Erosion-deposition Prone Assessment Along the Kelantan and Terengganu Coasts Due to Sea Level Rise

Y A Benson[1,2*], M M Hasan[3,4], M H Jamal[1,5], L H Lee[2], D Anthony[2], K A Mohamad[2], S B Hamzah[2,6] and I K Othman[5]

[1] Center For Coastal and Ocean Engineering (COEI), Universiti Teknologi Malaysia (UTM), Johore, Malaysia
[2] Senior Researcher, Coastal Management and Oceanography Research Centre, National Water Research Institute of Malaysia (NAHRIM)
[3] Faculty of Engineering, University of Sumatera Utara, Medan, Indonesia
[4] Senior Coastal Modeller, Hydroinformatics Institute (H2i), Singapore
[5] School of Civil Engineering, Engineering Faculty, Universiti Teknologi Malaysia (UTM), Johore, Malaysia
[6] Universiti Putra Malaysia (UPM), Selangor, Malaysia

*E-mail: yannie@nahrim.gov.my

Abstract. The erosion-prone zone is characterised by nearshore sand formed by the combined action of tides, wind, and recurring waves crashing on the beach. By running perpendicular to the coastline and bathymetry, 51 cross-shore sections were chosen from a total of 54 to study longshore transport along the beaches of Kelantan and Terengganu. The hydrodynamic model was used to determine water level, current speed, and spectral density, while the Spectral Wave Model and LitDrift were used to construct boundary wave variables and Net Transport across each sector. The model output was compared to previously published erosion-prone zones in the NCES Report (2015), and the results were agreed. The net transfer varies based on the angle of the coastline, the direction of the waves, and the beach profile. The net transport ranges from -693,000 m3/year to 444,000 m3/year depending on the beach profile, wave direction, and angle of the coastline. Net transit for each section was also calculated for 2030, 2050, and 2100, taking into consideration sea level rise. The most recent IPCC assessment (AR6) was applied to generate SLR forecasts for year 2030, 2050, and 2100. According to the statistics, all sections are expected to increase in year 2030, whereas only 53% and 67% are expected to develop in year 2050 and 2100, respectively. From 2030 to 2050 and 2100 to 2020, total net transport along the Kelantan and Terengganu beaches grows by 9.5%, 10%, and 4.5%, respectively.Net transportation is expected to grow until 2050, then steadily decline until 2100. However, by using a better anticipated wave model, the results of this inquiry can be improved.

Keywords: Longshore sediment, sea level rise, Litdrift model, erosion-deposition

1. Introduction

Longshore transport refers to the movement of beach and nearshore sand parallel to the shore through a combined effect of tides, winds, and waves and they also produce shore-parallel currents [1]. Mueller[2] stated that longshore sediment transport (LST) is the transport of sediments along the shore caused by wind, currents, and wave activity and this factor plays a vital role in the evolution of shorelines and is of particular interest to coastal engineers and environmental engineers when artificial marine structures disturb the natural sediment transport balances. New coastal structures like breakwaters, groins, and seawalls, as well as human activity such as dredging and beach nourishment, require a quantitative analysis of sediment transport rates to ensure that these structures are designed in an environment-friendly manner, and it will also help to protect the shoreline by selecting an optimum location.

According to Abdullah [3] and Fazly et al. [4], Malaysia has an approximate 4,809 km coastline characterized by mangrove-fringed mudflats and sandy beaches whereas Ariffin et al. [5] found that the east coast of Malaysia consists of sandy beaches. He also explained that high and low energy wave conditions are correlated with erosion and accretion of a coastal area. According to Ariffin [6], the rate of erosion in Malaysia's east coast region increases dramatically which is our study area. Ehsan et al.[7] mentioned that strong waves during monsoon lead to severe erosion closer to roads along the shoreline and Zolkiply [8] also stated that several coastal protection structures along Terengganu coast also affect the erosion-deposition pattern of the area. On the other hand, the northern part of the east coast at Kelantan shows huge accretion and a big sand bar has been forming for a long time. So, to prepare a proper and optimized plan for the east coast, it is necessary to have the sediment budget along the coastline and need to identify erosion-deposition prone areas based on that. In this study, one of our main objectives is to establish the baseline longshore sediment transport along Terengganu and Kelantan coasts.

Ami et al. [9] stated in their study that the rise in sea level is one of the devastating effects of climate change nowadays. The sea-level rise could negatively affect natural and existing coastal systems even if it is relatively small. Global sea-level rise has been triggered by the increase of anthropogenic activities, posing a threat to many low-lying, unprotected coastal areas. Sea levels will continue to rise at an accelerating rate in the 21st century if no measures are taken [9]. In this study, we will also investigate the change in longshore sediment transport along Terengganu and Kelantan coast due to SLR in 2030, 2050 and 2100 considering the latest report by IPCC (AR6)).

2. Study Area

The study area consists of the entire coastline of two peninsular states of Malaysia such as Terengganu and Kelantan (Figure 1). Both coastlines are dynamic in nature and experience severe erosion and deposition at different places. Terengganu coastline mostly experiences erosion, and it is severe in some places [7] whereas the Kelantan coastline mostly experiences accretion and, in some places, especially in the northern part it is quite severe where sand bars have been formed.

Both state’s coast was open to long fetch of wind and wave propaganda that came direct from South China Sea and mainly consisted of Quaternary alluvium from fluvial and marine which was formed by sand, gravel, silt, and clay and underlain by granite and meta-sedimentary rock [16]. Kelantan with the only Kelantan river that contributes the sediment discharge from the upstream while sediment along Terengganu coast was contributed by sources from it most main rivers: Besut, Terengganu, Marang, Dungun, Paka, Kemaman etc.

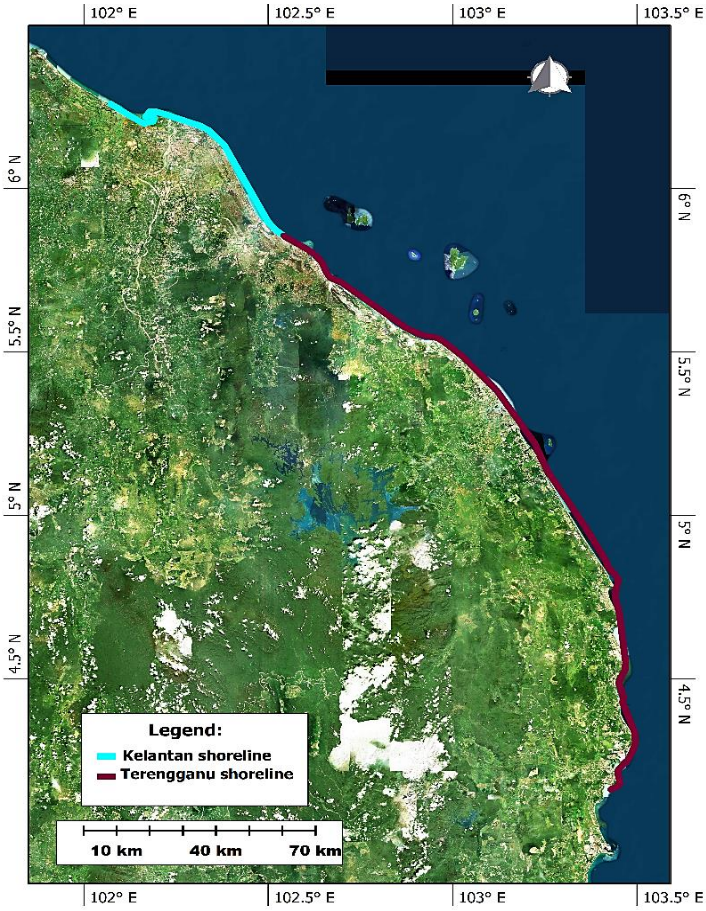


Figure 1. The study area from Kelantan to Terengganu coast.

3. Study Area

The research acquired extensive field data on cross-shore cross-section, water level, current speed, wave characteristics, and sediment qualities. This study collected 54 cross-shore sections (Figure 2) and three sediment samples at depths of -2 m, -3 m, and -5 m for each section, which enabled to produce of a valid sediment property for each section, which was then utilised as an input in a littoral drift model using LitDrift. Each cross-shore cross-section was chosen based on the erosion defined area documented in the National Coastal Erosion Study, 2015, as well as the significance of eroding and accessibility of the ground truthing.

Two ADCPs were deployed to collect current speed, current direction, and wave data for a month which was used to calibrate the hydrodynamic and wave models. Besides, historical wind and wave data were collected from ECMWF [5] where the resolution of wide data is 0.250° x 0.250° and the resolution of wave data is 0.50° x 0.50°.

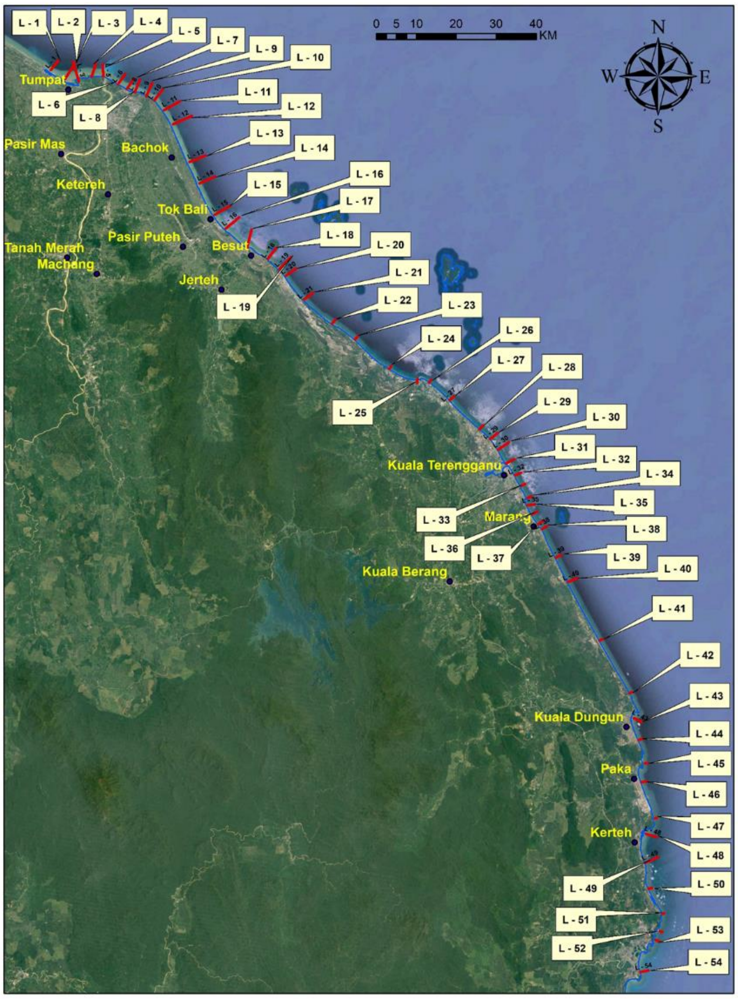


Figure 2. Locations of the cross-shore section.

4. Study Area

4.1. Hydrodynamic (HD) Model

Hydrodynamic modelling is a proven and tested technology that can be applied to any hydraulic study either for rivers or sea. A well-calibrated and validated Hydrodynamic model is the prerequisite for other models such as wave model, salinity model, morphological model, etc. In this study hydrodynamic model was developed as a prerequisite of the spectral wave model which is essential for the littoral drift model.

4.1.1. HD Model Setup

The model domain was adopted based on the extent of the study area. The grids were also prepared in such a way that the nearshore grids are fine in resolution (Figure 3) so that they can calculate more accurately the HD and wave parameters which are essential for longshore sediment calculation. Hydrodynamic boundary condition was taken from Global Tide Model [12]. The resolution of this model is 0.125° x 0.125° and a total of 12 constituents were used in the model: semidiurnal: M2, S2, K2, N2, diurnal: S1, K1, O1, P1, Q1 and shallow water: M4. Three levels of boundary mesh have been built up for HD model simulation: 300 m to 800 m, 1.5 km to 3.0 km, and 6 km to 12 km grid of mesh. All of these grids must then be smooth for smooth simulation.

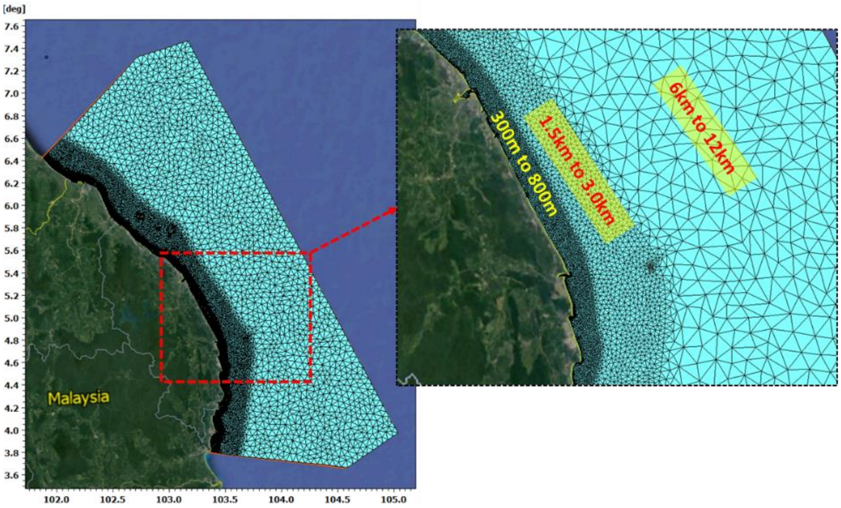


Figure 3. Distribution of computational grid together with model domain.

4.1.2. HD Model Calibration

The model domain was adopted based on the extent of the study area. The grids were also Quality Index (ρ) was employed in this study to assess the efficacy of the hydrodynamic calibration (Eq. 1). Initially, it was calibrated against the projected water level at ten secondary ports, and the quality index ranged from 0.98 to 0.99 [13], which is greater than JPS's minimal criterion (0.9). The model was calibrated against observed water levels at four different sites, and the quality index ranges from 0.97 to 0.99, which is greater than JPS's minimal requirement (0.9). The model was also validated against observed current speed at two sites for a month, and the quality index ranges from 0.84 to 0.87, which is greater than JPS's minimal requirement (0.8). It means that the Hydrodynamic Model was well-calibrated against water level and current speed and is ready for usage again. It was later modelled for 2020 (baseline), 2030 (with SLR), and 2050. (with SLR). Where mei represents measured value and moi represents model value.

$$Quality\ index, \rho = \frac{\sum_{i=1}^{N}(me_i - \overline{me})(mo_i - \overline{mo})}{\sqrt{\sum_{I=1}^{N}(me_i - \overline{me})^2 \sum_{I=1}^{N}(mo_i - \overline{mo})^2}} \qquad \text{(Eq.1)}$$

4.2. Spectral Wave (SW) Model

The influence of nearshore wave on coastal hydraulics is important, particularly on flow patterns and shoreline modifications. Using MIKE 21 SW in this study, a Spectral Wave model was constructed to examine the distribution of wave height, wave period, and wave direction (Spectral Wave Module). It is a wind-wave model that describes the rise, decline, and transformation of nearshore wind-generated waves and swells. It also considers the effects of refraction and shoaling due to depth variation, energy dissipation due to bottom friction, and wave breaking and wave-current interaction. MIKE 21 SW is a parametric model that is stationary and directionally decoupled. The essential equations of the model are derived from the conservation equation for the spectrum wave action density to account the effect of current.

4.2.1. SW Model Setup

The model domain was chosen to be the same as the Hydrodynamic Model so that it could receive input from the Hydrodynamic Model smoothly. Time series wind data from ECMWF [5] was utilised as an input for the model, and the data resolution is 0.250° x 0.250°, which is pretty appropriate. Time series wave characteristics from ECMWF [26] were utilised as boundary conditions, and the data resolution is 0.50° x 0.50°.

4.2.2. SW Model Calibration

The wave model was calibrated primarily against ECMWF reanalysis data at three separate sites in the model domain for significant wave height, mean wave period, and mean wave direction. The calibration was deemed adequate since the estimated values are very near to the reanalysis value. The calibration's performance was evaluated by calculating the Root Mean Square Error (RMSE), and the values of RMSE (Eq. 2) for significant wave heights ranged from 0.08m to 0.15m. The model was calibrated using significant wave height, mean wave period, and mean wave direction measurements from two separate locations. The calculated values are found to be pretty close to the observed values, with RMSE of significant wave heights of 0.045 and 0.12 for both sites. Pi represents predicted value and Oi represents observed value.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \qquad \text{(Eq. 2)}$$

4.3. Longshore Sediment Transport (ST) Model

Longshore transport is the movement of beach and nearshore sand parallel to the shore caused by the combined influence of tides, winds, and waves, as well as the shore-parallel currents produced by them [1]. Littoral Processes Module or Litdrift from the DHI LITPACK programme was utilised to calculate this transport in this investigation. LITDRIFT is a deterministic numerical model with two key components: a hydrodynamic model and a sediment transport model (STP). The sediment transport model STP from LITPACK provides a basic description of sediment transport based on coupled wave and current action. Due to the combined effect of waves and currents, turbulent interactions in the near bed boundary layer are crucial for both bed shear stresses and eddy viscosity distributions. The turbulent wave-current boundary layer model of Fredsøe [15] is used to simulate sediment transport. The model can also be used on complex coastline profiles with longshore bars. The model sequence is depicted in detail in the image below.

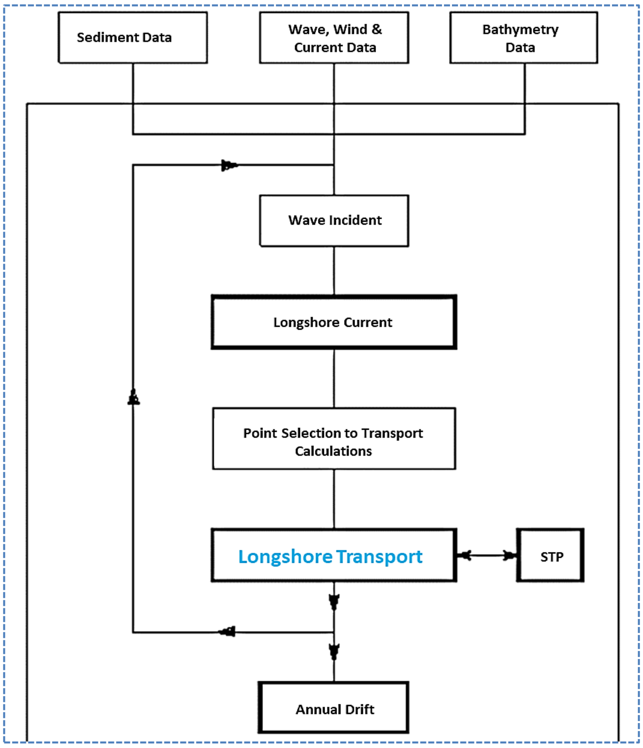


Figure 4. Flow chart for littoral drift model.

4.3.1. ST Model Setup

Sediment qualities such as d50, settling velocity, and so on are important input parameters for the mode. To create representative sediment properties for all sections, a total of 108 sediment samples (two for each section) were collected and examined in the laboratory, and the sediment input for each section was calculated by averaging the two samples. It also requires limits such as water level and current speed, which were derived from HD model findings, as well as wave parameters from the SW Model, which were also used as boundary conditions. Boundary conditions for whole years such as 2020, 2030, 2050, and 2100 were prepared.

5. Longshore Sediment Transport: Baseline (2020)

This study collected 54 cross-shore sections along the coasts of Terengganu and Kelantan to assess longshore sediment transport. Table 1 provides a summary of net transport along all portions. The net transport changes direction depending on the coastal orientation, and the direction can be determined by the sign (negative or positive). The negative sign shows the direction of net transport towards the northwest, while the positive sign depicts the direction towards the southwest. The difference in net transport between two consecutive sections indicates how much sediment has been deposited or removed at that segment. The table shows that net transport varies from 1,000 m^3/year to 635,500 m^3/year, with the main reasons causing these variances being wave characteristics and bathymetry. Bagyaraj et. al [16], Ariffin et. al [17], and DID [18] have all supported changes in net transport due to these factors.

Table 1. Net longshore sediment transport along Terengganu and Kelantan shoreline.

Section	Net Drift (m^3/year)	Section	Net Drift (m^3/year)	Section	Net Drift (m^3/year)
1	11,870	19	11,220	37	-25,910
2	-105,010	20	-1,070	38	220,210
3	-635,580	21	1,920	39	9,910
4	-273,970	22	-66,360	40	71,010
5	-192,850	23	-12,060	41	77,660
6	-100,470	24	-14,820	42	69,160
7	-100,220	25	-270,110	43	2,108,380
8	-63,450	26	-119,250	44	317,640
9	-528,270	27	-1,250	45	-543,570
10	-51,190	28	-77,160	46	322,720
11	204,150	29	-50,680	47	0
12	217,560	30	-17,610	48	294,750
13	56,110	31	31,950	49	125,130
14	53,840	32	139,980	50	54,970
15	28,570	33	33,260	51	-12,830
16	-1,590	34	35,710	52	1,565,700
17	-486,090	35	385,480	53	314,100
18	-20,890	36	8,780	54	32,520

Note: '+' sign indicates sediment movement towards south

Section-47 could not be simulated in this study because the cross shore section was not continuous, and it was also discovered from the data that sections 43 and 52 generated fairly unexpectedly high values, which are not acceptable and do not represent the actual local occurrence. As a result, the two findings were also omitted. Later, it was discovered that the cross-shore sections for 43 and 52 were not perfectly perpendicular to the beach, as required by the littoral drift model.

The effective or working zone of littoral drift was also assessed in this study. Figure 5 shows the calculated start and termination depths of littoral drift along each cross-shore section. We discovered an intriguing tendency in this effective zone. The effective zone changes from -3.44 m MSL (start) to -0.9 m MSL (end) in the northern section of the research region near the Thai border, indicating that littoraldrift occurs within 2.54 m of the zone. However, in the southern half of the research area near Chukai, the effective zone ranges from -4.58 m MSL (start) to 1.9 m MSL (end), indicating that littoral drift occurs within 6.48 m of the zone.

The image clearly shows that the working zone of littoral drift expands from north to south of the research area. It is also clear from the HD model results that the tidal range goes from lower to higher from north to south of the research area, implying that the working zone of littoral drift is directly proportionate to the tidal range (Figure 5).

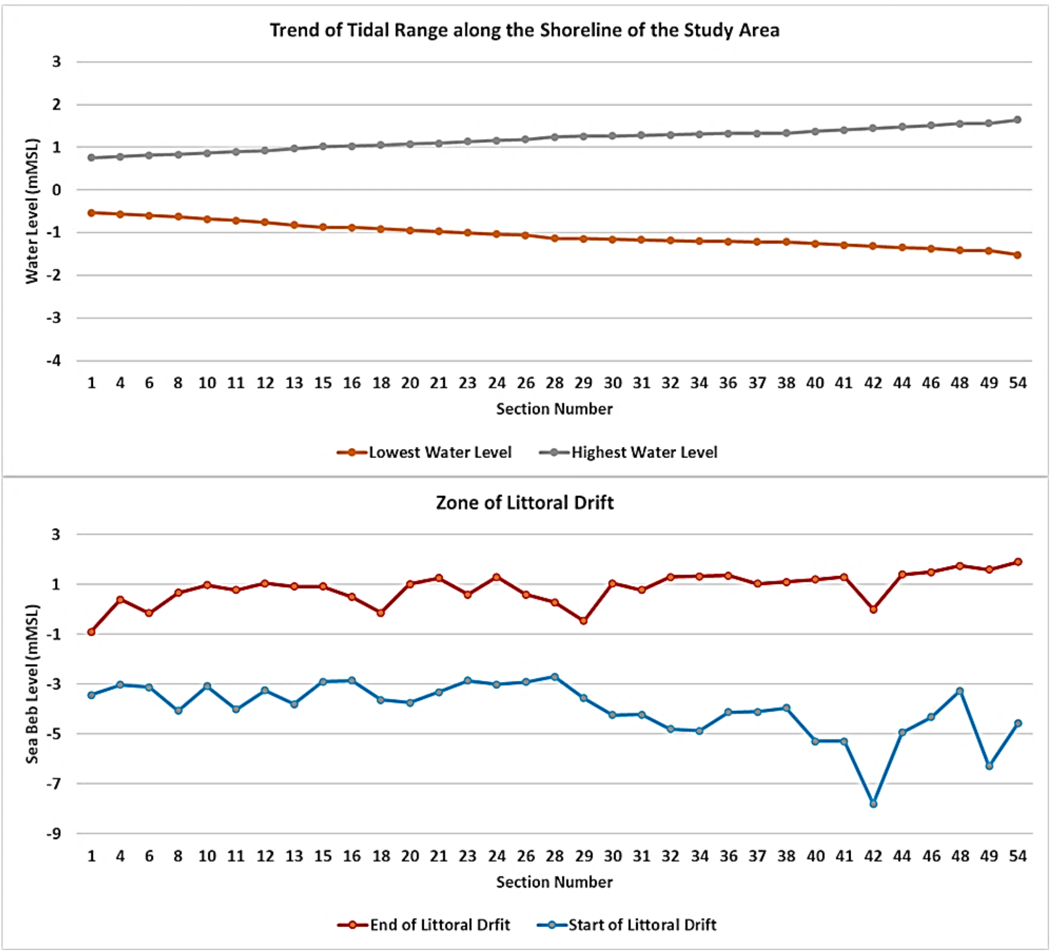


Figure 5. Tidal range and **w**orking zone of littoral drift along Terengganu and Kelantan coastline.

The net longshore sediment movement statistics from Kelantan to Terengganu shoreline were then used to produce the erosion-deposition prone area shown in Figure 6. Based on the baseline (2020) data, there were 8 locations that underwent erosion: two in Kelantan state and the other six in Terengganu. On the other hand, 6 locations clearly demonstrated deposition solely along the Kelantan-Terengganu beach, and Southern Terengganu demonstrated a more stable shoreline than the Northern part of the Kelantan-Terengganu shoreline

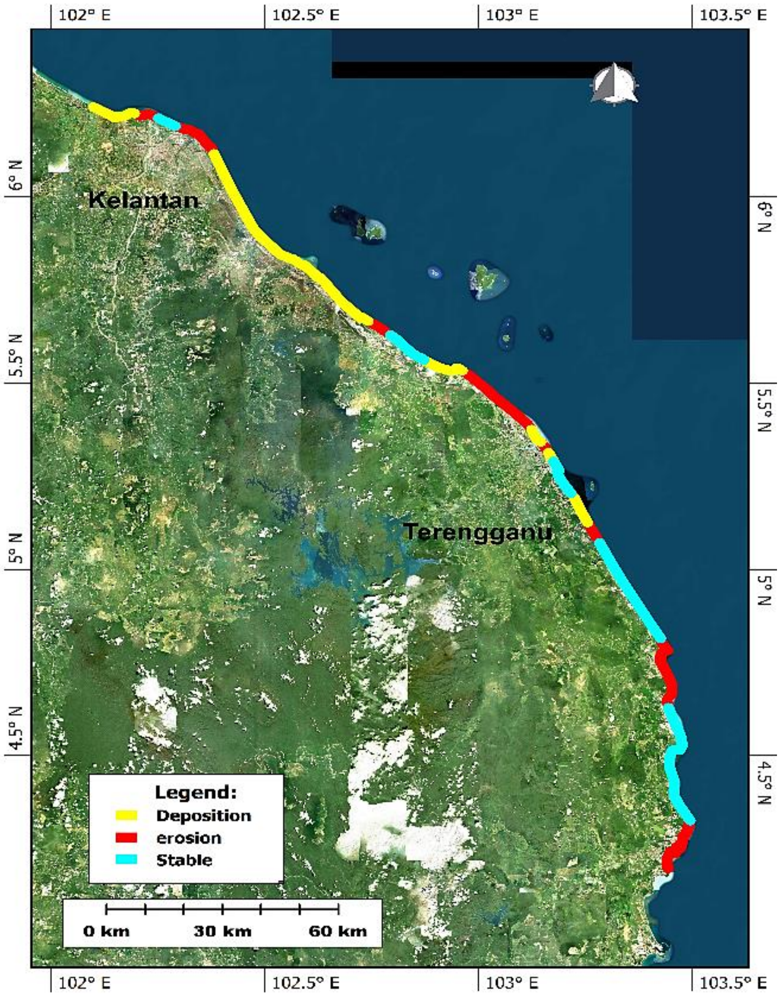


Figure 6. Erosion-accretion prone area along Terengganu and Kelantan coastline.

6. Changes in Longshore Sediment Transport Due To SLR

In this study the SLR for the year 2030, 2050 and 2100 has been adopted based on the latest IPPC report namely Sixth Assessment Repot AR6 [19]. Baseline for this study was taken as 2020 and based on that the SLRs for 2030, 2050 and 2100 were adopted as 0.098m, 0.294m and 0.784m respectively using AR6.

6.1. Impact Analysis

The main objective of this research was to assess the impact of climate change on longshore sediment transport along east coast at the year 2030, 2050 and 2100. The baseline was already established, and the base year was selected as 2020. Littoral drift model was simulated for year 2020, 2030, 2050 and 2100. Net drift for each section for 2020, 2030, 2050 and 2100 was calculated from model result and all the results are furnished in Table 2.

It is evident from the table that climate change especially SLR has some impact on the longshore sediment transport which cannot be ignored [20-23]. This because it would endanger the not only in the stability but also in effectiveness of existing hard and soft defense, thus demand an up-scaling of more soft-protection measures [20,23-24]. Figure 7 and 8 shows the pattern of changes in net transport due to climate change condition. In Figure 8(a), the light red indicates the higher value of net transport in 2030 than 2020, in 2050 than 2030 and in 2100 than 2050.

Table 2. Net transport along Terengganu and Kelantan coastline for Baseline (2020), 2030, 2050 and 2100.

Section	**Net Drift (m^3/year)**				**Section**	**Net Drift (m^3/year)**			
	2020	**2030**	**2050**	**2100**		**2020**	**2030**	**2050**	**2100**
1	11,870	13,050	12,280	11,880	28	-77,160	-85,250	-84,830	-73,010
2	-105,010	-111,040	-96,490	-143,300	29	-50,680	-53,620	-48,050	-30,370
3	-635,580	-693,040	-604,660	-419,610	30	-17,610	-19,500	-19,240	-18,890
4	-273,970	-311,800	-321,590	-355,900	31	31,950	36,010	35,970	37,540
5	-192,850	-210,530	-186,900	-156,780	32	139,980	157,050	154,210	155,000
6	-100,470	-126,150	-146,920	-136,750	33	33,260	37,100	37,570	38,030
7	-100,220	-110,810	-108,460	-101,450	34	35,710	39,560	39,960	42,090
8	-63,450	-72,130	-73,550	-74,330	35	385,480	443,660	464,420	535,240
9	-528,270	-616,780	-684,600	-724,500	36	8,780	10,080	9,940	10,870
10	-51,190	-57,120	-64,380	-77,420	37	-25,910	-28,170	-28,010	-28,330
11	204,150	231,950	236,090	248,300	38	220,210	24,490	23,880	24,230
12	217,560	244,060	238,800	255,420	39	9,910	11,090	11,600	13,080
13	56,110	59,080	61,600	65,810	40	71,010	79,430	78,070	76,630
14	53,840	59,080	58,930	62,470	41	77,660	79,560	81,460	85,790
15	28,570	31,160	30,360	28,710	42	69,160	76,460	76,590	74,160
16	-1,590	-2,110	-2,630	-3,100	43	2,108,380	2,397,860	2,525,870	2,603,880
17	-486,090	-543,210	-521,050	-334,220	44	317,640	366,650	385,720	450,300
18	-20,890	-23,030	-23,950	-37,350	45	-543,570	-634,850	-688,110	-404,310
19	11,220	13,310	13,930	14,240	46	322,720	378,790	397,780	460,120
20	-1,070	-1,110	-1,140	-2,810	47	0	0	0	0
21	1,920	2,000	2,100	-8,620	48	294,750	343,070	388,590	464,590
22	-66,360	-71,910	-66,700	-58,720	49	125,130	135,330	127,240	125,480
23	-12,060	-12,880	-12,680	-14,520	50	54,970	61,400	64,820	78,720
24	-14,820	-16,470	-16,480	-19,450	51	-12,830	-13,880	-13,400	-13,960
25	-270,110	-291,920	-255,270	-180,640	52	1,565,700	1,920,020	1,889,670	1,689,130
26	-119,250	-131,580	-130,150	-130,230	53	314,100	348,800	325,430	264,080
27	-1,250	-1,330	-1,450	-4,000	54	32,520	34,220	37,000	39,330

Note: '+' sign indicates sediment movement towards south

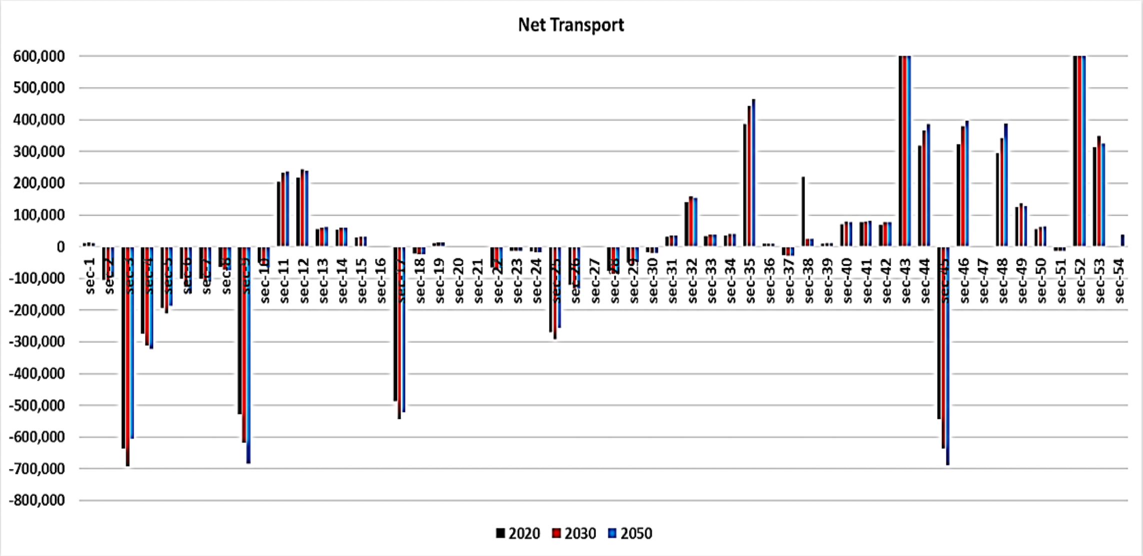
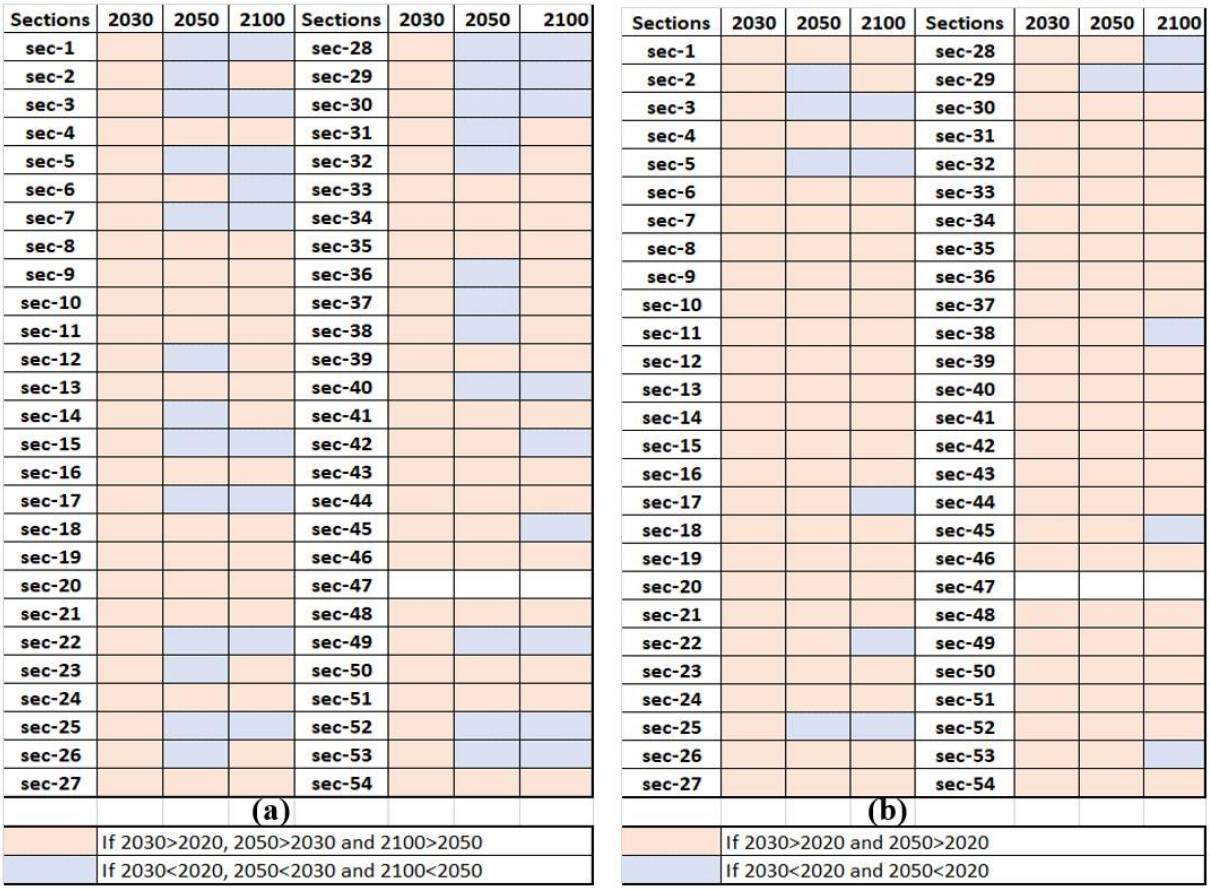


Figure 7. Net Transport along the entire coast of the study area for 2030 and 2050 under climate change condition.

There is a rising trend of net transport from 2020 to 2030 for the entire costal area of Terengganu and Kelantan, implying that the rate of erosion-deposition would likewise develop for the entire area. Until 2030, the erosion-prone area may become more eroded, and the deposition-prone area may become more deposited. After 2030, some of the parts begin to behave in the other direction and show a falling tendency. However, 24 portions continue to indicate a growing tendency, necessitating further monitoring for those areas

The results reveal that all sections exhibit an increasing trend of net transport in 2030 than in 2020, with 53% showing an increase in 2050 than in 2030 and 67% showing a rise in 2100. Again, in Figure 8(b), light red shows a larger net transport value in 2030, 2050, and 2100 than in 2020, whereas light blue indicates a lower value in 2030, 2050, and 2100 than in 2020. Only 10 sections have lower transport in 2100 than in 2020, and 5 sections have lower net transport in 2050 than in 2020, although all of them have more transport in 2030 than in 2020. Total net transport along the Terengganu-Kelantan coast, on the other hand, may increase by 9.5%, 10%, and 4.5% in 2030, 2050, and 2100, respectively.



Sections	2030	2050	2100	Sections	2030	2050	2100
sec-1	🟥	🟦	🟦	sec-28	🟥	🟦	🟦
sec-2	🟥	🟦	🟥	sec-29	🟥	🟦	🟦
sec-3	🟥	🟦	🟦	sec-30	🟥	🟦	🟦
sec-4	🟥	🟥	🟥	sec-31	🟥	🟦	🟥
sec-5	🟥	🟦	🟦	sec-32	🟥	🟦	🟥
sec-6	🟥	🟥	🟦	sec-33	🟥	🟥	🟥
sec-7	🟥	🟦	🟦	sec-34	🟥	🟥	🟥
sec-8	🟥	🟥	🟥	sec-35	🟥	🟥	🟥
sec-9	🟥	🟥	🟥	sec-36	🟥	🟦	🟥
sec-10	🟥	🟥	🟥	sec-37	🟥	🟦	🟥
sec-11	🟥	🟥	🟥	sec-38	🟥	🟦	🟥
sec-12	🟥	🟦	🟥	sec-39	🟥	🟥	🟥
sec-13	🟥	🟥	🟥	sec-40	🟥	🟦	🟦
sec-14	🟥	🟦	🟥	sec-41	🟥	🟥	🟥
sec-15	🟥	🟦	🟦	sec-42	🟥	🟥	🟦
sec-16	🟥	🟥	🟥	sec-43	🟥	🟥	🟥
sec-17	🟥	🟦	🟦	sec-44	🟥	🟥	🟥
sec-18	🟥	🟥	🟥	sec-45	🟥	🟥	🟦
sec-19	🟥	🟥	🟥	sec-46	🟥	🟥	🟥
sec-20	🟥	🟥	🟥	sec-47			
sec-21	🟥	🟥	🟥	sec-48	🟥	🟥	🟥
sec-22	🟥	🟦	🟦	sec-49	🟥	🟦	🟦
sec-23	🟥	🟦	🟥	sec-50	🟥	🟥	🟥
sec-24	🟥	🟥	🟥	sec-51	🟥	🟥	🟥
sec-25	🟥	🟦	🟦	sec-52	🟥	🟦	🟦
sec-26	🟥	🟦	🟥	sec-53	🟥	🟦	🟦
sec-27	🟥	🟥	🟥	sec-54	🟥	🟥	🟥

(a)

🟥	If 2030>2020, 2050>2030 and 2100>2050
🟦	If 2030<2020, 2050<2030 and 2100<2050

Sections	2030	2050	2100	Sections	2030	2050	2100
sec-1	🟥	🟥	🟥	sec-28	🟥	🟥	🟦
sec-2	🟥	🟦	🟥	sec-29	🟥	🟦	🟦
sec-3	🟥	🟦	🟦	sec-30	🟥	🟥	🟥
sec-4	🟥	🟥	🟥	sec-31	🟥	🟥	🟥
sec-5	🟥	🟦	🟦	sec-32	🟥	🟥	🟥
sec-6	🟥	🟥	🟥	sec-33	🟥	🟥	🟥
sec-7	🟥	🟥	🟥	sec-34	🟥	🟥	🟥
sec-8	🟥	🟥	🟥	sec-35	🟥	🟥	🟥
sec-9	🟥	🟥	🟥	sec-36	🟥	🟥	🟥
sec-10	🟥	🟥	🟥	sec-37	🟥	🟥	🟥
sec-11	🟥	🟥	🟥	sec-38	🟥	🟥	🟦
sec-12	🟥	🟥	🟥	sec-39	🟥	🟥	🟥
sec-13	🟥	🟥	🟥	sec-40	🟥	🟥	🟥
sec-14	🟥	🟥	🟥	sec-41	🟥	🟥	🟥
sec-15	🟥	🟥	🟥	sec-42	🟥	🟥	🟥
sec-16	🟥	🟥	🟥	sec-43	🟥	🟥	🟥
sec-17	🟥	🟥	🟦	sec-44	🟥	🟥	🟥
sec-18	🟥	🟥	🟥	sec-45	🟥	🟥	🟦
sec-19	🟥	🟥	🟥	sec-46	🟥	🟥	🟥
sec-20	🟥	🟥	🟥	sec-47			
sec-21	🟥	🟥	🟥	sec-48	🟥	🟥	🟥
sec-22	🟥	🟥	🟦	sec-49	🟥	🟥	🟥
sec-23	🟥	🟥	🟥	sec-50	🟥	🟥	🟥
sec-24	🟥	🟥	🟥	sec-51	🟥	🟥	🟥
sec-25	🟥	🟦	🟦	sec-52	🟥	🟥	🟥
sec-26	🟥	🟥	🟥	sec-53	🟥	🟥	🟦
sec-27	🟥	🟥	🟥	sec-54	🟥	🟥	🟥

(b)

🟥	If 2030>2020 and 2050>2020
🟦	If 2030<2020 and 2050<2020

Figure 8. Pattern of change in net transport due to sea level rise

However, because net transport is entirely dependent on bathymetry and sediment statistics, this pattern may not be relevant to other coastal areas. The same bathymetry, on the other hand, was utilised to determine the total net transport value for 2030, 2050, and 2100. Bathymetry may also fluctuate over time, as may net transport. A long-term anticipated bathymetry might also help.

7. Conclusion

The transportation of sediment along a coastline caused by wave action is known as longshore sediment transport, and its value is determined by the wave angle and cross-shore bathymetry. This phenomenon shapes the geography of a coastline through erosion and deposition patterns, as well as shoreline movement. In this study, we calculated longshore sediment movement to develop a baseline characteristic of the Terengganu and Kelantan coastlines, which aids in identifying the erosion-deposition prone area along the shoreline. On the other hand, climate change, particularly sea level rise, has a huge impact on all seas and cannot be disregarded. So, using AR6, we attempted to calculate the changes in longshore patterns in the following years (2030, 2050, and 2100). Model results reveal that there is a rising tendency for longshore transport until 2030, and then certain areas show a falling trend; by year 2050 and 2100, 53% and 67% of sections respectively. Total net transport along the Kelantan-Terengganu coast, on the other hand, may increase by 9.5%, 10%, and 4.5% in the year 2030, 2050, and 2100, respectively. According to the study findings, there is a propensity for longshore transport to shift due to sea level rise, which may change the erosion-deposition pattern and coastline movement in the near future. This research can be utilised to predict future shoreline changes along the Terengganu and Kelantan coasts.

References

[1] Seymour RJ. Longshore Sediment Transport. In: Schwartz M.L. (eds) Encyclopedia of Coastal Science. Encyclopedia of Earth Science Series. Springer, 2005, Dordrecht. https://doi.org/10.1007/1-4020-3880-1_199

[2] Mueller A. Modelling Longshore Sediment Transport, 2012, Technical Report. Available from https://www.researchgate.net/publication/280944048

[3] Abdullah S. Coastal Developments in Malaysia – Scope, Issues and Challenges by Dato’ Ir. Hj. Shahrizaila Bin Abdullah’, 1993.

[4] Fazly AM, Khairul NAM, Othman AK, Rawshan AB, Awang NA, Ahmad A. Comprehensive Coastal Vulnerability Assessment and Adaptation for Cherating-Pekan Coast. 2019 Pahang, Malaysia’, Ocean Coast. Manag., vol. 182.

[5] Ariffin EH, Sedrati M, Akhir MF, Yaacob R, Husain ML. Open sandy beach morphology and morphodynamic as response to seasonal monsoon in Kuala Terengganu, Malaysia. Journal of Coastal Research. 2016;75(sp1):1032–6.

[6] Ariffin EH. Effect of Monsoons on Beach Morphodynamics in the East Coast of Peninsular Malaysia: examples from Kuala Terengganu coast. Environmental Science [Internet]. 2017 Sep 28 [cited 2022 Nov 9]; Available from: https://www.semanticscholar.org/paper/Effect-of-Monsoons-on-Beach-Morphodynamics - in- the-%3A-Ariffin/a76e171c 63ca5597af38fcad1cc6211f064a7ee2#citing-papers

[7] Ehsan S, Begum RA, Ghani MNN, Nizam AMK. Current and potential impacts of sea level rise in the coastal areas of Malaysia. IOP Conference Series: Earth and Environmental Science. 2019. 228:012023

[8] Zolkiply ZI. When will the Coastal Erosion Problem End?, Retrieved from: Berita Harian, Kuala Terengganu, Sep-2018.

[9] Hamid AI, Din AH, Hwang C, Khalid NF, Tugi A, Omar KM. Contemporary sea level rise rates around Malaysia: Altimeter Data Optimization for Assessing Coastal Impact. Journal of Asian Earth Sciences. 2018.166:247–59.

[10] Ali Khan MM, Shaari NA, Bahar AMA, Baten MA. Impact of the flood occurrence in Kota Bharu, Kelantan using statistical analysis. Journal of Applied Sciences. 2014. 14(17):1944–51.

[11] Dee DP, Uppala SM, Simmons AJ, Berrisford P, Poli P, Kobayashi S, Andrae U, Balmaseda MA, Fazly AM, Khairul NAM, Othman AK, Rawshan AB, Khan MF, Jaafar WSWM, Sharifah MSA, Toriman ME, Kamarudin MKA, Gasim MB, and Wahab NA. An Assessment of Coastal Vulnerability of Pahang’s Coast due to Sea Level Rise, 2018, Int. J. Eng. Technol., vol. 7, no. 3.14, pp. 196–201.

[12] Cheng YC, Andersen OB. Improvement in global ocean tide model in shallow water regions. 2010, Poster, SV.1-68 45, OSTST, Lisbon, Oct.18-22.

[13] Williams JJ, Esteves, LS. Guidance on setup, calibration, and validation of hydrodynamic, wave, and sediment models for shelf seas and estuaries. Advances in Civil Engineering, 2017, pp. 1–25. Available at: https://doi.org/10.1155/2017/5251902.

[14] European Centre for Medium-Range Weather Forecasts. 2016. Shinfield Park, England: ECMWF.

[15] Fredsøe J. Turbulent Boundary Layers in Combined Wave Current Motion. Journal of Hydraulic Engineering, ASCE. 1984. Vol. 110, No. HY8, pp. 1103-1120.

[16] Bagyaraj M, Bhuvaneswari M, Priya BN. The high/low rainfall fluctuation mapping through GIS technique in Kodaikanal Taluk, Dindigul, District, Tamil Nadu. Int. J. Adv. Res. 3 (11). 2015. 1606–1613.

[17] Ariffin EH, Sedrati M, Daud NR, Mathew MJ, Akhir MF, Awang NA, et al. Shoreline Evolution under the influence of Oceanographic and monsoon dynamics: The case of Terengganu, Malaysia. In: Mu. Ramkumar, R. Arthur James, David Menier and K. Kumaraswamy (eds.) Coastal Zone Management. Burlington: Elsevier, 2019. pp. 113-130.

[18] DID, Ministry of Natural Resources and Environment (NRE). National Coastal Erosion Study for Malaysia 2015 Volume 1: Executive Summary. Kuala Lumpur, Federal of Kuala Lumpur: DID. 2016 p. ES-15-ES-19.

[19] Fox-Kemper B, Hewitt HT, Xiao C, Aðalgeirsdóttir G, Drijfhout SS, Edwards TL, Golledge NR, Hemer M, Kopp RE, Krinner G, Mix A, Notz D, Nowicki S, Nurhati IS, Ruiz L, Sallée JB, Slangen ABA, Yu Y. Ocean, Cryosphere and Sea Level Change. In Climate Change 2021, The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [MassonDelmotte, Zhai VP, Pirani A, Connors SL, Péan C, Berger S, Caud N, Chen Y, Goldfarb L, Gomis MI, Huang M, Leitzell K, Lonnoy E, Matthews JBR, Maycock TK, Waterfield T, Yelekçi, O, Yu R, and Zhou B. Cambridge University Press. In Press.

[20] Stive M. How Important is Global Warming for Coastal Erosion?, Climate Change.2004. 64, pp. 27–39. Available at: https://doi.org/10.1023/B:CLIM.0000024785.91858.1d.

[21] Hugo PM. The impact of climate change effects on the planform of a headland-bay beach on the southern coast of South Africa. dissertation. SUNScholar.2013

[22] Bramante JF. et al. Sea level rise will drive divergent sediment transport patterns on fore reefs and reef flats, potentially causing erosion on Atoll Islands. Journal of Geophysical Research: Earth Surface. 2020. 125(10). Available at: https://doi.org/10.1029/2019jf005446.

[23] De Winter R.C, Ruessink BG. Sensitivity analysis of climate change impacts on dune erosion: Case study for the Dutch Holland Coast, Climatic Change. 141(4). 2017. pp. 685–701. Available at: https://doi.org/10.1007/s10584-017- 1922-3.

[24] De Schipper M.A. et al. Initial spreading of a mega feeder nourishment: Observations of the Sand Engine Pilot Project. Coastal Engineering, 111. 2016. pp. 23–38. Available at: https://doi.org/10.1016/j.coastaleng.2015.10.011.

[25] Dee DP, Uppala SM, Simmons AJ, Berrisford P, Poli P, Kobayashi S, et al. The ERA-Interim reanalysis: configuration and performance of the data assimilation system. Quarterly Journal of the Royal Meteorological Society (QJRMS) [Internet]. 2011Apr 28 [cited 2022 Nov 9];137(656):553–97. Available from: https://rmets.onlinelibrary. wiley.com/doi/epdf/10.1002/qj.828

Acknowledgments

The authors would like to express their appreciation for the cooperation on data collection, analysis, reports, and technical support provided by research officers and research assistant teams of the Research Centre for Coastal and Oceanography (PKPO), NAHRIM, which has been given the trust of KASA in conducting this study successfully. Author also would like to express a gratitude to all authors, especially to Senior Coastal Modeller, Hydroinformatics Institute (H2i), Singapore that continuously contributes in this paper. A huge thanks too for all anonymous reviewers for the constructive comments and suggestions in improving this manuscript