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Coastline Changes in Vicinity of Runway Platform of Sultan Mahmud Airport, Kuala Terengganu: Comparative Analysis of One-line Model Versus Satellite Data

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Abstract: The aim of the research is to quantify the changes of coastline nearby the reclamation of sand for runway of airport Sultan Mahmud, Kuala Terengganu. The reclamation was built towards sea with beach nourishment in order to accommodate the operation of 747-400 aircraft landing at the airport. From the visual observation the offset changes from the original position of shoreline due to erosion was more than 10 m during 2010 to 2011. The numerical method that used for solve coastline case in this research is Littoral Processes and Coastline Kinetics numerical model (LITPACK). The results from the numerical model were then compared and verified with data from satellite. The computation of shoreline evolution was calibrated and validated by changing the bed roughness of the seabed. The method of Root Mean Square Percentage Error (RMSPE) was performed to find the percentage error of the simulation against the actual data. From the results obtain, it is found that the bed roughness of 0.004 m shows the good agreement with the actual data where the RMSPE is 0.76%. It is also found that the reclamation of sand for runway platform contributes severe erosion on an average of 21.3 m at the north side and accretion on an average of 24.8 m at the south sides of the between in year 2010-2013.

Key words: Accretion, coastline changes, coastal development, erosion, LITPACK numerical model

INTRODUCTION

Many ports must be protected and secured against waves by associating them with others coastal development such as breakwater, revetment etc. In turn, the coastal development creates hazard in which affects the natural environment such as erosion. An example of coastal erosion due to man-made product was the project of reclamation of sand to form a runway platform of Sultan Mahmud Airport Kuala Terengganu. The extension was built towards sea with beach nourishment in order to accommodate the operation of 747-400 aircraft landing at the airport. An engineered structure so call revetment was constructed along the bell shape of the extension to protect the new artificial sandy beach from retreatment of the sand. The approach is considerably successfully to protect the new runaway but the greatest erosion is occurred. Figure 1 shows the erosion is taken place on the North side of the development. The erosion has threatened the villagers staying along this beach and many food outlets on the coast have been carried away by erosion. From the visual observation the offset changes from the original position of shoreline due to erosion was more than 10 m during 2010 to 2011 and it is believed that the offset becomes more if no action is taken.

Fig. 1: Erosion occurs at the north side of the runway platform of Sultan Mahmud Airport, Kuala Terengganu

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Study of shoreline changes become an interested area for many researchers due to increase of understanding of physic in sediment transport process, development of mathematical model and high competency of computer development. Among them, study by using mathematical model is considered as effective ones that have been used for a long time. Many researchers widely used mathematical model to study shoreline changes, such as work from (Larson *et al*., 1987; Hanson, 1988; Hanson and Kraus, 1989; Hoan, 2006; Thach *et al*., 2007). One-dimensional coastal morphology model (One-line model) is used to describe the shoreline change (Komar, 1971; Perlin and Dean, 1983; Larson *et al*., 1987; Hanson 1988; Hanson and Kraus, 1989; Kamphuis, 1993; Dabees and Kamphuis, 1998; Hoan, 2006; Thach *et al*., 2007).

The main objective of this research is to predict changes of coastline nearby the reclamation of sand for runway of airport Sultan Mahmud, Kuala Terengganu. The prediction was undertaken by simulating the LITPACK. The results were validated with data from satellite images. The LITPACK modules are discussed elsewhere and not mention in this study (Thach *et al*. (2007) and Szmytkiewicz *et al*. (2000).

METHODOLOGY

Area of study: The geographical area of Sultan Mahmud Airport is located at 05°22'57"N and 103°06'12"E of East Coast of Peninsular Malaysia in the State of Terengganu and adjacent to the South China Sea is captured in Fig. 2. The East part of Peninsular Malaysia is subjected to seasonal climates so called Southwest Monsoon and Northwest which occurs during late May to September and November to March respectively. The monsoons create high significant waves as well as high intensity of currents and caused alongshore sediment transport to the north and south of East Coast Peninsular Malaysia. As mentioned by Phillips (1985) the net longshore sediment transport is occurred towards the north of Peninsular Malaysia. According to Mohamad *et al*. (2012) the highest wave occurs during November to March where the average of wave angle is 60-70 degree from the north with the wave high is more than 3 m and tidal range is about 2.04 m from mean sea level.

The growth of population, business activity, tourism gateway and educational hub demands the expansion of the Airport Sultan Mahmud Airport to become more efficient and accommodate various types of aircraft such

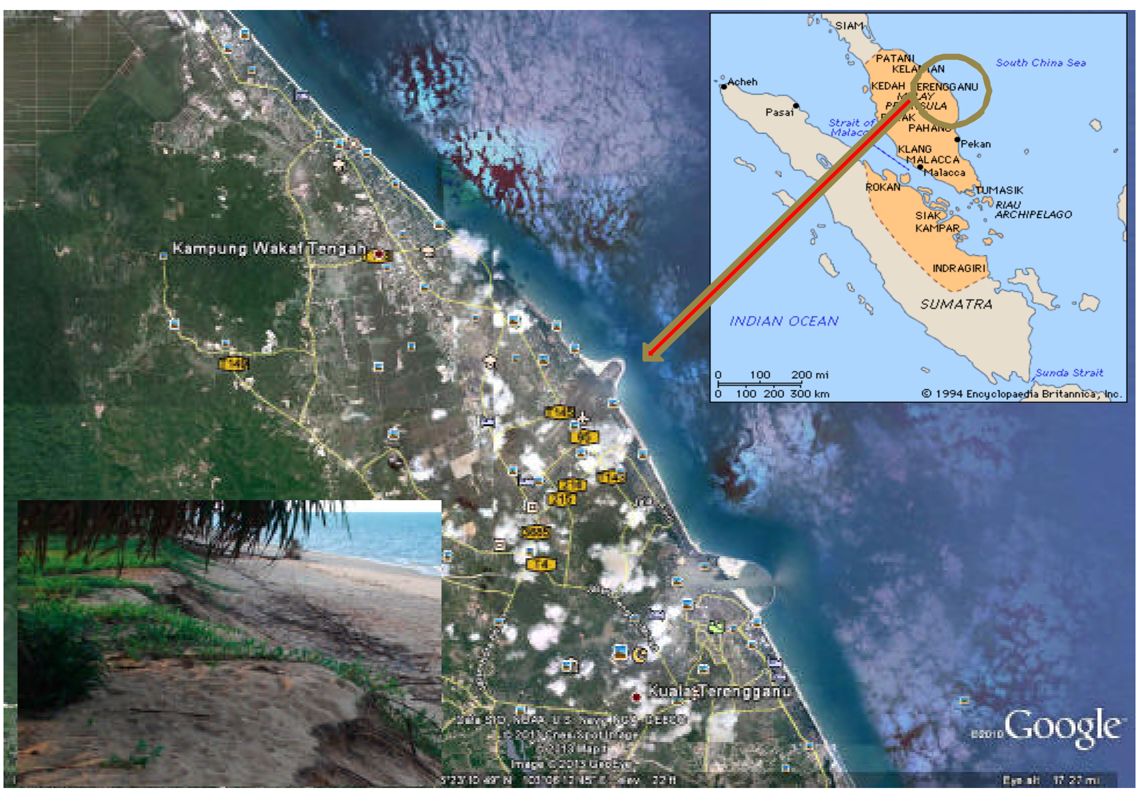


Fig. 2: Location of study area of Sultan Mahmud Airport, Kuala Terengganu

as B747. For instance, in 2008, the airport handled 487,495 passengers with 10,045 aircraft movements. In January 2008, the Malaysian government was approved RM200 million to upgrade the airport. This including an extension 2800 m length of the existing runway and upgrade the terminal of the airport. It was decided that the extension of the runway about 600 m outwards to sea with the reclaiming of sand to form a runway platform. The reclaiming of sand was exposed the runway directly to waves due to its location, thus a preventive measures from erosion was undertaken such the design was in form of bell shape to reduce the intensity of the longshore current. Besides that coastal structure which so called revetment made from quarry stones was constructed at the edge of the reclaiming area to protect the erosion is shown in Fig. 3.

Mathematical model for shoreline change: Two basic assumptions are considered in one line model. The first assumption is that the beach profile moves landward (erosion) and seaward (accretion) while retaining the same shape are captured in Fig. 4. Therefore at any point on the profile is sufficient to specify the horizontal location of the profile with respect to baseline. One contour line can be used to describe changes in the beach plan shape where the beach is either erodes or accretes. This contour line is taken as the shoreline (in this figure is modelled direction y) and the model is called "One Line Model".

The second assumption is the sand is transported alongshore between two well-defined limiting elevations on the profile. The sand actively moves over the profile to a certain limiting depth is located at the top of the active berm (D_B) and beyond which the bottom does not move. This depth is called the depth closure (D_C).

One line model account for the alongshore sediment transport rate and it is assumed that the alongshore sediment transport is engendered by oblique breaking waves.

Fig. 3: Application of revetment to protect further erosion in vicinity of Sultan Mahmud Airport, Kuala Terengganu

Derivation of one line model: The partial differential equation governing shoreline change in the one line model is formulated by conservation of sand volume under the above assumptions. Consider the Fig. 5, where, y = shoreline position; x = distance alongshore; Δy = change in shoreline position; the length of the shoreline segment is Δx; D_B = profile move within a vertical extent defined by the berm elevation and D_C = the closure depth.

The change in volume of the section is written as:

$$\Delta V = \Delta x \Delta y\ (D_B + D_C) \ldots \ldots \ldots \ldots \ldots \ldots \quad (1)$$

is determined by a net amount of sand that enters or exits the section from its four sides. One contribution to the volume change results if there is a difference in the long shore sand transport rate, Q at the lateral sides of the section and the associated the sand continuity is written as:

$$\Delta V = Q\Delta t - \left\{ \left(\frac{\partial Q}{\partial x} \right) + \Delta x + Q \right\} \Delta t \ldots \ldots \ldots \quad (2)$$

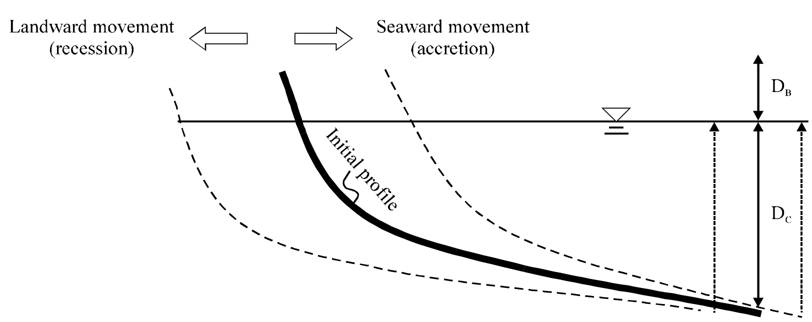


Fig. 4: Change of shoreline

Table 1: Wave height and wave period during year in Kuala Terengganu coastline

	Month/direction and wave height (m)											
	11	12	1	2	3	4	5	6	7	8	9	10
Wave period time (sec)	NE	NE	NE	NE	SE	E	SE	SE	SE	SE	SE	E
0.0-0.5							5.3	10.5			6.9	
0.5-1.0				7.6	5.1	4.6			7.4	4.6		
1.0-1.5	6.3		6.6									5.9
1.5-2.0		9.0										

NE: North east, SE: South east and E: East

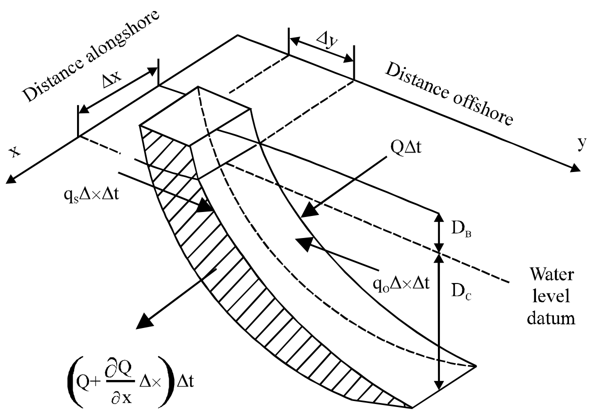


Fig. 5: Cross section of profile one line model

Fig. 6: North and south side of study area

Another contribution can arise from a line source or sink of sand which adds or removes a volume of sand per unit width of beach from either the shoreward side at the rate q_s or from the offshore side at the rate of q_o. This contribution gives a rate of $q = q_s+q_o$ and associated volume change of $\Delta V = q\Delta x\Delta t$, so that is becomes:

$$\Delta V = -\left(\frac{\partial Q}{\partial x}\right) + \Delta x\Delta t + q\Delta x\Delta t \ldots\ldots\ldots\ldots \quad (3)$$

By rearranging the Eq. 4, it becomes as:

$$\frac{\partial y}{\partial t} = \frac{1}{(D_B + D_C)}\left\{-\left(\frac{\partial Q}{\partial x}\right) + q\right\}\ldots\ldots \quad (4)$$

where, Q is a function of the wave climate, current, cross-shore profile, sediment properties and coastline orientation at a given position.

The continuity equation for sediment transport (Eq. 4) is solved using an implicit Crank-Nicholson scheme, giving the development of coastline position in time.

Simulation: In order to investigate shoreline change position along the Kuala Terengganu coastline, a set data is needed to simulate the model. Modeling study shoreline is implemented by using LITPACK to simulate, calculate and forecast the change orientation. The area of study was 5°24'06.67" N and 103°05'55.08" E until 5°22'50.82" N and 103°06'51.13"and divided north and south side as shown in Fig. 6.

The flow chart of the simulation is shown in Fig. 7. The simulation starts with input data of initial shoreline, cross shore profile and wave climate. The input data of the initial and cross shoreline was in profile series while wave climate was in time series. The data was calibrated by using LTDRIFT and LINTABL modules to find reliable result (DHI, 2007b). After the calibration was done, then the simulation of shoreline evolution was performed by using LITLINE module (DHI, 2007a). In order to observe the changes of the coastline the revetment was included in the simulation. The result from the simulation was validated with the image of satellite and further analyses were carried to verify and validate the accuracy of the result.

The input data consists of wind speed and wave height as shown in Fig. 8 and Table 1, respectively. Others input data such sea water level, sediment and other input parameter were also considered. Topographical data was taken in 2010 with 2958 m long of coastline and revetment was placed along the reclamation of sand. Wave data based on frequency of wave height and wave period are shown in Table 1. This simulation uses initial shoreline that measured from the specified

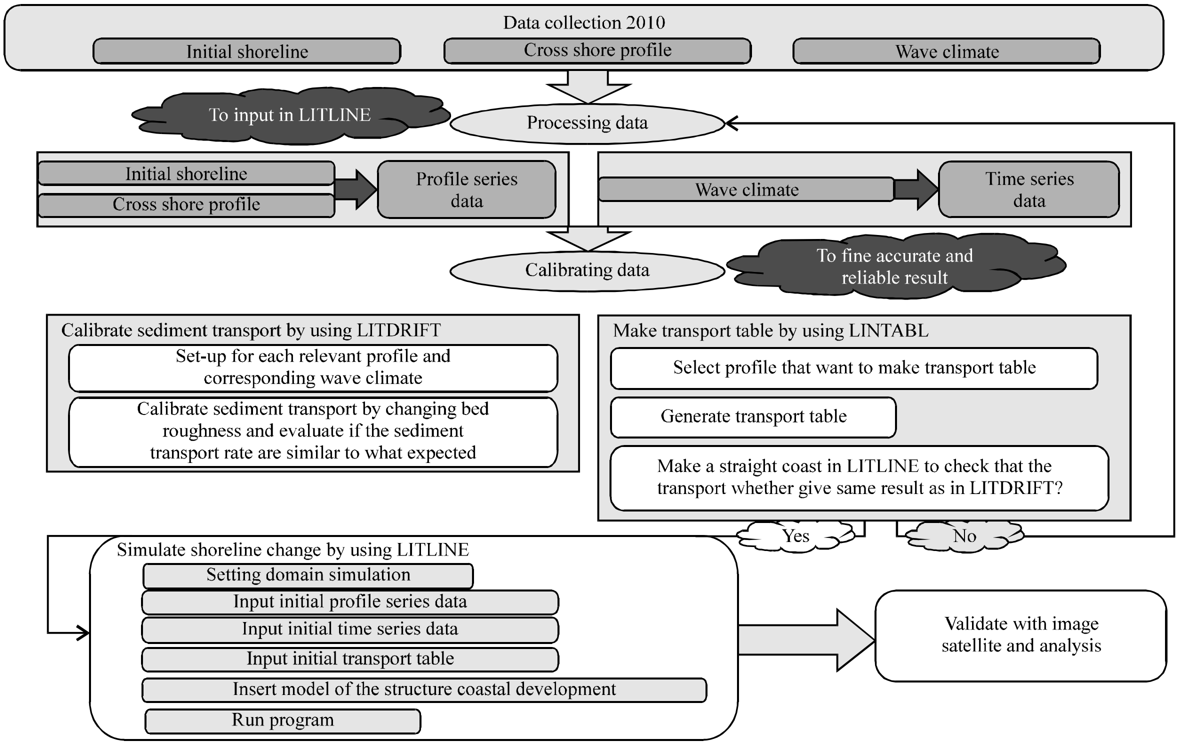


Fig. 7: Flow chart of simulation

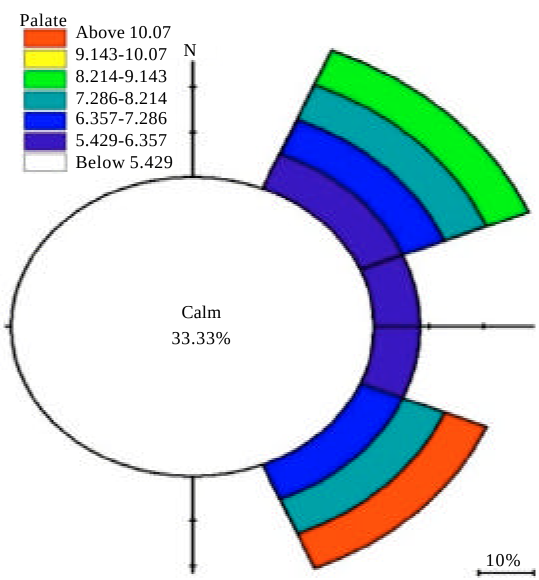


Fig. 8: Direction and wind speed at study area

baseline. This baseline is divided into 87 cells with length 34 m. The method of Root Mean Percentage Error (RMSPE) was carried to find the percentage error of simulation results. The equation was given by Hyndman *et al*. (2006) and written as:

$$\text{RMSPE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left\{100.\frac{(y_s)i-(y_o)_i}{(y_o)_i}\right\}2}\ldots \quad (5)$$

where, y_s is shoreline simulation; y_o is shoreline observation and N is number of cells.

COMPARATIVE ANALYSIS AND DISCUSSION

Calibration and validation: As in the case of tested model, the shoreline data for the year of 2010 and 2012 were used. The revetment was presented in the modelled area which covers the new shoreline due to the extension of the airport. The north and south parts of the extension were set up as existed shoreline. The process of simulation was taken to observe the evolution of shoreline for two years due to the modification of shoreline with the hard coastal structure development. The data shoreline of 2012 was taken as modelled validation.

For the validation purposes, the process of calibrate was made by fine tuning the bed roughness (K) in which the values were set upto 0.001, 0.004, 0.008 and 0.012 m. The values are suggested as tuning parameter after work done by Thach *et al*. (2007) and Voogt *et al*. (1991).

The results of the calibration for shoreline evolution between measured and simulated for 2010-2012 are shown in Fig. 9a-h. In Fig. 9a, c, e and g show the results of bed

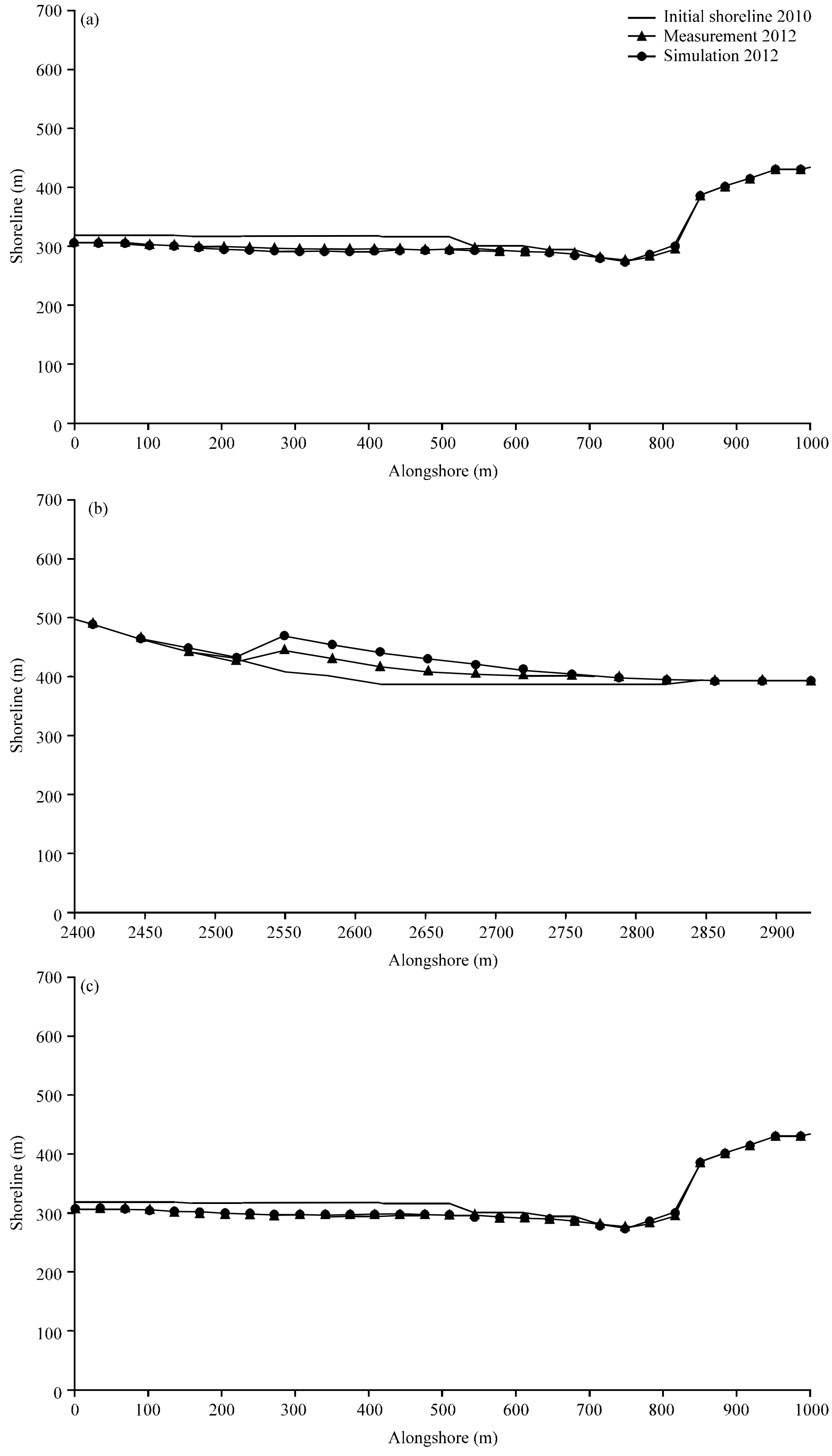
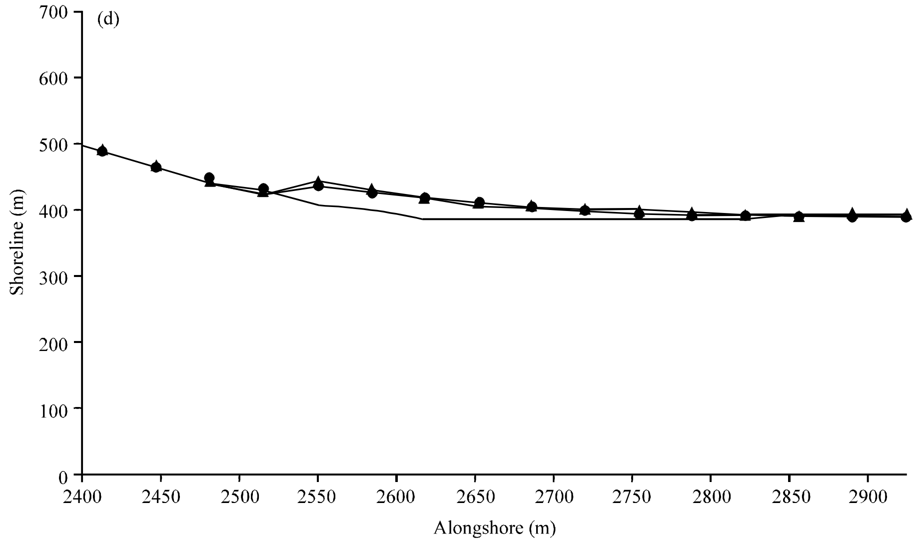
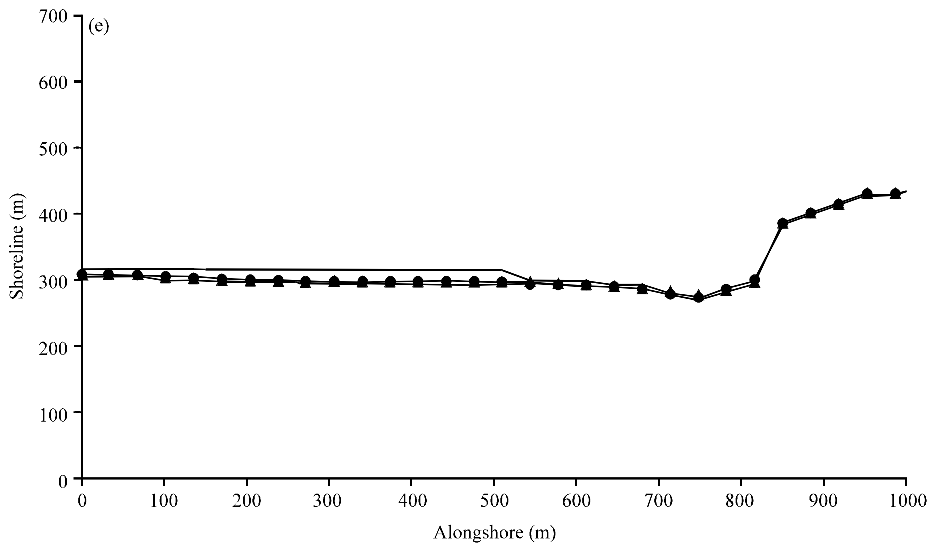


Fig. 9(a-h): Continue





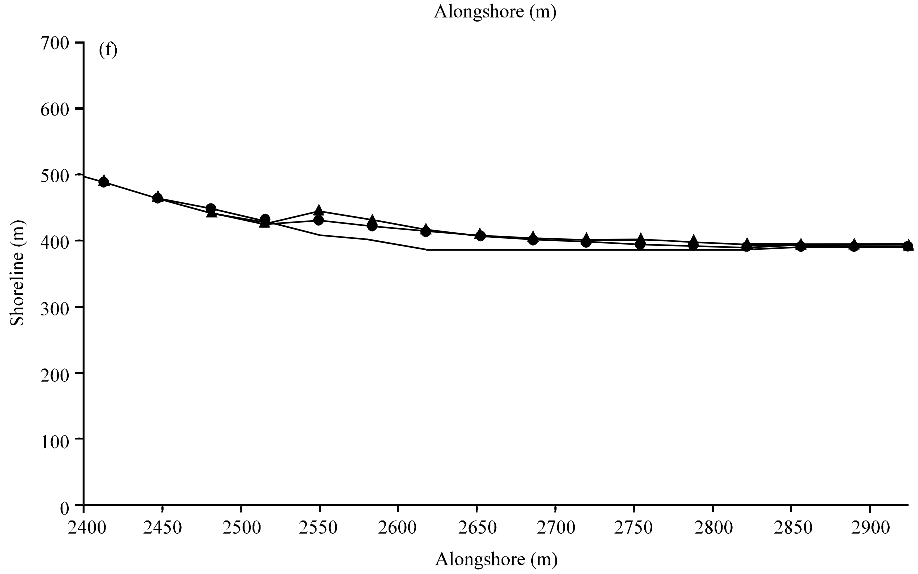
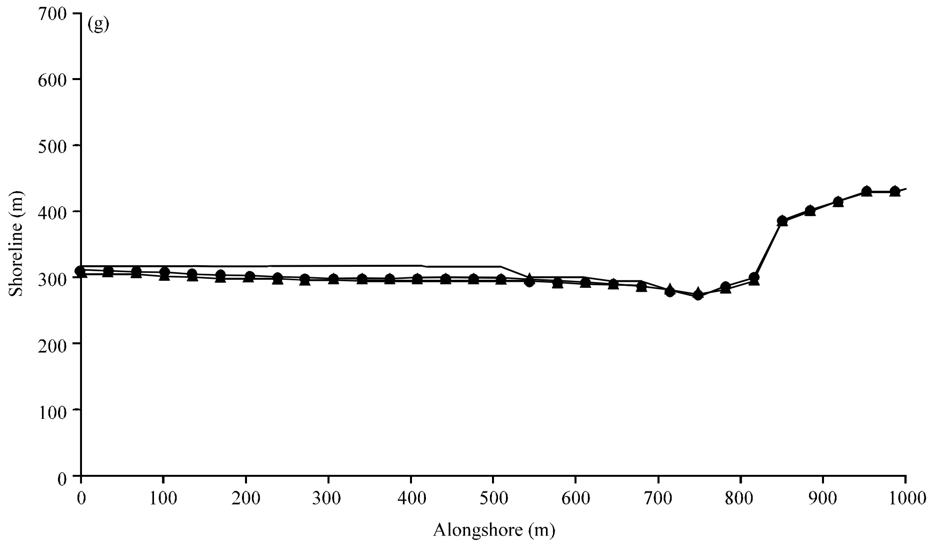


Fig. 9(a-h): Continue



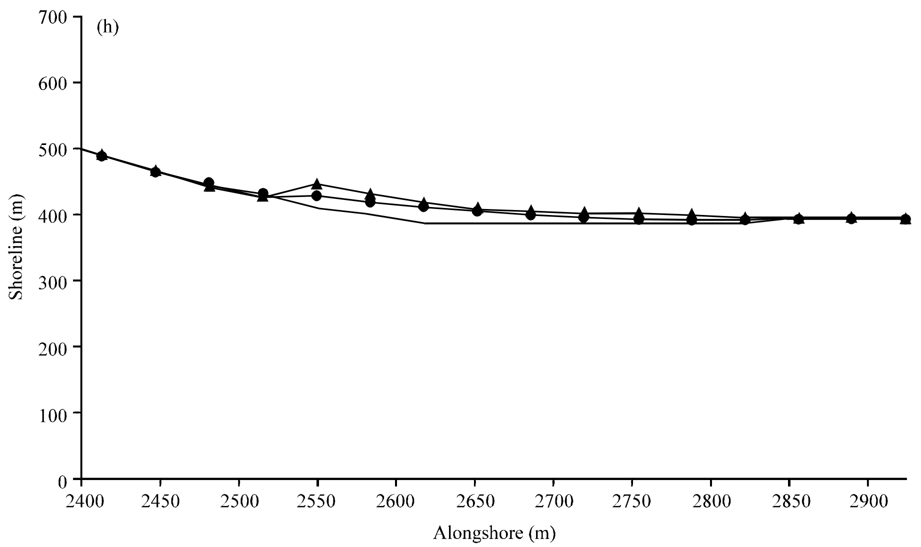


Fig. 9(a-h): Shoreline erosion measured and simulated for K (a) 0.001 m in the north side, (b) 0.001 m in the south side, (c) 0.004 m in the north side, (d) 0.004 m in the south side (e) 0.008 m in the north side, (f) 0.008 m in the south side, (g) 0.012 m in the north side and (h) 0.012 m in the south side

roughness, K = 0.001, 0,004, 0.008 and 0.012 m, respectively for the North side. Whereas in Fig. 9b, d, f and 9h show the results of bed roughness, K of 0.001, 0.004, 0.008 and 0.012 m, respectively for the south side. From the Fig. 9c and d, the value of bed roughness of K = 0.004 m show the most comparable result between simulated and observed for the North and south sides.

Quantitative analysis of computational inaccuracies using root mean square percentage error (RMPSE): The assessments done previously were based on visual comparisons between the model results and the satellite data. In addition, an attempt was made to assess the accuracy between the actual and the modelled shoreline changes. The proposed tool was believed to provide some more precise quantitative analysis.

The RMSPE method is needed to quantify the percentage error between the simulated against the observed shoreline. The less percentage of error will indicate the goodness of the modelled area. The data simulated and observed shorelines were plotted in Fig. 10a-d to analysis the RMSPE with the differences of bed roughness. In Fig. 10a-d show the results of RMSPE with the bed roughness (K) of 0.001, 0.004, 0.008 and 0.012 m, respectively. In Fig. 10a-d show the RMSPE of 1.98, 0.76, 1.09 and 1.48%, respectively. The lowest RMSPE calculated was 0.76% which obtained when the bed roughness of 0.004 m was applied in the simulation

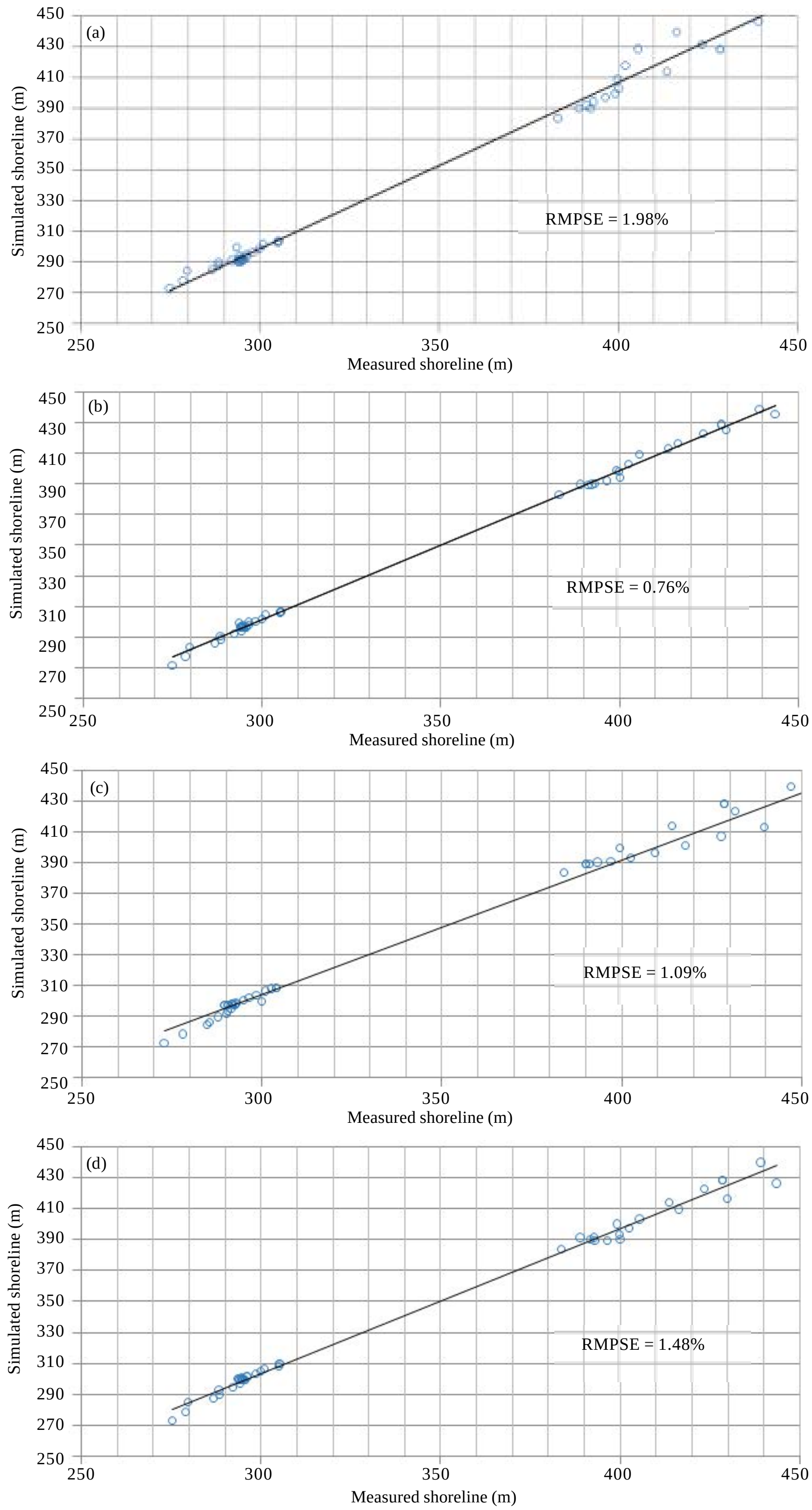


Fig. 10: (a-d): Linear regression shoreline for K (a) 0.001 m, (b) 0.004 m, (c) 0.008 m and (d) 0.012 m

(Fig. 10b). Therefore, the bed roughness of 0.004 m is suitable to set as a tuning parameter, thus quantify the changes of the coastline.

DISCUSSION

The simulation of modelled area was calibrated using bed roughness as a tuning parameter to adjust the result of shoreline change as close as possible to the observeddata from satellite image. The simulation results show the shape of erosion and accretion occur similar pattern with observed data. The most accurate result is obtained by setting the bed roughness 0.004 m. In Fig. 11, the results show that the North side of the airport experienced erosion whereas accretion at south side. During the Southwest monsoon season it is expected that the longshore current is greater than Northeast monsoon and the net longshore transport will be towards the north. It is confirmed by Phillips (1985) in his study that the net longshore sediment transport is moved towards the north of Peninsular Malaysia. The longshore current and sediment transport are reduced and blocked respectively by the new land of airport. The sediment is piling up at the south side and form a new shoreline which is gradually increases the beach area.

The monsoon northeast influenced the area where the erosion is taken place severely at the nearest adjacent of the revetment. Based on the simulation shows that an average erosion from 2010 until 2012 along north of runway extension Sultan Mahmud Airport is 13.3 m (green line in Fig. 12). This erosion becomes more dangerous in 2013, this reach for an average of 21.3 m

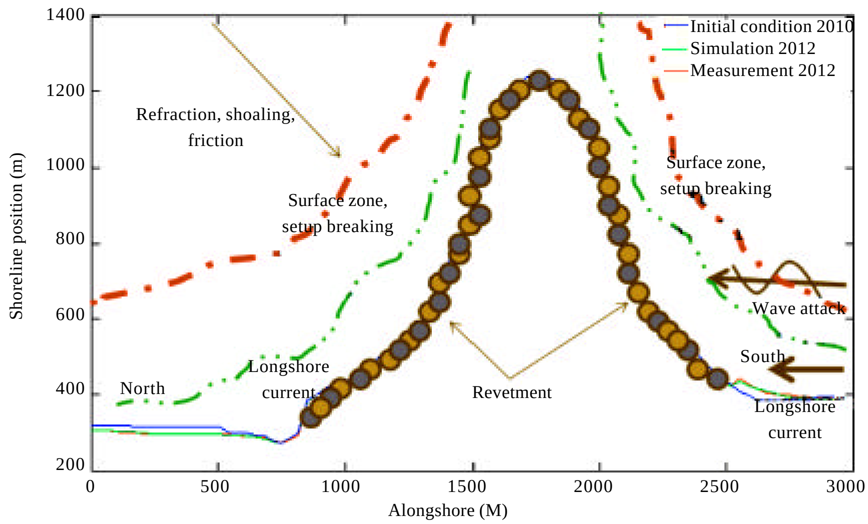


Fig. 11: Simulation of shoreline change during 2010-2012 at Kuala Terengganu coastline

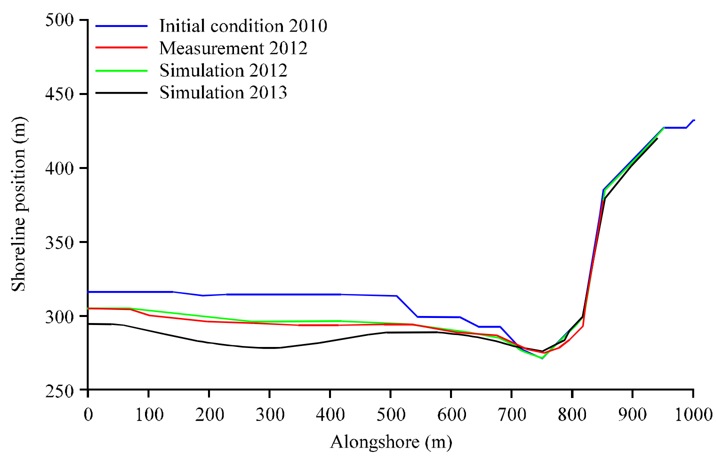


Fig. 12: Erosion around the north of runway extension Sultan Mahmud Airport using simulation (Enlargement figure at north side)

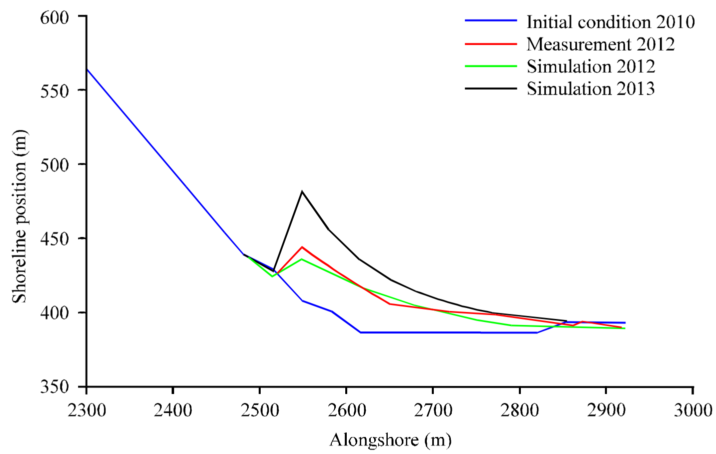


Fig. 13: Accretion around the south of runway extension Sultan Mahmud Airport using simulation (Enlargement figure at south side)

(black line in Fig. 12). Meanwhile, in the south of the runway extension Sultan Mahmud Airport occur accretion with average 14.1 m during 2010 until 2012 (green line in Fig. 13) and 24.8 m during 2010 until 2013 (black line in Fig. 13).

CONCLUSION

The land extension for the airport may cause changes in hydrodynamic pattern and longshore sediment transport. The surf zone area will slightly follow the shape of the sand reclamation and the breaking point of the wave is changed accordingly with the bathymetry. The wave refraction is also occurred as the wave direction is adjusted by the topography of the seabed. The breaking wave which creates the longshore current may change the shape current pattern from straight to curve. The curve pattern of the long shore current caused severe erosion on the north side especially at the edge of the revetment. This could be the area is not yet covered by the protection and the high intensity of long shore current may transport the sediment away from the original position. Meanwhile on the south side the same processes are occurred however the longshore current and long sediment transport are being reduced and blocked respectively by the sand reclamation.

The development of sand reclamation for runway platform of Sultan Mahmud airport changes the hydrodynamic and longshore sediment transport pattern which in turn may lead to accretion and erosion of a coastal system. Average erosion occurs around the north of this building reach 13.3 meters during 2010 until 2012 and 21.3 meters during 2010 until 2013. Whilst an average accretion occurs around the south of this building reach 14.1 meters during 2010 until 2012 and 24.8 meters during 2010 until 2013.

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