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Analysis of Shoreline Changes in the Coastal Area of Kuala Terengganu, Malaysia

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ABSTRACT

The analysis of shoreline change trends is fundamental to a broad range of investigations undertaken by coastal scientists, coastal engineers, and coastal managers, as well as the government, in this case, the coastal development policy-maker. In order to know the changing of shoreline position around the coastal area of Kuala Terengganu, an analysis and then simulation of shoreline change was performed over, respectively, 2 years, 3 years and 4 years. In this simulation, the longshore distance was divided into 87 cells of length 34 m. Shoreline positions from satellite imagery in 2010 were used in this simulation as the initial condition. Based on the numerical result, both erosion (north side) and accretion (south side) occurred around the Sultan Mahmud Airport, Kuala Terengganu. The average erosion and accretion during the 4 year period is 42.93 m and 40.89 m, respectively.

***Keywords*:** accretion, coastal development, erosion, implicit scheme, Crank-Nicolson

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1. INTRODUCTION

A coastal area is a transition area between the land and the sea. Coastal areas cover less than 20% of the global land surface but host more than 45% of the entire world's population [1], [2]. A shoreline can be defined as the intersections of the land with the water surface at a selected tidal elevation level [3]. The stability of shorelines is continuously under threat because of changes to the natural environment brought about by the agencies of wind, waves, tides, currents, and also due to human intervention that leads to changes in the dynamic equilibrium prevalent at a given coastal stretch [4]. Shoreline changes are strongly influenced by changes in wave conditions, which are projected to intensify in the future at various locations over the world [5] - and also along the coast of Kuala Terengganu [6].

Many researchers have studied shoreline change due to coastal engineering projects. For example, Frihy and Lotfy [7] studied shoreline changes along the northern coast of Sinai using admiralty chart 1992, aerial photograph 1955 and topographic map 1992 (the magnitude of shoreline changes was not estimated in this study owing to the different surveying techniques of the maps examined). Additionally, Ahmad et al. [6] and Hidayat et al. [8] studied shoreline changes in vicinity of runway platform of Sultan Mahmud Airport, while Ozturk and Sesli [9] investigated temporal changes that occurred in the shorelines of the Kizilirmak Lagoon Series during 1962-2013 in terms of area, shoreline length and shoreline development index (SDI) due to the complex characteristics of lagoon shorelines and changes. Furthermore, Ahmad et al. [10] and Subiyanto et al. [11] used a numerical method to study shoreline changes. Analysis of shoreline change during a forty-five-year period with satellite derived shoreline was carried out in El-Arish coastal zone using three different modules [12]. In this study, the assessment of the introduced modules shows the importance of exploring shoreline change using image-processing analysis, and it also demonstrates their applicability at similar locations. Other studies of note include Robinet et al. [13], who simulated shoreline change on timescales from hours (storm) to decades at low computational cost, and Esmail et al. [14], who studied the assessment of shoreline kinematics response due to the existence of these structures during the period from 1990 to 2015 in Damietta city, at the Northern coast of Egypt.

2. MATERIALS AND METHODS

2. 1. Area of study

The area of study is approximately 3 km changes around of the runway extension Sultan Mahmud Airport, Kuala Terengganu. This area located between 5º24'06.67" N, 103º05'55.08" E and 5º22'50.82" N, 103º06'51.13" E as shown in Figure 1.

In this simulation, the baseline in longshore direction was divided into 87 cells with length 34 m start from point A until point B as shown in Figure 1. The shoreline positions from the satellite image in 2010 were used in this simulation as initial condition.

2. 2. Coastline Changes Model

The main equation in this model is the continuity equation for coastline changes [15-17]:

$$\frac{dy_c}{dt} = -\frac{1}{h_{act}}\frac{dQ}{dx} + \frac{Q_{sou}}{h_{act}\Delta x} \qquad (1)$$

in which y_c is the coastline position, t is time, Q the longshore transport rates, x the long-shore position, Q_{sou} the supply of sediment from sources [18]. The total height of the active profile h_{act} consists of three contributions:

- The active depth relative to mean water level
- A height of the beach above mean water level which moves forth and back with the coastline position
- Finally possible "dunes", which may erode if the coastline reaches their position during erosive states, but will not accrete again.

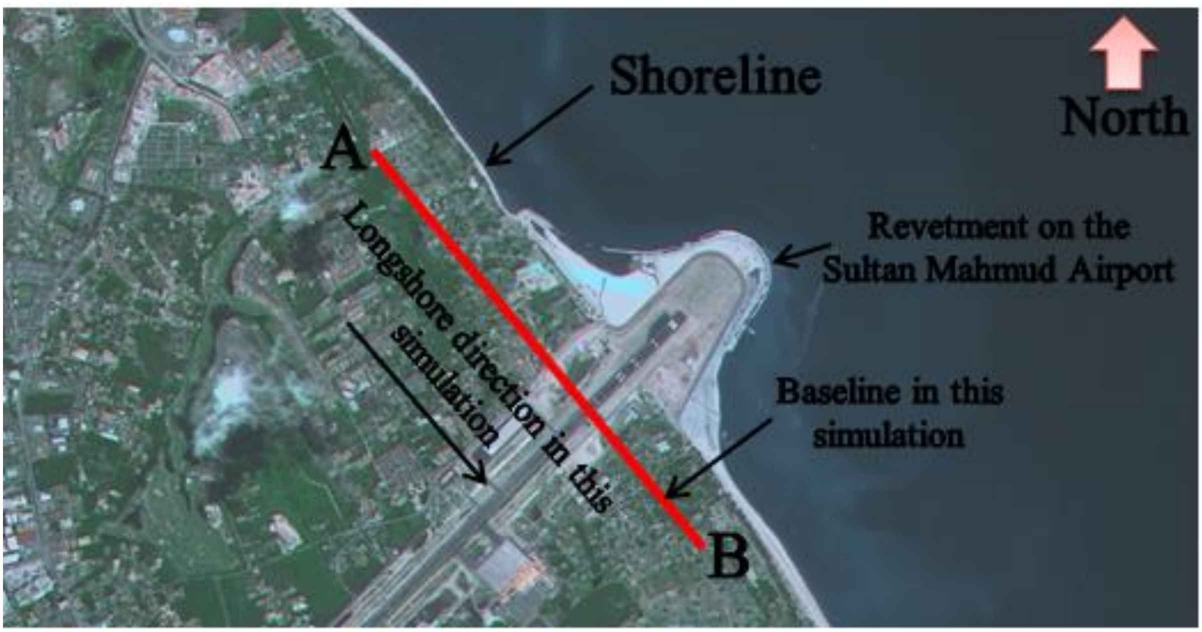

Figure 1. Area of the Research

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

The Crank-Nicolson scheme is the development of an explicit and implicit scheme [19-21]. In an explicit scheme, the right hand section is written at time i. In the implicit scheme, the right-hand side is written for time $i+1$. In both schemes the time differential is written in the form:

$$\left(\frac{\partial u}{\partial x}\right)_{i,j} = \frac{u_{i+1,j} - u_{i,j}}{\Delta x} \tag{2}$$

which means the differential is cantered with respect to time $i + \frac{1}{2}$. The Crank-Nicolson scheme writes the right hand segment at time $i + \frac{1}{2}$ which is the average value of the explicit and implicit scheme [20]. The count point network scheme is shown in Figure 2.

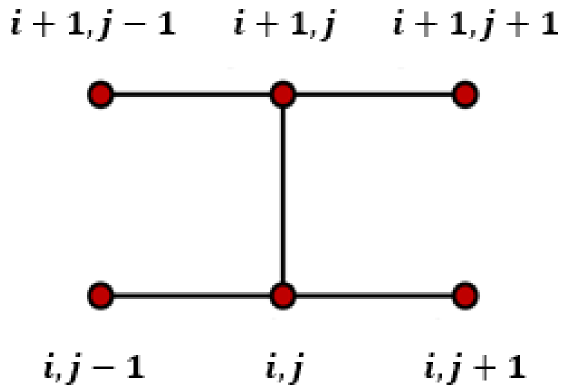

Figure 2. Crank-Nicolson Calculating Point Network Scheme.

This scheme uses weighting techniques for the discretization of the present time (i) and the discretization of the future time $(i+1)$ in a more flexible way, namely by using a time weighting factor. Differences up to space (x):

$$\left(\frac{\partial^2 u}{\partial x^2}\right)_{i,j} = \theta\left(\frac{u_{i+1,j+1} - 2u_{i+1,j} + u_{i+1,j-1}}{(\Delta x)^2}\right) + (1-\theta)\left(\frac{u_{i,j+1} - 2u_{i,j} + u_{i,j-1}}{(\Delta x)^2}\right) \tag{3}$$

with $0 \le \theta \le 1$ is a time ballast factor.
where θ is having a value:
$\theta = 0$, if the scheme is explicit
$\theta = 1$, if the scheme is implicit
$\theta = \frac{1}{2}$, if the scheme is Crank-Nicolson

So equation (3) can be written as follows

$$\left(\frac{\partial^2 u}{\partial x^2}\right)_{i,j} = \frac{1}{2}\left(\frac{u_{i+1,j+1} - 2u_{i+1,j} + u_{i+1,j-1}}{(\Delta x)^2}\right) + \frac{1}{2}\left(\frac{u_{i,j+1} - 2u_{i,j} + u_{i,j-1}}{(\Delta x)^2}\right) \tag{4}$$

In this paper, the numerical problem is solved by using equation 3.

3. RESULT AND DISCUSSION

The coastal area around Sultan Mahmud airport is characterized by the northeast monsoon, with semidiurnal tides and the highest wave occurs during November to March. At this time, the average wave angle is 60–70 degrees from the north and wave height is more than 3 meters, while tidal range is about 2.04 m from mean sea level.

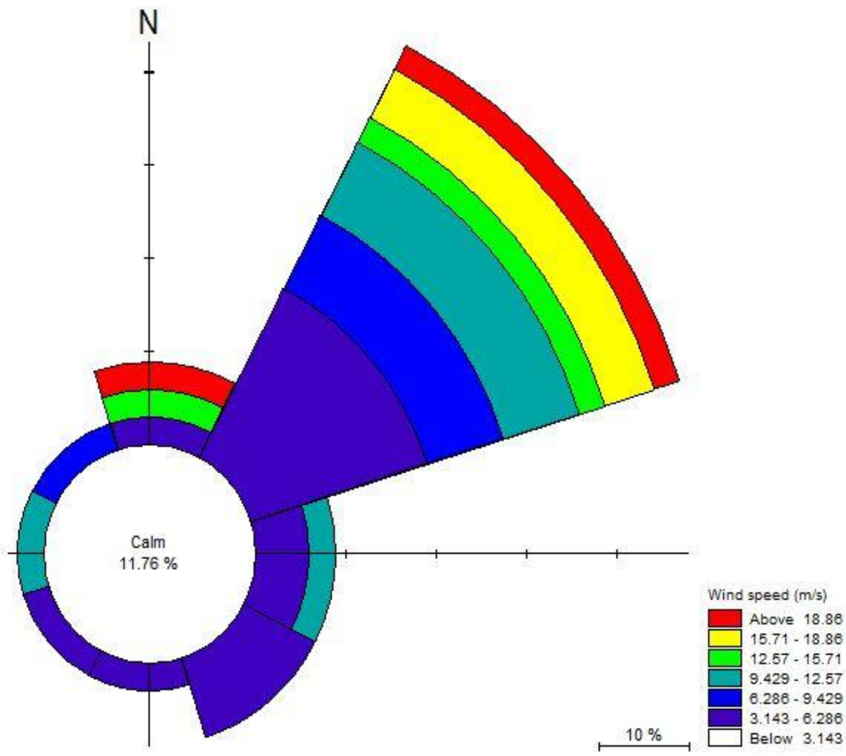

Figure 3. Wind rose on the north-east monsoon (2010) in the area of study

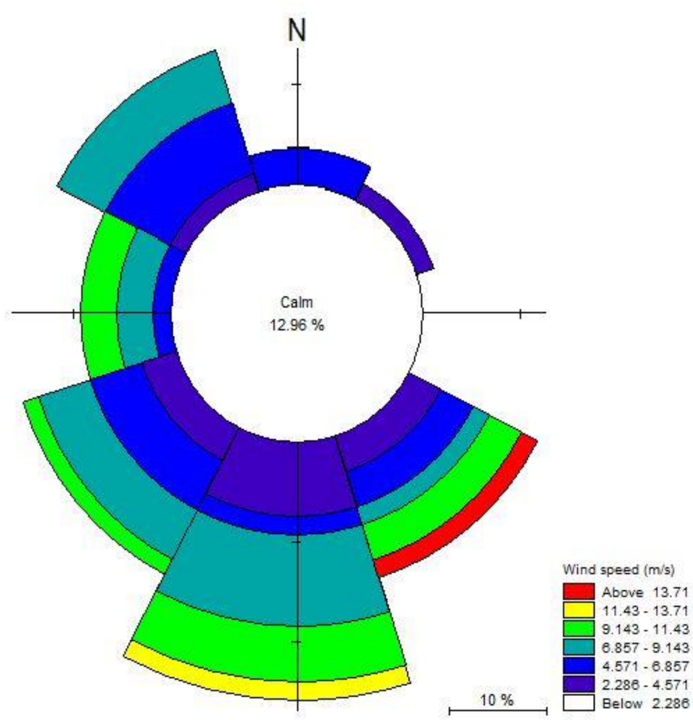

Figure 4. Wind rose on March 2010 – October 2010 in the area of study

Existing net longshore sediment transports occurred towards the north of peninsular Malaysia, however, the net of longshore sediment transport will be changed due to the expansion of sultan Mahmud Airport. We can assume that the expansion of the airport can be treated as a coastal structure in this simulation.

Environmental condition data, including shoreline position data, bathymetry data, wave data, wind data, sediment characteristic data that were used for simulation purposes in this study were obtained from many sources, including government agencies and field data from previous work. The shoreline position data used for simulation in this study were obtained from QuickBird satellite imagery in 2010 and 2012 (QuickBird is a high-resolution commercial earth observation satellite owned by DigitalGlobe). The shoreline positions were calculated from the baseline seen in Figure 1. The bathymetry data were obtained from an experiment which was performed by the Institute of Oceanography and Environment of Universiti Malaysia Terengganu in 2010. The bathymetry data were measured by means of echo sounders and the global positioning system. Accordingly, the value of depth is higher at northwest side of Sultan Mahmud Airport compared to the northeast. The overall bed slope in the surf zone between the shoreline and the 5 m depth contour is about 0.86º and 0.11º between the shoreline and the 8 m depth contour. Sediment characteristic data were obtained from previous work, and the relevant data was collected from October 2010 to November 2010. This showed that the bed profile is composed of fine to coarse sand, and the beach consists of sediment with the average grain size being around 0.12 mm-0.17 mm.

The wind data used for simulation in this study were obtained from the Malaysian Meteorological Department during a one-year period. The wind speed and wind direction in this area are presented in Figure 3 and 4.

The area of the study is affected by the Northeast monsoon between November and February. During the monsoon season, wind blows from the Northeast with average speeds between 9.2 m/s and 13.8 m/s. During the rest of the season, major winds blow from the South, Southeast and Southeast sector with average speeds between 5.7 m/s and 9.8 m/s. The wave data used for simulation purposes used in this study were obtained from a one year experiment which was conducted by Institute of Oceanography and Environment of Universiti Malaysia Terengganu (January 2010 until December 2010) (Table 1).

Table 1. Wave height and wave period during 1 year (January 2010-December 2010) in the area of study.

Month		**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Direction		NE	NE	NE	NE	SE	E	SE	SE	SE	SE	SE	E
Wave Period T (s)	Wave Height (m)												
	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										

Note: NE-North East, SE-South East and E-East

The obtained data show that the average wave height is 6.65 meters and the minimum is 4.6. The maximum wave height occurs during the Northeast monsoon season (from November to February until at the end of March). At this time, the coastline is influenced by strong waves and currents. During the rest of the year, it is subject to moderate and relatively weak waves.

The result of the simulation is a description of shoreline position around the runway extension of Sultan Mahmud Airport, Kuala Terengganu. The result of this simulation are presented in Figures 5 to 7.

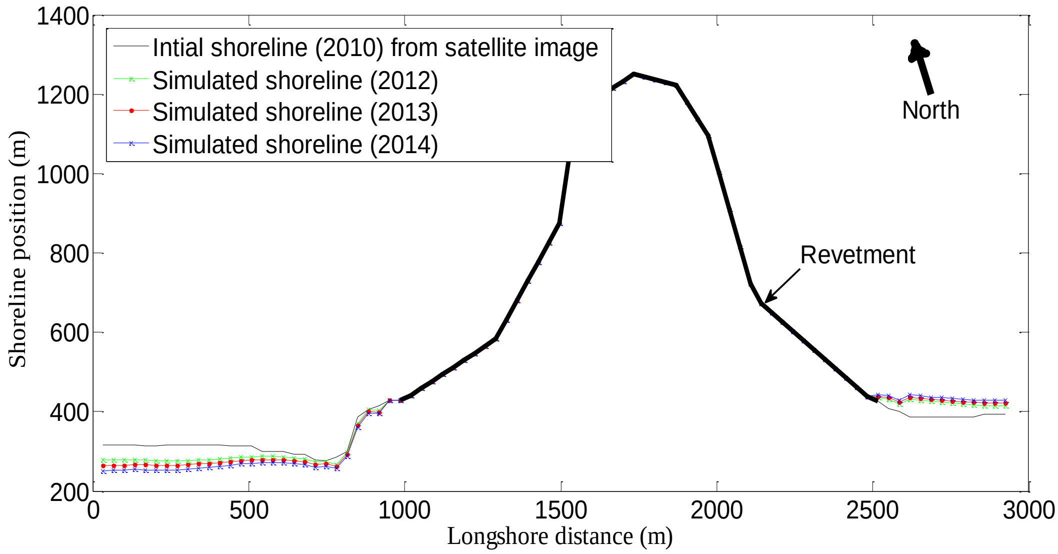

Figure 5. Simulation result of shoreline changes nearby Sultan Mahmud Airport, Kuala Terengganu coastline.

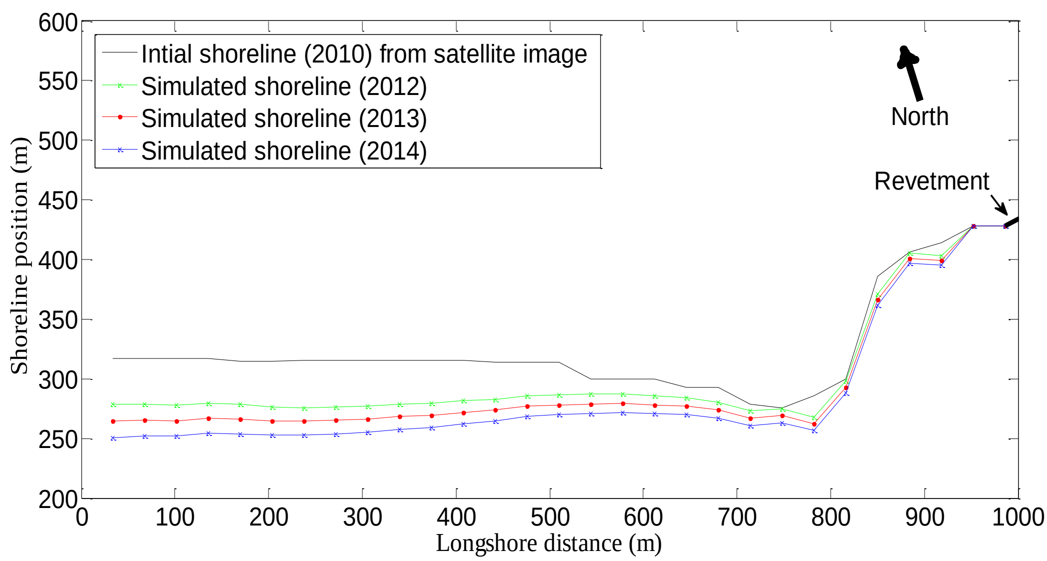

Figure 6. Shoreline changes around the north side of the Sultan Mahmud Airport Kuala Terengganu

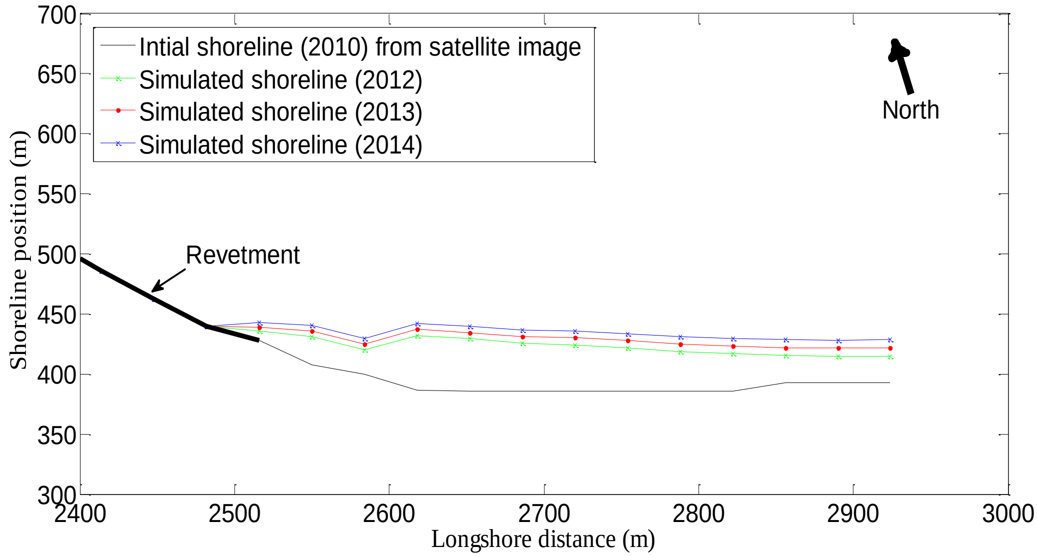

Figure 7. Shoreline changes around the south side of the Sultan Mahmud Airport Kuala Terengganu

Figure 5 shows that the shoreline changes around the Sultan Mahmud Airport during a 4 year period. Based on this figure, the shoreline profile is subject to erosion and accretion. The erosion occurs on the north side and the accretion occurs on the south side of the airport.

Figure 6 shows the changing of shoreline position on the north side of the Sultan Mahmud Airport from 2 years from baseline, to 4 years. In this figure, the shoreline profile around this airport is seen to be subject to erosion. The erosion is greater with increasing simulation time. Figure 7 shows the changing of shoreline position on the south side of the Sultan Mahmud Airport from 2 years from baseline, to 4 years. In this figure, the shoreline profile around this airport is subject to accretion. The accretion is greater with increasing simulation time.

4. CONCLUSIONS

In this study, an analysis of shoreline changes was applied on the coastal area around of the runway extension of Sultan Mahmud Airport, Kuala Terengganu. Based on the numerical results, the average erosion in this area during 2 years and 3 years are 24.88m and 33.90m. The average erosion becomes worst when the simulation was done for 4 years, the resulting figure being 42.93m. Thus, an effective coastal management and coastal protection scheme is needed to minimize this erosion in the future. Meanwhile, the average accretion in this area during 2 years, 3 years and 4 years are 29.81m, 35.31m and 40.89m, respectively. This indicates that the shoreline distance from baseline becomes greater with increasing time.

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