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HYDRODYNAMIC ASSESSMENT ALONG THE COAST OF TANJUNG SEDELI, MALAYSIA

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Graphical abstract

Coastal waters of Tanjung Sedeli, view from Jason Bay

Abstract

Tidal influence plays a significant role in coastal hydrodynamics as the impact may lead to coastal erosion. Tanjung Sedeli located on the southern coast of Malaysia is exposed to low tidal issues which disrupts the navigation of local fishermen due to the shallow river mouth in the area. This study presents the hydrodynamic processes along the shoreline of Tanjung Sedeli. BLUEKENUE was used as the pre-processor to create a bathymetry file and perform mesh generation to set up the initial model boundary which functions as input files for numerical study. TELEMAC2D further processes the hydrodynamic data (tides and currents), calibrated, and validated with the measured field data collected between 24th September to 6th October 2020 covering both spring and neap tide conditions. The nature of tides in the area was mainly mixed tides, predominantly semidiurnal tides. Modelled hydrodynamic values show good conformity with field measurements with an error of 1.4% for water level values, 10.6% and 20° for current speed and direction respectively. Water flows north into the estuary during spring tide with maximum velocity is 0.756m/s surrounding the river mouth and Pulau Tagal. Low velocity values were recorded at the left bank of the river (0.028 m/s) and Pulau Tagal (0.085 m/s) during spring tide. This study provides information on current hydrodynamic condition of the study area.

Keywords: river mouth, ADCP, Numerical model, coastal waters, TELEMAC2D
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1.0 INTRODUCTION

Coastal zones involve a dynamic ecosystem where marine and atmospheric processes produce rocky coasts, beaches, dunes, tidal inlets, and shape deltas [1]. Coastal environments provide infrastructure and ecosystems that are the key to modern human life, but in recent years have been densely populated and are among the most urbanized area in the world [2]. In coastal zones, currents are driven mainly by tides, winds, and waves. The state of the art in hydrodynamic studies of tidally dominated environments now makes it possible to accurately estimate water movements at time scales ranging from a few minutes to several weeks or months. Coastal processes on the east coast of Peninsular Malaysia are highly influenced by monsoonal seasons, mainly the northeast monsoon occurring from October to March and the southwest monsoon from May to September. The natural phenomenon of current speeds, tides, waves, winds, and rainfall frequency during these seasons eventually impacts beaches resulting in frequent erosion and accretion on Malaysia's shoreline [3].

Over the years, many hydrodynamic models have been used to predict movement of tidal flow in rivers and estuaries [4,5]. Comprehensive numerical modelling in hydrodynamic studies has been developed extensively in Malaysia focusing on a diversity of research involving water quality studies, sea level rise and flood forecasting [6, 7, 8, 9, 10]. In the eastern part of the Johor coastal shores, several field studies were directed toward water quality, beach evolution and field studies mainly emphasised studying tidal characteristics [11, 12, 13, 14]. To date, hydrodynamic assessment studies in the eastern part of Johor remains scarce. This study presents the first hydrodynamic assessment research conducted on the east coast of Malaysia along the coast of Tanjung Sedeli, Kota Tinggi, Johor.

Famous for its tourism spot among the locals, the coast along Tanjung Sedeli is exposed to threats of changes in shoreline from effects of natural phenomenon. Local fishermen have reported facing navigational issues especially difficulty in manuevering along the river mouth. It is believed that low velocity coupled with shallow bed causes the area to be prone to sedimentation. Thus, a hydrodynamic study was conducted to understand the tidal pattern in the area. This study aims to simulate the hydrodynamics pattern around Pulau Tagal, Tanjung Sedeli. Secondary data information on the study area was analysed and the open-source numerical model, TELEMAC2D model was utilized to simulate and analysed the hydrodynamic processes around Tanjung Sedeli. Information obtained from this study is important for relevant authorities to provide next course of action to preserve the coast or solve issues of low tidal velocity experienced in the study area. It is worth noting that this study focuses only on the hydrodynamic pattern of the area without simulation on sediment transport.

2.0 STUDY AREA

The study area covers the coastline about 10 km north and south of Tanjung Sedeli, rich in the mangrove forest, rocky beaches, and sandy beaches (Figure 1). Seabed gradient along the coast ranges between 1:300 to 1:600 where the tidal range reaches about 3.1 m with mean sea level (MSL). Based on the National Coastal Erosion Study (NCES, 2015), maximum wind speed during northeast monsoon possible reaches 15 m/s in the northeast direction while wind speed during southwest monsoon is up to 10 m/s predominantly from the southwest to the south [15]. Wave height may reach nearly 3.5 m and 1.5 m during northeast and southwest monsoon respectively.

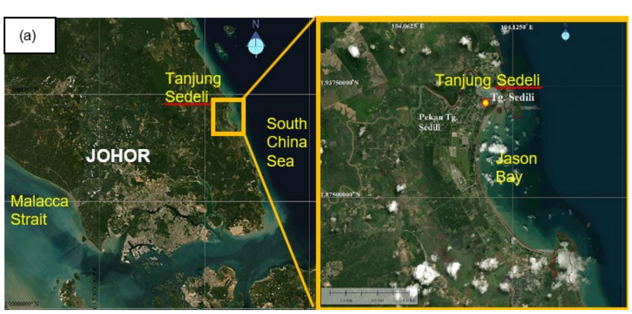

Figure 1 (a) Location of Tanjung Sedeli (b) View of Pulau Tagal from north of Tanjung Sedeli (c) View of Tanjung Sedeli from Jason Bay

3.0 METHODOLOGY

3.1 Data Collection

Currents and water level fluctuations data were measured covering both spring and neap tidal conditions. Water depth data were collected at the site using an Acoustic Doppler Current Profiler (ADCP) and RBRduet. The location of deployment is at a latitude of 1.871383° and longitude of 104.198433°, around 10km off the coast of Tanjung Sedeli, Johore at about 13m water depth (Figure 2). The ADCP and RBRduet was attached to a ADCP housing and deployed. The current meter sensor was installed using the bottom deployment method where the bottom mounted frame is extra heavy weighted to provide a stable platform. During the retrieval process, a transponder was installed in the system to locate the ADCP location. The retrieval was done by NAHRIM using an inflated special balloon to assist the ascending process of the ADCP to the surface (Figure 2).

A summary of the predicted water level variations is tabulated in Table 1. The maximum tidal range and mean sea level were 3.13 m and 1.7 m CD, respectively.

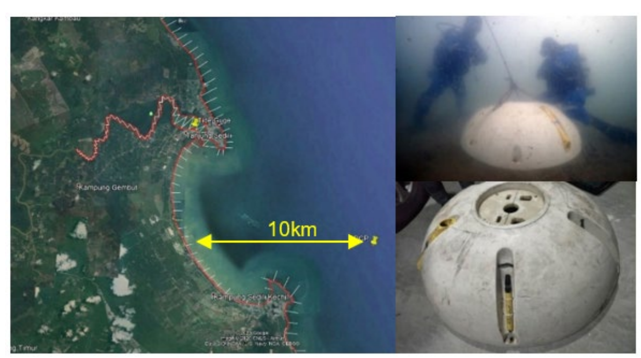

Figure 2 Location of the ADCP deployment

Table 1 Predicted tidal levels and tidal ranges at standard port: Tanjung Sedeli

Description	Abbreviation	Predicted Tidal Levels (m)
Highest Astronomical Tide	HAT	3.13
Mean Higher High Water	MHHW	2.92
Mean Lower High Water	MLHW	1.79
Mean Sea Level	MSL	1.70
Mean Higher Low Water	MHLW	1.61
Mean Lower Low Water	MLLW	0.49
Lowest Astronomical Tide	LAT	0.00
Maximum Tidal Range		3.13
Mean Range of Tide (MN)		0.18
Great Diurnal Range (GT)		2.43

Note: All the levels illustrated in the table above are referred to Chart Datum (CD). [16]

3.2 Numerical Model Characteristics

Flow hydrodynamics within the study area was simulated using the software package TELEMAC-2D. It was developed by the National Hydraulics and Environment Laboratory (Laboratoire National d'Hydraulique et Environnement - LNHE) of the Research and Development Directorate of the French Electricity Board (EDF-DRD), in collaboration with other research institutes. TELEMAC-2D is a fully vectorised finite element software for the computational solution of shallow water equations [17]. The flow field in the model domain is depth-averaged over a two-dimensional horizontal space. The first part of the modelling process requires the discretisation of the model domain into non-structured spatial meshes using triangular or quadrilateral elements [18]. In the TELEMAC2D system, the computational mesh was generated using BLUEKENUE. It constructs meshes for a particular model domain and allows the interactive definition of the boundary conditions along the domain borders. BLUEKENUE is used as pre-processing and post-processing software, connected with the TELEMAC2D.

Water surface elevation and components of horizontal velocity are calculated for each node of the mesh and stored at designated intervals. Triangular meshing is refined around the area of interest of the model domain for higher accuracy. Maintaining coarser elements in remote areas of little interest speeds up computational time. Outputs from the flow computations are post-processed using a graphical package to derive quantities such as speeds and flow directions, stresses, bed bathymetry and water surface elevations.

3.3 Model Mesh Discretisation and Bathymetry

Mesh of the model domain was generated using BLUEKENUE, allowing variable triangular finite element mesh sizes throughout the model domain. The computation of TELEMAC2D requires the building up of a numerical domain and mesh discretization whereby the density of mesh at the studied area has more intense density and the density gradually increases away from the study area. A growth rate of 1.2 was used to generate the mesh resulting in a total of 102609 elements and 52830 nodes were generated from the mesh (Figure 3). Bathymetry data were digitized from available Admiralty Chart no. MAL 6202, MAL 625, and MAL 6147 serve as secondary data for the baseline input for pre-processing works. Bathymetry data that has been digitized were compiled and superimposed with existing surveyed data. Priorities were given to on-site surveyed data which has more accurate and denser information on the existing condition. Digitized chart data acts as secondary data which complements the lack of information, especially in the seawards part of the study area. BLUEKENUE was utilized for bathymetry data compilation and visualization (Figure 3). The depths of each node in the model were interpolated from the charts whereby density is coarser at the study area and the deepest depths found within the domain are 35 m below CD.

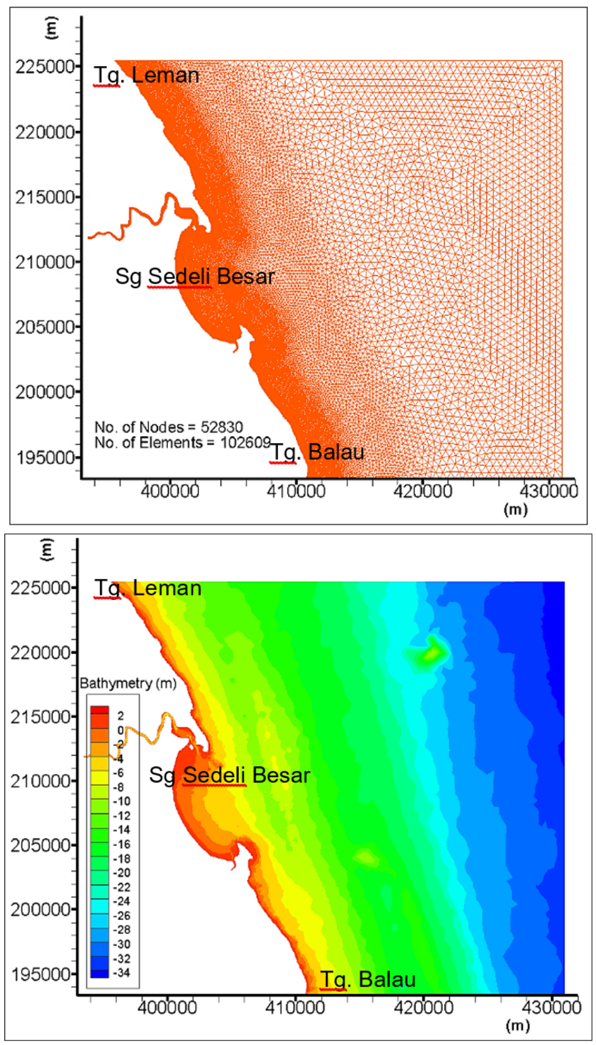

Figure 3 Model mesh (top) and bathymetry (bottom)

4.0 RESULTS AND DISCUSSION

4.1 Fieldwork Analysis

Water level fluctuations information was obtained through on-site data collection. ADCP Nortek-600kHz deployment measured the water level and current speed and direction for every 10 min and at every 1 m of water depth from 24 September to 12 October 2020, covering both neap (24-30 September 2020) and spring tides (1-8 October 2020). A deployed RBRduet successfully retrieved water levels for every 20 min from 25 September 2020 until 6 October 2020. Measured water level variations were compared with predicted water level variations from Malaysian Tide Table 2020 [19].

The coastline around the study area is influenced by water level fluctuations that are mixed in nature, with the occurrence of two high waters and two low waters with unequal heights within one tidal day. These tides illustrate a large inequality in either the high or low water heights. The tides are mainly mixed in the study area, predominantly semidiurnal tides (Figure 4). Superimposed plots showing the time series of field-measured tidal data at ADCP against that with predicted tidal values at Tanjung Sedeli tidal station (extracted from the 2020 Malaysian Tide Tables) as illustrated in Figure 4. Curves indicate similar trends of water level fluctuations displaying mixed characteristics throughout the time series. The maximum water level recorded by ADCP at Tanjung Sedeli is 2.75 m above CD while the minimum water level recorded is 0.6 m. Field-recorded tides retrieved were utilized for calibration and validation works in the model simulation.

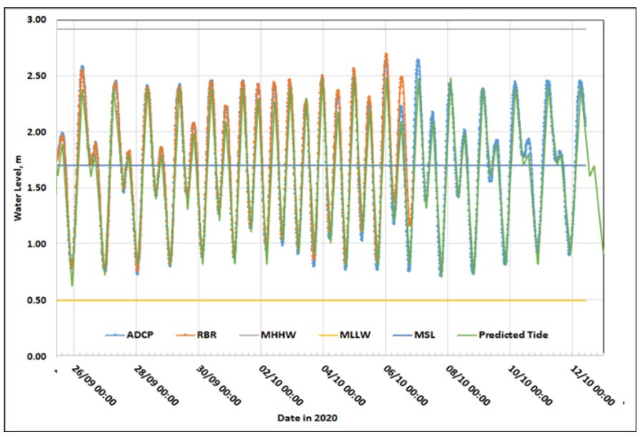

Figure 4 Comparison between measured water levels using ADCP and RBR duet and predicted tide from tide table

The overall current movement is generated by the cyclic changes of water level fluctuations or tides. In-situ measured currents data in the study area have been utilized as parameters for calibration and validation works. ADCP was set up to measure current speed and direction at every 10 minutes and every 1m layer of water depth. Time series data of the current speed and its direction were averaged and plotted as shown in Figure 5. During in-situ measurements of 2020, the maximum current speed recorded at the ADCP station was 0.44 m/s directed at 331.24^0 and the average current speed in the area was 0.18 m/s.

Water temperature variations are shown in a graphical plot (Figure 6). The recorded water temperature was observed to be in the range of 28.8^{o}C to 32.92^{o}C. These temperature values fall within the normal range for Malaysian waters. Seawater temperatures in the coastal tidal area have exhibited complicated variations due to topography and tides [20, 21]. This is because the temperature in shallow areas responds more quickly to the atmosphere than in deep areas, thus it leads to a condition where the mean temperature in shallow coastal areas is higher than in the deeper sea, especially during the warm season. Figure 6 shows that the measured temperature positively decreased when the tide decreased during this Southeast monsoon (24 September to 4th October 2020) but negatively decrease with the tide pattern when it started to inter monsoonal period on 4th October 2020.

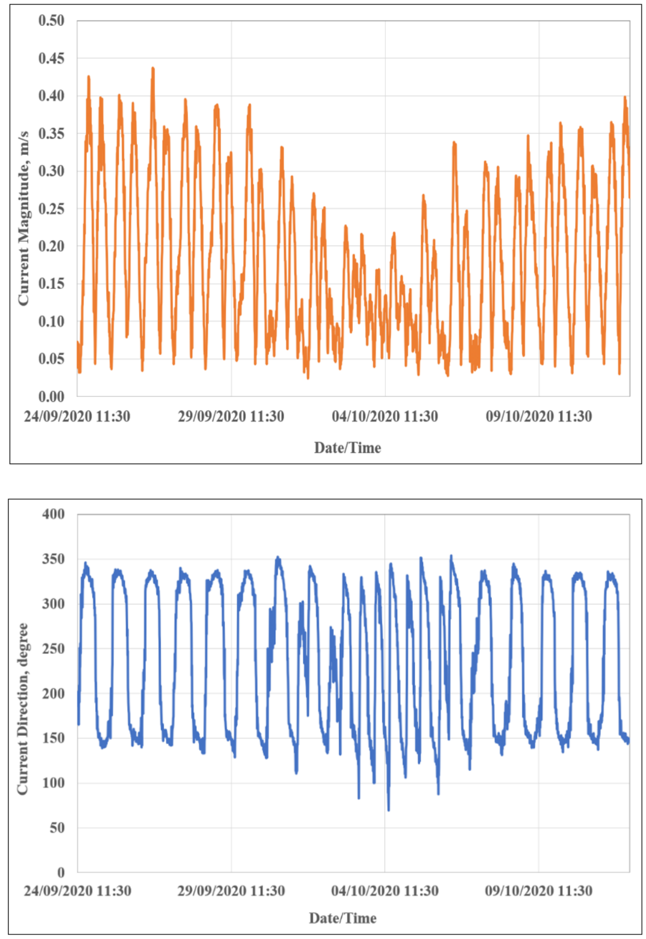

Figure 5 Measured current magnitude (top) and direction (bottom) from 24 September- 12 October 2020

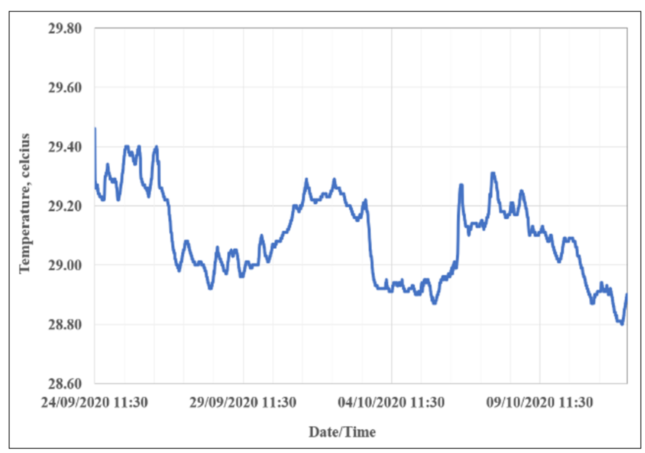

Figure 6 Measured seawater temperature at ADCP

4.2 Model Simulation

Hydrodynamic simulation output from TELEMAC2D model was displayed in the form of currents vectors extracted at a particular time step. The computed current flow during flood and ebb tide is illustrated in Figure 7 with the main flow of flood tide was from north to south while ebb tide condition was predominantly in the south-north direction. During flood tide, the velocity recorded flowing into the river is higher compared to ebb tide. This shows that the flushing system of the river was relatively weak and sediment from upstream may possibly be deposited around the left banks of the river mouth. Lower velocity magnitudes were also found below Pulau Tagal during both flood and ebb tides explaining that most area south of Pulau Tagal had been covered with sediment, thus disrupting flow of water.

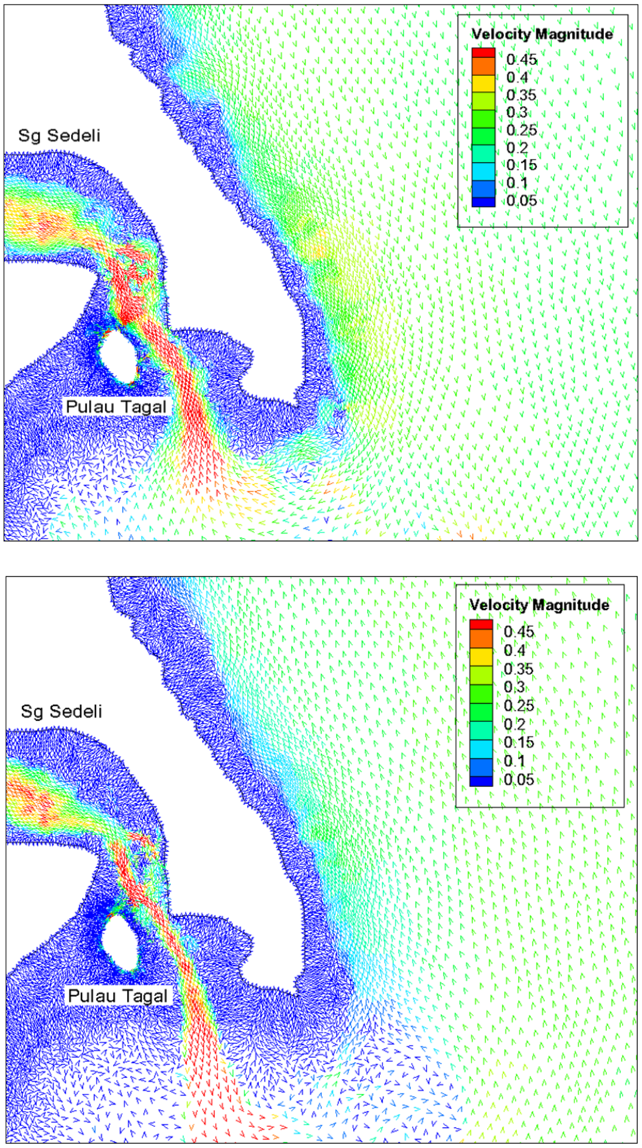

Figure 7 Current vector diagram during flood tide (top) and ebb tide (bottom)

4.3 Calibration and Validation

Model calibration and validation were achieved by comparing current speeds and directions at the ADCP station within the model domain. The position of the ADCP location in the model domain was shown in Figure 2. The bottom friction, tidal and velocity coefficients were adjusted in the model to ensure close agreements between the observed and modelled values. Water level and current values were used mainly for model calibration covering both spring and neap tide from 29 September 2020 to 12 October 2020 (Figure 8).

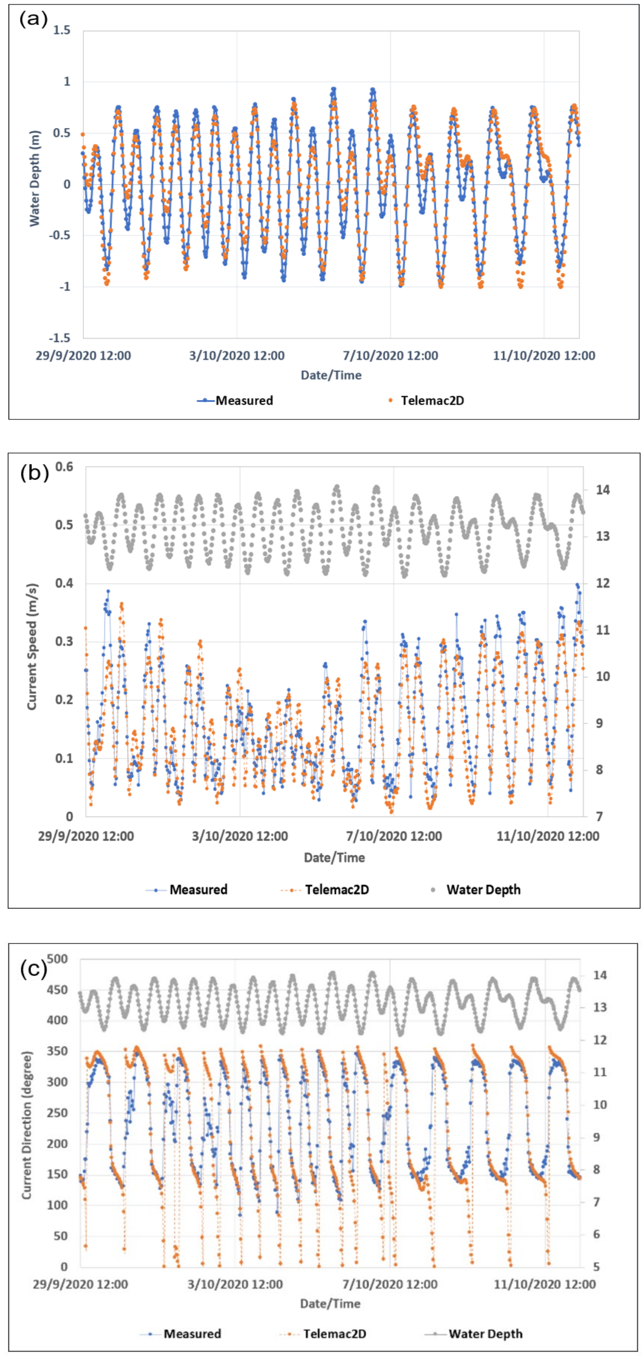

Figure 8 Calibration and validation curves for (a) water level, (b) current speed and (c) current direction

4.4 Model Performance Indicator

The performance of the model in the whole region was evaluated via statistical parameters utilising the root-mean-square-error (RMSE) and adjusted relative-mean-absolute-error (ARMAE) as shown in Equations 1 and 2. Results from the measured and simulated water level, current speed and magnitude are also evaluated based on the guidelines for the preparation of coastal engineering hydraulic study and impact evaluation by the

Department of Irrigation and Drainage Malaysia (DID). Based on the guidelines, the average difference in water level for model verification should be less than 10% and the average difference in speed and direction of current should be less than 20% and 20°, respectively [22, 23].

$$RMSE = \sqrt{\frac{1}{N}\sum_N (X_n - Y_n)^2} \quad \text{(Equation 1)}$$

$$ARMAE = \frac{<|Y-X|-OE>}{<|X|>} \quad \text{(Equation 2)}$$

where X_n are the observed values, Y_n are the computed values, and N is the number of observations. Table 2 summarizes the water level and mean speed and direction of the currents according to the RMSE value. The water level modelled recorded an error of 1.4% which meets the evaluation assessment by DID (<10%). The average difference in current magnitude and direction is 10.6% and 20° respectively. These values reach an agreement with the DID standards as mentioned in the above paragraph.

Table 2 Categorisation of RMSE results [38, 39]

Parameter	RMSE	DID Standards
Water level	1.4%	< 10%
Current Magnitude	10.6%	< 20%
Current Direction	20°	< 20°

Another assessment of the simulation agreement is calculated based on ARMAE [24]. Table 3 summarizes the water level and mean speed and direction of the currents according to the ARMAE error. The measurement indicator for error classification for ARMAE is shown in Table 4. The water level recorded is 0.01 and can be classified as excellent. ARMAE values listed for current magnitude and direction are both 0.2 which is within the range of good agreement (0.2-0.4) between simulated and observed values. Overall, the model performance indicates that the water surface elevations and currents from the numerical model are in good agreement with the measured data.

Table 3 Categorisation of ARMSE results

Parameter	ARMAE	DID Standards
Water level	0.01	Excellent
Current Magnitude	0.2	Good
Current Direction	0.2	Good

Table 4 Error classification

Classification	Range of ARMAE [40]
Excellent	< 0.2
Good	0.2 - 0.4
Reasonable	0.4 - 0.7
Poor	0.7 – 1.0
Bad	> 1.0

4.5 Hydrodynamic Modelling Results

4.5.1 Maximum Velocity at Designated Points

Nine locations were designated during spring tide conditions at approximately 1 km away from the shore (Figure 9). The maximum velocity and bed level below the chart datum of each point was extracted and tabulated in Table 5. The highest velocity was observed at Point A (0.530 m/s), north of Tanjung Sedeli while the lowest velocity was at Point F, 0.073 m/s. This shows that velocity within the bay was significantly reduced and sheltered from strong tidal influence from the South China Sea. Lower velocity at the coast also pointed to the possibility of sedimentation that may alter the morphodynamical processes of the area.

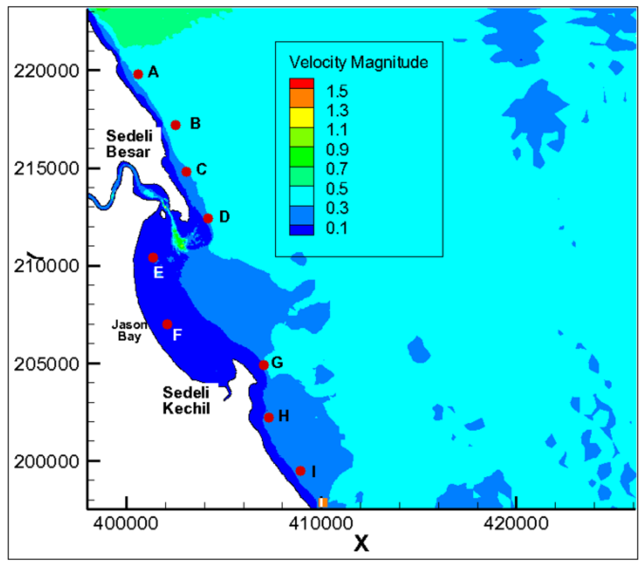

Figure 9 Location of designated points

Table 5 Maximum velocity simulated at designated points during spring tide

Location	Maximum velocity (m/s)	Bed level (m CD)
A	0.530	4.98
B	0.509	6.37
C	0.378	5.02
D	0.391	5.54
E	0.129	0.74
F	0.073	1.91
G	0.395	2.72
H	0.200	2.06
I	0.286	5.00

4.5.2 Maximum Velocity at River Mouth and Pulau Tagal

Figure 10 shows eight designated locations at the river mouth of Sungai Sedeli Besar and nearby Pulau Tagal whereby bottom indicates the bed level of the study area. The maximum velocity recorded at these points can be seen in Table 6. Location 2 which is at the centre of the channel had a higher velocity (0.756 m/s) as compared to the left and right sides of the channel. Meanwhile, the current velocity at the right side of the Pulau Tagal (0.702 m/s) was stronger than the left side (0.085 m/s). The existence of Pulau Tagal where mangrove forest is present, consists of a silty muddy area that slowed down the velocity of the area and naturally changed the morphodynamics of the area. The much slower velocity at the left bank may contribute to severe sedimentation occurrence along the left side of Pulau Tagal at Point 4 including upstream at Point 1 where "Lembaga Kemajuan Ikan Malaysia, LKIM" jetty is located. It was believed that low velocity flow and shallow bed in the area hindered local fishermen's boats from navigating especially during low tide, causing a stake in the livelihoods of the locals. Therefore, dredging works can be done along location 1, 4 and 6 to increase the depth of the river and ease movement of fishing vessels.

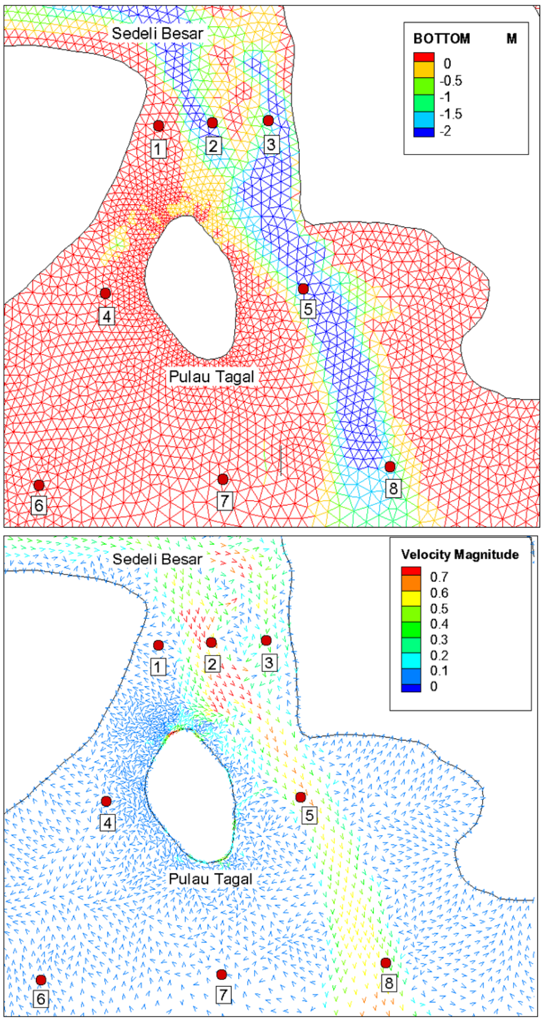

Figure 10 Bed elevation (top) and velocity (bottom) field around Pulau Tagal

Table 6 Maximum velocity

Location	Maximum velocity (m/s)	Bed level (m CD)
1	0.028	-1.25
2	0.756	1.96
3	0.487	1.69
4	0.085	0.28
5	0.702	0.62
6	0.001	-1.03
7	0.030	-0.78
8	0.523	1.65

5.0 CONCLUSION

In this study, the TELEMAC2D model was utilized to assess the hydrodynamic process in the coastal area along the shoreline of Tanjung Sedeli. Water level fluctuations were found mainly mix-diurnal predominantly semi-diurnal tides in nature within the study area. The self-recording ADCP was used for model calibration and validation which covered both neap and spring tides from 25th September till 6th October 2020. The recorded maximum current was 0.44 m/s at a direction of 331.24° N. Seawater measurements showed that the recorded water temperature ranged between 28.80°C to 29.46°C. These temperatures fall within the normal range for Malaysian waters.

The model simulation was conducted utilizing the TELEMAC2D with a total area boundary of approximately 36.0 km^2 by 32.4 km^2 covering Tg. Leman and Tg. Balau where Tanjung Sedeli is located at the centre of the model boundary. Calibration and validation of water surface elevations, current magnitude, and direction showed a good agreement between the numerical model with the measured data. Current velocity was higher in the north of Tanjung Sedeli in comparison to the south where Teluk Mahkota and Jason Bay are located. The velocity entering the river was higher during flood tide demonstrating a weak flushing system of the river. Low-velocity values were recorded south of Pulau Tagal with higher bed values in the area vicinity which inhibits water flow. Lower current velocity between Pulau Tagal and river bank with 0 to 0.5m bed elevation values demonstrate the possibility of severe sedimentation occurrence and could be caused by land use changes along the river. Shallow bed values coupled with low velocity shows that the channel is no longer suitable for navigation purposes. Dredging works should be done to increase the depth of the channel for navigation of fishing vessels.

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