the form of reclamation.

Currents are a medium for the mobility of material contained in water, including sediment particles and pollutants. Noya et al. (2019) modeled the effect of currents on the distribution of particles in the waters of Ambon Bay. Although the hydrodynamic modeling in this study has not considered the distribution of particles by currents, changes in the speed and direction of the currents that occur will determine the distribution of particles in the water column until the particles settle.

Changes in hydrodynamic processes that occur will also affect aquatic ecology. Huang et al. (2020) explained that the wetlands in Huixian have the potential for moderate ecological pollution from the metals Arsenic, Mercury, Copper, Chrome, Cadmium, Nickel, Zinc, Tin in soil and sediment samples. Research conducted by Adriano (2001) states that metals as water pollutants are declared dangerous. In addition, the production of heavy metals is increasing from year to year and is estimated to be increasingly worrying because of its persistent, accumulative, toxic nature, and its impact on organisms and the possibility of humans consuming them (Richir and Gobert 2016). Ecological conditions will influence water quality conditions, which in turn will have an impact on the socio-economy of the surrounding area. Water quality is a relevant parameter for eco-labels (McKenna et al. 2010). Furthermore, the causal relationship between changes in water quality and anthropological influences will form a feedback cycle between environmental and socio-economic components (Costa et al. 2005)

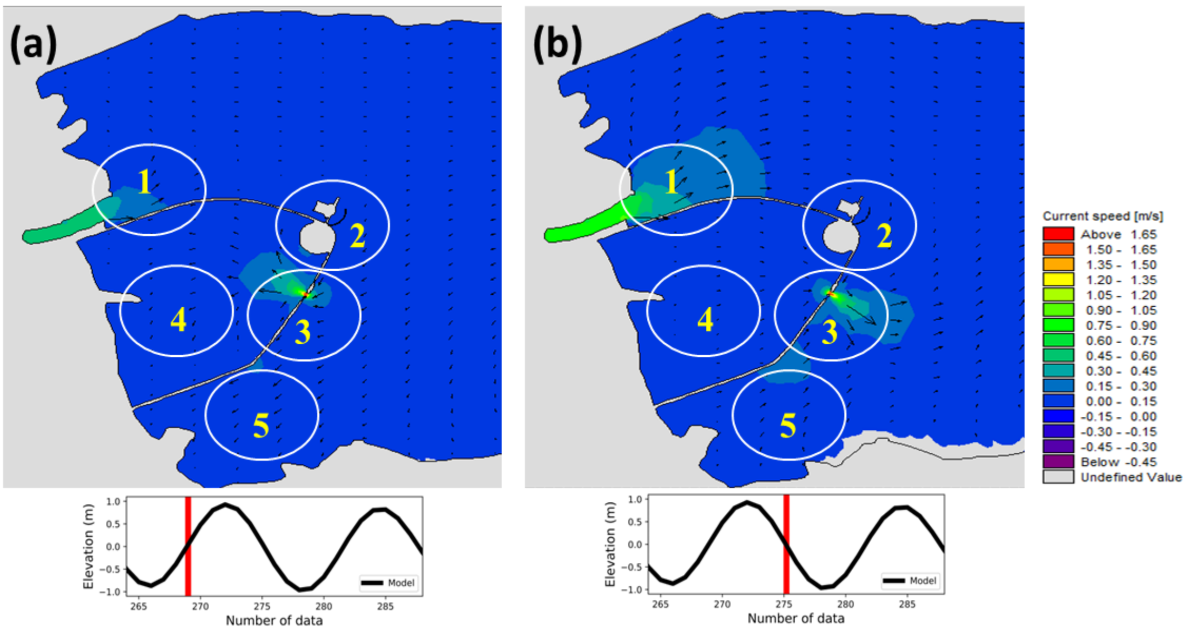

Figure 3-6: Tidal Current velocity during spring tide (a) low to high tide and (b) high to low tide in several of the Kendari Bay reclamation area.

4 CONCLUSIONS

Based on bathymetry conditions and hydrodynamic models, Kendari Bay is a shallow water with circulation of water masses influenced by tides with a tidal elevation range of 1.75 m at full moon. The maximum tidal current speed is 0.1784 m/s and a minimum of 0.0057 m/s. Based on the formzahl number value of 0.51, the tidal type is included in the mixed tidal type, leaning towards double daily. The current circulation model results show an alternating direction from east to west at high tide and vice versa at low tide, where there is an amplification of the mass flow of water at several points in the bay area which is suspected to be due to narrow gaps. In the estuary area, the current velocity is in the range of 0.36 m/s to 0.42 m/s ebb to high tide, 0.24 m/s to 0.32 m/s during the high tide to low tide phase when conditions are full. The area of the mouth of the bay and the western part of Bungkutoko Island has a value of the mouth of the bay with a range of 0.36 m/s to 0.42 m/s in the low tide to high tide phase, ranging from 0.48 m/s to 0.56 m/s high tide to low tide phase. The existence of the reclamation area affects changes in current velocity which are significantly smaller and the direction of the current which is deflected follows the shape of the reclamation area. The direction of the current is to the southeast then turns to the northeast when it recedes towards high tide and to the east then turns towards the northeast when the tide goes to the full moon compared to research before reclamation. This research describes a new hydrodynamic configuration, which can then become a strategy in managing coastal areas in the Kendari Bay area, especially at reclamation sites. On each side of the reclamation, the response to changes in direction and speed is different, so it requires different handling and attention.

ACKNOWLEDGEMENTS

This research was conducted at the Big Data and Ocean Modeling (BiOM) Laboratory, Department of Marine Science and Technology, Faculty of Fisheries and Marine Sciences, Bogor Agricultural University. The team of authors would like to thank for permission to use the MIKE 21 software MZ25957 from the Spatial and Marine Mapping and Modeling Laboratory, Department of Marine Science and Technology, Bogor Agricultural University.

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