VOL 4, NO.2 (2024) 104-123
https://jagst.utm.my

JAGST
Journal of Advanced Geospatial Science & Technology

Simulation of Sea Level Rise at Major Town of East Coast of Peninsular Malaysia

Isfarita Ismail[1], Mohd Lokman Husain[3], Ejria Saleh[1,2*], Mohamed Shawal M. Muslim[3]
[1]Borneo Marine Research Institute, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia
[2]Natural Disaster Research Centre, Faculty of Science and Natural Resources, Universiti Malaysia Sabah, Jalan UMS, 88400, Kota Kinabalu, Sabah, Malaysia
[3]Institute of Oceanography and Environment, Universiti Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu, Malaysia

*Corresponding author: ejsaleh@ums.edu.my

Abstract – Global warming is caused by greenhouse gases resulting from natural causes and human activities. This event causes the sea level rise (SLR). The effects of SLR are the submerging of an area, saltwater intrusion, erosion, and the destruction of infrastructure and marine ecosystems. The objectives of this study are to identify the year when the sea water level rises 1 m, 2 m, and 3 m and to estimate inundated areas that are affected by floods at different sea water level scenarios at major towns of East Coast Peninsular Malaysia. The major cities selected are Kota Bharu, Kuala Terengganu, Kuantan, and Kota Tinggi, with a study site area of 96 km^2, 38 km^2, 16 $km^{2,}$ and 10 km^2, respectively. Study site selection is based on the high concentration of socioeconomic (quality of life, economic value, and infrastructure). The SLR of 1 m, 2 m, and 3 m was based on tidal data and IFSAR data for the SLR simulation. The data collected were analyzed using ERDAS 2011 and ArcGIS software. Based on the 1 m to 3 m SLR, the water level is predicted to occur from 2319 to 2374 for all study areas. Results indicate that Kota Bharu is the most affected by the 1, 2, and 3 m SLR, with an inundation area of 15%, 37%, and 60% of its total study area. For 1 m SLR, just 5% of the total study area will be inundated in Kuala Terengganu, but this will increase to 51% when the water level rises to 3 m. Kuantan and Kota Tinggi are located on higher ground, where an increase in seawater level to 3 m will affect about 40% of the study area. Other factors related to extreme events or/and human activities would be accelerating sea-level rise to severe impacts on low-lying over a short period.   However, information on SLR projection at the local level is indeed part of the future coastal management and town development. Adaptation options and flood mitigation for the most affected area should be considered to minimize the impact of SLR.

Keywords *– Sea level rise, inundation area, major town, East Coast of Peninsular Malaysia*

Article History: Received 3 July 2024, Accepted 8 August 2024, Published 31 August 2024

How to cite: Ismail, I., Husain, M. L., Saleh, E. and Muslim, M. S. M. (2024). Simulation of Sea Level Rise at Major Town of East Coast of Peninsular Malaysia. Journal of Advanced Geospatial Science and Technology. 4(2), 104-123.

1.0 Introduction

Over the last few centuries, global warming has contributed to seawater warming, thermal expansion, and melting glaciers in polar regions. This warming contributes to the global sea-level rise (SLR). The physical consequences of SLR can be broadly classified into shoreline erosion, temporary flooding, and saltwater intrusion in the coastal area. The most apparent result of an SLR in the coastal area is coastal flooding (inundation) of low-lying areas and small islands (IPCC, 2013; Mimura, 1999; Heberger et al., 2009). SLR is also displacing the coastal population due to loss of land and change in the sedimentary process (EPU, 1992; Mimura, 2013). There are various methods to predict SLR. It can be estimated using the values of a global SLR from greenhouse climate warming models (Warrick & Oerlemans, 1990; Church et al., 2000), worldwide tide gauge records (IPCC, 2007), glacier ice flow dynamic (Pfeffer et al., 2008), the relationship between changes in sea level and global temperature (Rahmstorf, 2007; Grinsted et al., 2010), and climate or simulation model (Church & White, 2006; Mohd, 2018).

SLR can be simulated and predicted to estimate the inundation area by coastal flooding. SLR research was carried out worldwide (Kont et al.,1997; Heberger et al.,2009; Rowley et al., 200; Yoskowitz et al.,2009), but only a few studies were done in Malaysia. For example, Din et al. (2012) predicted SLR using data from DSMM for 15 years and linear regression analysis. Omar et al. (2006) reported that the SLR in Malaysia is estimated at 1 mm/year based on satellite altimetry. The estimated SLR value is slightly high (between 1.2-2.6 mm/year) based on satellite altimetry data (1993-2010) and the Atmospheric-Oceanic General Circulation Model (AOCGM) (NAHRIM & CHRL, 2010).

The SLR inundation area can be identified from the SLR scenario. Data from multiple altimeter missions over 1993-2015 shows that the SLR trends around Malaysia range from 3.27 ± 0.12 mm yr-1 off eastern Malaysia to 4.95 ± 0.15 mm yr-1 west of Malaysia (Hamid et al., 2018). Generally, SLR can be simulated to identify the inundated area and determine its impacts at different water levels. Simulating and predicting the effect of SLR is essential for quantifying the percentage of flooding and arranging strategies to reduce or prevent damage from SLR.

The rising sea level phenomena have significant long-term impacts on the coastal area, and their severity depends on the coastal regions' local tidal levels, topography, climatology, and vulnerability (Faour et al., 2013; Ismail et al., 2018). The SLR impacts coastal land with assets, critical economic sectors, and social, cultural, and ecological values. For example, coastal erosion, inundation of low-lying areas, and saltwater intrusion put millions of lives and billions of dollars worth of properties and infrastructures at risk. MOSTE (2000) estimated the economic costs from socioeconomic impacts based on the high rate of SLR (0.9 cm/year) in Malaysia, which projected the agricultural production loss at RM46 million from eroded/inundated lands in the Western Johor Agricultural Development Project area. Therefore, to offset the damage due to climate change, adaptation strategies are necessary measures that refer to any adjustments to human activities that reduce the vulnerability of humans and ecosystems to climate change impacts (IPPC, 2007). The objective of this study is to produce a potential SLR inundation map and to estimate submerged areas by different levels of SLR. Potential SLR inundation maps can assess the population, road systems, and other inundated regional infrastructures.

2.0 Materials and Methods

The East Coast of Peninsular Malaysia consists of four states: Kelantan, Terengganu, Pahang, and Johor. Most major towns in these states are located in low-lying areas and are known to have high populations, business centres, and agricultural regions. The city developed within the estuaries and closer to the riverbanks (Figure 1). In this study, the SLR of four major towns, Kota Bharu (Kelantan), Kuala Terengganu (Terengganu), Kuantan (Pahang) and Kota Tinggi (Johor), was analyzed from local tidal stations data (Table 1). The estimated annual rate of SLR data from the tidal stations located in Geting, (6^{o}13’35” N, 105^{o}06’24” E) Kelantan, in Chendering, (5^{o}15’54” N, 103^{o}11’12” E) Terengganu, in Tanjung Sedili (5^{o}’54”N, 104^{o}06’54”E), Pahang and Tanjung Gelang, (3^{o}58’30”N, 103^{o}25’48”E) Johor are 1.73 mm, 3.20 mm, 2.64 and 1.83 mm, respectively (Din et al., 2012). The SLR annual rate of each station was simulated for 1 m, 2 m, and 3 m water levels to determine the inundation area of the four towns. The year sea level increased to a meter was calculated using ERDAS 2011 and ArcGIS 2010 software.

The prediction scenarios of SLR were set up for 1 m, 2 m and 3 m by assuming the SLR as a linear trend. Using the data from the Department of Survey and Mapping Malaysia (DSMM), the SLR change is 3.2 mm/year (DSMM, 2008). The main variable to simulate SLR is the contour line around the town. The contour lines were extracted from the Interferometric Synthetic Aperture Radar (IFSAR).

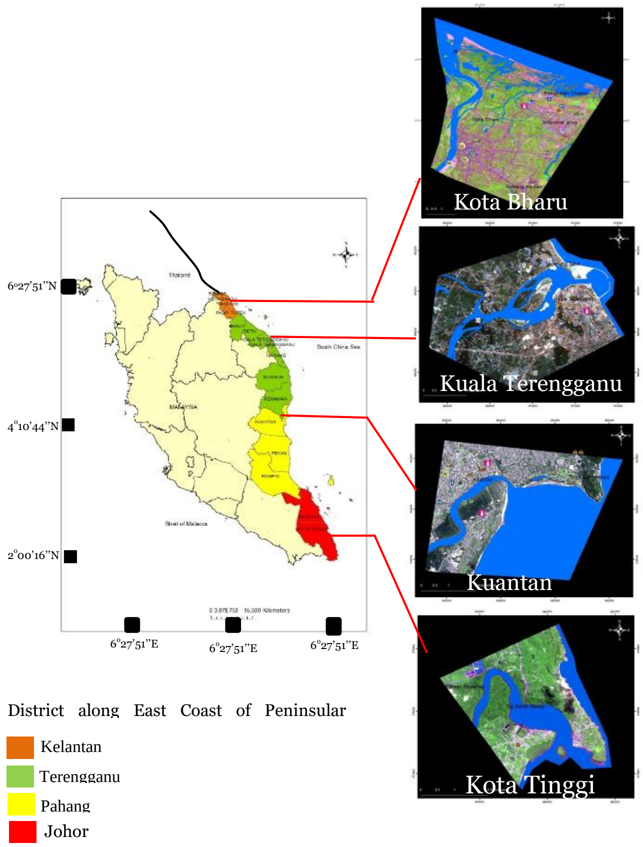
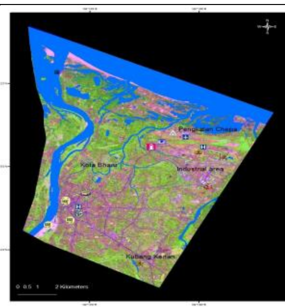
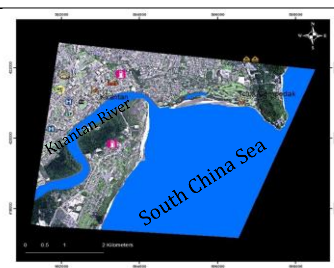
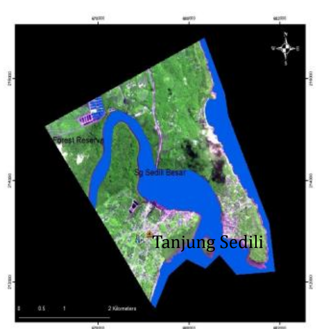


Figure 1. Location of major town on the East Coast of Peninsular Malaysia for SLR simulation. Images indicate that the city is located within the coastal areas.

The low contour value indicates plat areas are prone to coastal flooding. The simulation of SLR at 1 m, 2 m, and 3 m was carried out using digital elevation model data from IFSAR. The simulation of SLR was presented as a dimensions map. The coverage area for SLR simulation in Kota Bharu, Kuala Terengganu, Kuantan, and Kota Tinggi are 96 km^2, 38 km^2, 16 km^2 and 10 km^2, respectively (Table 1). The size of the simulation coverage area for each town was determined based on its socioeconomic status, such as quality of life, economic value, and infrastructure (Ismail et al., 2020). The percentage of inundation areas at different water levels was also calculated to estimate the impacts of SLR.

Table 1. Map description of four significant towns on the East Coast of Peninsular Malaysia.

Town/Tide gauge station/ SLR change (Din et al. 2012).	**Map (data from IFSAR)/ Coverage area (km^2)**	**Description of the study area**
Kota Bharu/ Geting/ 1.73 mm/year	 Coverage area 96 km^2	Kota Bharu and adjacent areas included the Kelantan River, administrative, industrial, and other important buildings.
Kuala Terengganu /Chendering/ 3.20 mm/year	 Coverage area 38 km^2	Kuala Terengganu covers the capital city and consists of administrative buildings adjacent to the Terengganu River estuary, nearby housing areas and villages such as Kg. Seberang Takir, Kg. Losong, Kg. Paloh, and Kg. Paya.
Kuantan/ Tanjung Sedili/2.64 mm/year	 Coverage area 16 km^2	Kuantan is the capital city of Pahang, where the administrative buildings are located. It comprises important infrastructures like the Kuantan River, villages, and mangrove forests.
Kota Tinggi/ Tanjung Gelang/ 1.83 mm/year	 Coverage area 10 km^2	Kota Tinggi area consists of the Tanjung Sedili estuary and villages such as Kg. Tanah Puteh and Kg. Teluk Jeri.

A simulation of sea level rise along the east coast of Peninsular Malaysia was carried out using IFSAR elevation data with a 5 m elevation based on local data. This simulation was produced based on SLR scenarios in Malaysia. The raw IFSAR data was converted to '.TIF' format using ArcGIS. The '.TIF' file was opened using ERDAS 2011 and later processed as a Digital Elevation Model (DEM). The IFSAR data was shaped into DEM data, representing either a raster or a vector-based triangular irregular network (TIN).

To improve data visualization, raster data from SPOT satellite images was used as an overlay on the IFSAR data. These satellite images help to display the data more effectively. Once the data was prepared, the simulation of SLR for each 1 m increment could begin. In theory, the 100% reference is based on the DEM data. For example, the area covered by a 1 m water level corresponds to regions with a lower elevation of 1 m. A 'water layer' file was created in ERDAS 2011 to produce the simulation. Values were added to the water elevation properties to observe changes in water level.

3.0 Results and Discussion

3.1 Prediction Year of SLR at Different Water Levels

The scenarios of SLR for 1 m, 2 m and 3 m are predicted for the major town on the East Coast of Peninsular Malaysia based on Din et al. (2012). Assuming the SLR as a linear trend, the SLR increases to 1 m would likely occur in the year 2319 to the year 2585 (Table 2) along the East Coast of Peninsular Malaysia. If the SLR increases to 2 m, it is likely to happen from the year 2632 to year 3163, and the 3 m water level is expected from year 2944 to year 3741. The potential inundation predicted by SLR may increase with a change of rainfall regime, and storms result from cyclical monsoons bringing heavy and regular rainfall and inadequate drainage systems to curb the excessive rainfall intensifying flooding problem (Ehsan et al., 2019; Ho, 2009).

Hamid et al. (2018) identified from multiple altimeter missions that from 1993-2015, the mean SLR around Malaysia was 4.22± 0.12 mm yr-1. However, the SLR in Malaysia is varied by state. The SLR rate on the East Coast of Peninsular Malaysia was identified as decreasing from Kelantan to Johor (Awang & Abd. Hamid, 2013; NAHRIM & CHRL, 2010). The SLR rate in Kelantan waters varies between 5.02 and 5.70 mm/year and is reduced to 4.29 mm/year in Terengganu waters. The SLR rate in the coastal waters of Pahang and Johor is 3.46 mm/year and 2.7 mm/year, respectively.

Table 2. Prediction year of SLR for 1 m, 2 m, and 3 m at the major town on the East Coast of Peninsular Malaysia.

Town (State)	SLR change (mm/year). Din et al. (2012)	Scenarios of SLR (Year)		
		1 m	2 m	3 m
Kota Bharu (Kelantan)	1.73	2585	3163	3741
Kuala Terengganu (Terengganu)	3.20	2319	2632	2944
Kuantan (Pahang)	2.64	2386	2765	3143
Kota tinggi (Johor)	1.83	2553	3100	3646

3.1.1 Inundation Area of Kota Baharu Based on 1- 3 m SLR

SLR projection for low-lying areas in Kelantan is estimated to be 0.25 - 0.5 m by the year 2100 (NAHRIM & CHRL, 2010). The impacts of SLR in Kota Bharu, Kelantan for 1 m, 2 m, and 3 m are varied based on the topographic formation of the area (Figure 2a-c). The SLR at 1 m in Kota Bharu will be expected to occur by 2585 (Table 2). Based on the 96 km^2 of Kota Bharu area, about 15% or 14.59 km^2 of the area will be inundated at 1 m SLR. The areas predicted to be inundated in this 1 m SLR scenario are mainly located at estuaries and riverbanks (Figure 2a). These include Kg. Teluk Katak, Kompleks LKIM Kuala Besar, Che Da Resort Kelantan, Kg. Semut Api, Kg. Padang Jambu, Kg. Tok Kaya and infrastructures such as Pantai Cahaya Bulan, HB Village, Pantai Sabak and aquaculture ponds near Sg. Pengkalan Chepa (Figure 2). Pantai Sabak is one of the famous tourist spots at Kota Bharu (ESI, 2010).

The inundated area in Kota Bharu will increase to 37% (35.45 km^2) of the total city area if the SLR increases to 2 m. The inundated area will be extended to Kg. Bharu, Kg. Pulau Pasir, Kg. Pengkalan Chepa, Alkaramah Mosque, Kg. Baung, Kg. Kubang Tuman, Kok Keli primary school, jetty near Sg. Kelantan (Figure 2b). The SLR is expected to occur by the year 3163.

The simulation of SLR at 3 m in Kota Bharu is expected to occur in year 3741. The inundation area is anticipated to be up 60% (57.94 km^2) of the city areas and affected Kg. Padang Pasir Luas, Kg. Tok Betek, Taman Uda Murni, Masjid Mukim Chekok Panji, Kg. Lundang, Universiti Sains Malaysia (USM) Health Campus, Universiti Malaysia Kelantan (UMK) Faculty of Agro-Industry and Natural Resources, Sg. Pinang secondary school, Pantai Senok primary school and similar areas with 2 m SLR (Figure 2c). Awadalla and M-Noor (1991) predicted that a

15% increase in rainfall would raise the flood peak around Kelantan River. The remaining dry areas are The Sultan Ismail Petra Airport and 8 Brigade Army Camp, administrative buildings, and several villages such as Kg. Dusun Muda, Kg. Paya Bahagia and other vital infrastructures. These areas are located on higher ground than other parts of Kota Bharu.

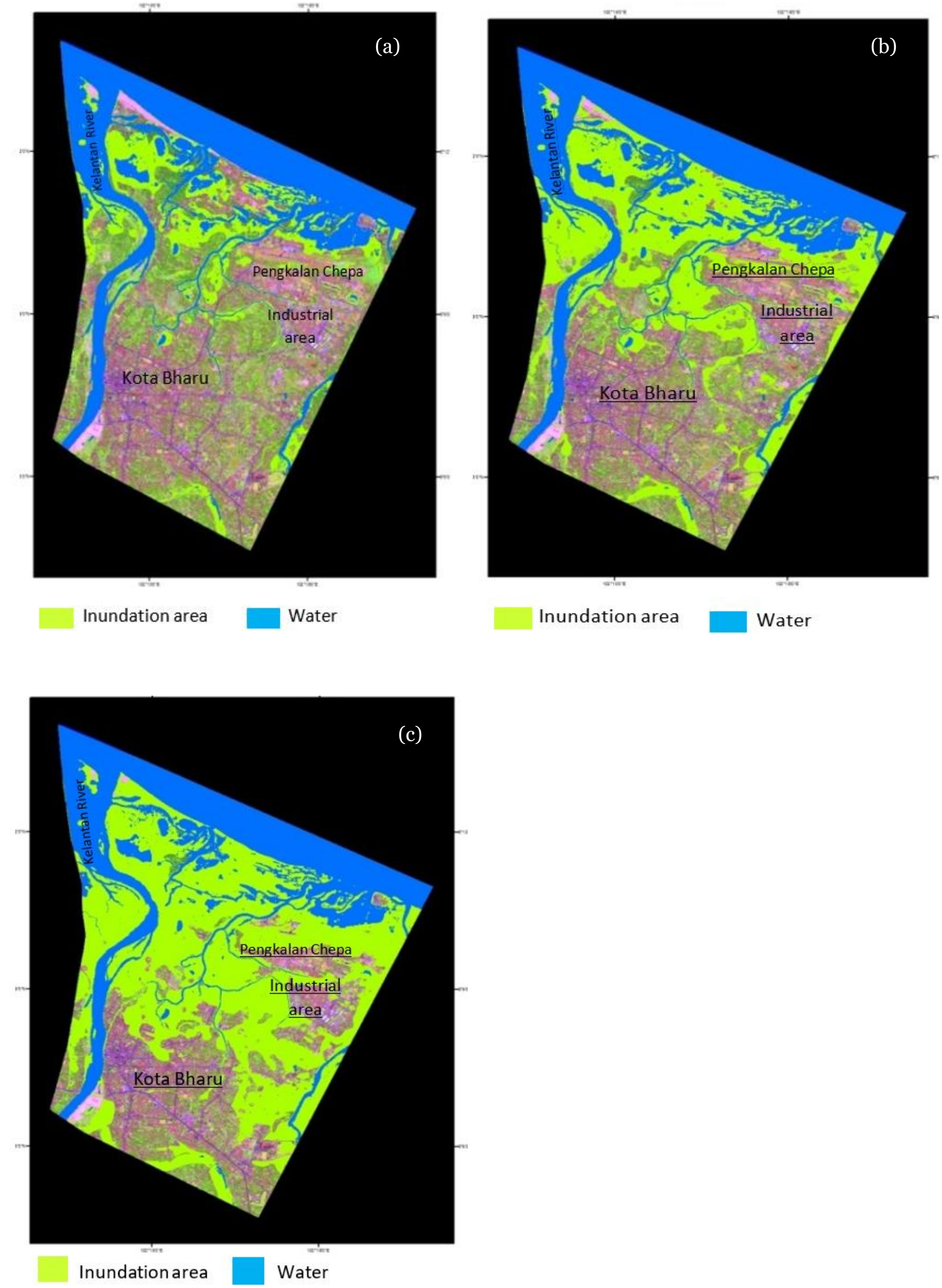


Figure 2. Simulation of 1m (a), 2 m (b) and 3 m (c) inundation area based on 1.73 mm/year SLR (Din et al., 2012) in Kota Bharu.

3.1.2 Inundation Area of Kuala Terengganu Based on 1- 3 m SLR

The rate of SLR in Kuala Terengganu is estimated at 3.2 mm/year (Din et al., 2012). Assuming the SLR as a linear trend, the 1 m, 2 m and 3 m of SLR are expected to be in the years 2319, 2632 and 2944, respectively (Table 1). About 38 km^2 of the city area was assessed in this study. A 1 m sea level increase will inundate about 1.57 km^2 (4%) of the city area. The affected area is adjacent to the Terengganu River, Pulau Besar, near the Sultan Mahmud Bridge and Kg. Paloh and Sg. Rengas (Figure 3a). Based on the 147 km^2 study area in Kuala Terengganu, an SLR of 1 m will affect about 7.15 km^2 (5 %), 6.81 km^2 (18%) and 5,000 people (14%) of the study area, development area and population, respectively (Ehsan et al., 2019).

The inundation area will be increased to double if SLR to 2 m. It will affect about 7.61 km^2 (20 %) of the lowland areas (Figure 3b), including the Kg. Pulau Duyung Besar, Pulau Endok, Kg. Pulau Wan Man, Kg. Pulau Besar, Kg. Pulau Tok Hakim, Kg. Pulau Tengah and Kg. Pulau Che Yok. The other place further inland that will be inundated is Kg. Paloh, Kg. Sekati, Kg. Tanjung Bunut, Kg. Losong Pasir, all Kg. Losong (Panglima Perang, Haji Awang, Wan Nik, Masjid) areas, Kg. Hiliran, Kg. Tanjung Bunut, Kg. Leban, Kg. Seberang Bukit Tumbuh, Kg. Seberang Cik Haji, Kg. Pengkalan Batu and Kg. Banggol Tuan Muda. Darul Syakirin and Kg. Gong Pantai is a recreational area affected by the flood.

The inundated area increases to 51% (19.31 km2) of the study area to areas where the SLR increases to 3 m (Figure 3b). The Terengganu River will overflow to adjacent lowland areas. The inundated areas will be extended to Kg. Pulau, Che Long, Pak Kub, Duyung Kecil, Sekati, Kambing, Kg. Losong (Dato Amar, Feri, Atap Zin), Kg. Hiliran Surau, Kg. Tiong, Kg. Panglima, P. Pak Soh, Kg. Seberang Takir, Kg. Gong Kijang, Kg. Bukit Tunggal, Kg. Paya Datu, Kg. Buluh Gading, Kg. Padang Buluh Gading, Kg. Teluk Pasu and Kg. Banggul areas. Landmarks in city areas such as Crystal Mosque, Islamic Heritage Park, Giant Hypermarket, and Mydin Mall will also be affected.

Meanwhile, the area that survives at a 3 m sea level are expected to be the administration buildings, infrastructures in Bukit Puteri, Hotel Sri Malaysia, Hospital Besar Kuala Terengganu, and several villages such as Kg. Teluk Ketapang, Kg. Surau Besar, Kg. Ladang Padang Cicar, Kg. Ladang Tok Pelam and small area of Kg. Batu Enam.

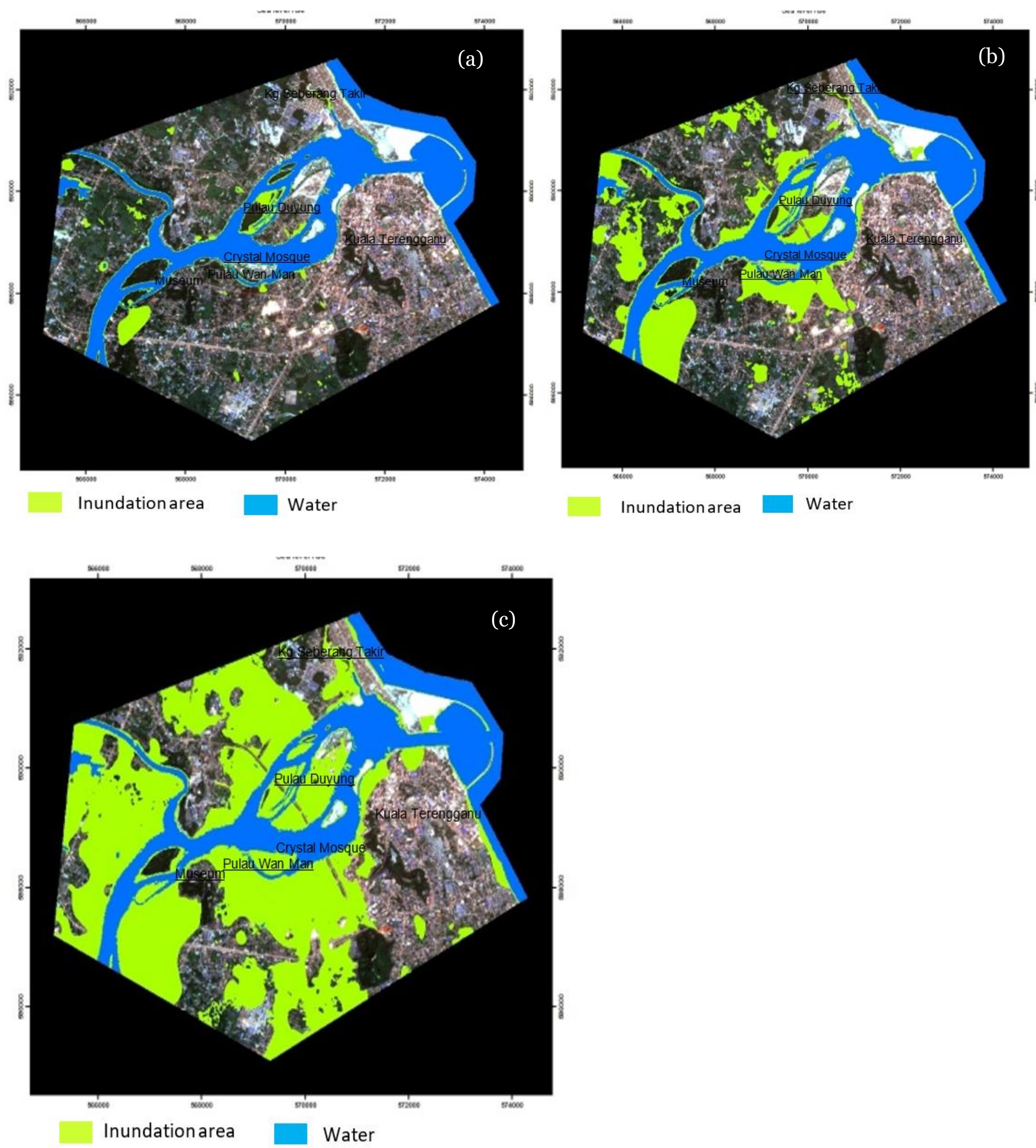


Figure 3. Simulation of 1m (a), 2 m (b) and 3 m (c) inundation area based on 3.2 mm/year SLR (Din et al., 2012) in Kuala Terengganu.

3.1.3 Inundation Area of Kuantan Based on 1- 3 m SLR

Kuantan is the biggest town in Pahang, and sea level change would be at a rate of 2.64 mm/year (Din et al., 2012). Mohd et al. (2018) identified the potential of coastal inundation areas due to SLR for 2020 and 2080 along the Cherating to Pekan shoreline, affecting the socioeconomic and livelihood of the seaside community. The expectation of water increases in Kuantan for 1,2 and 3 m is by the years 2386, 2765 and 3143, respectively (Table 2).

Small areas (3 %) or 0.56 km^2 are affected by 1 m SLR within 30 km^2 of the Kuantan area. The inundated area that will be affected is Kg. Selamat and infrastructures such as Surau Galing Kecil and Pantai Selamat Supermarket (Figure 4a). However, the inundated area increases to 2.15 km^2 (14 %) when SLR increases to 2 m. The residential areas affected are Taman Plaza, Taman Suria, and Kg. Tanjung Lumpur, Taman Teruntum, and part of Kg. Peramu Maju. Infrastructures such as the International School of Kuantan, the Botanical Garden and the Royal Pahang Polo Club Pekan are also affected (Figure 4b).

About 41% or 6.44km^2 of the study area comprises many villages, and infrastructures are flooded when SLR is up to 3 m (Figure 4c). The affected area is IKIP International College (IIC), Pantai Tanjung Sisek, Tok Sira Mosque, Kuantan District Health Office, Taman Kuantan, Taman Orchid, Taman Ngit Sin, Taman Ah Heng, Taman Eastern, Taman Happy, Taman Ruby, Taman Galing Park, Padang Lalang industrial area, Vistana Hotel, Sri Malaysia Hotel, Taman Bakti, Taman Kingdom, Suria Cherating Beach Resort, Kg. Peramu, Kg. Peramu Hulu, forest reserve area near Sg. Belat and Tanjung Santai. The central coastal tourism spots in Cherating and Teluk Cempedak (ESI, 2010) are also affected by the 3 m SLR. Tourism is a significant source of income for the state. Ismail et al. (2020) identified that Kuantan has a very high value ranking (12.70 out of 15.00 value) on the Socioeconomic Vulnerability Index (SeVI). The remaining area and structures free from 3 m SLR are administration buildings in Kuantan Town, such as Kuantan District Police Headquarters, Stadium Darul Makmur, residency (Taman Fairmount, Taman Mahsuri), and hotels such as Hyatt Regency Kuantan and Central Hotel area (Figure 4c).

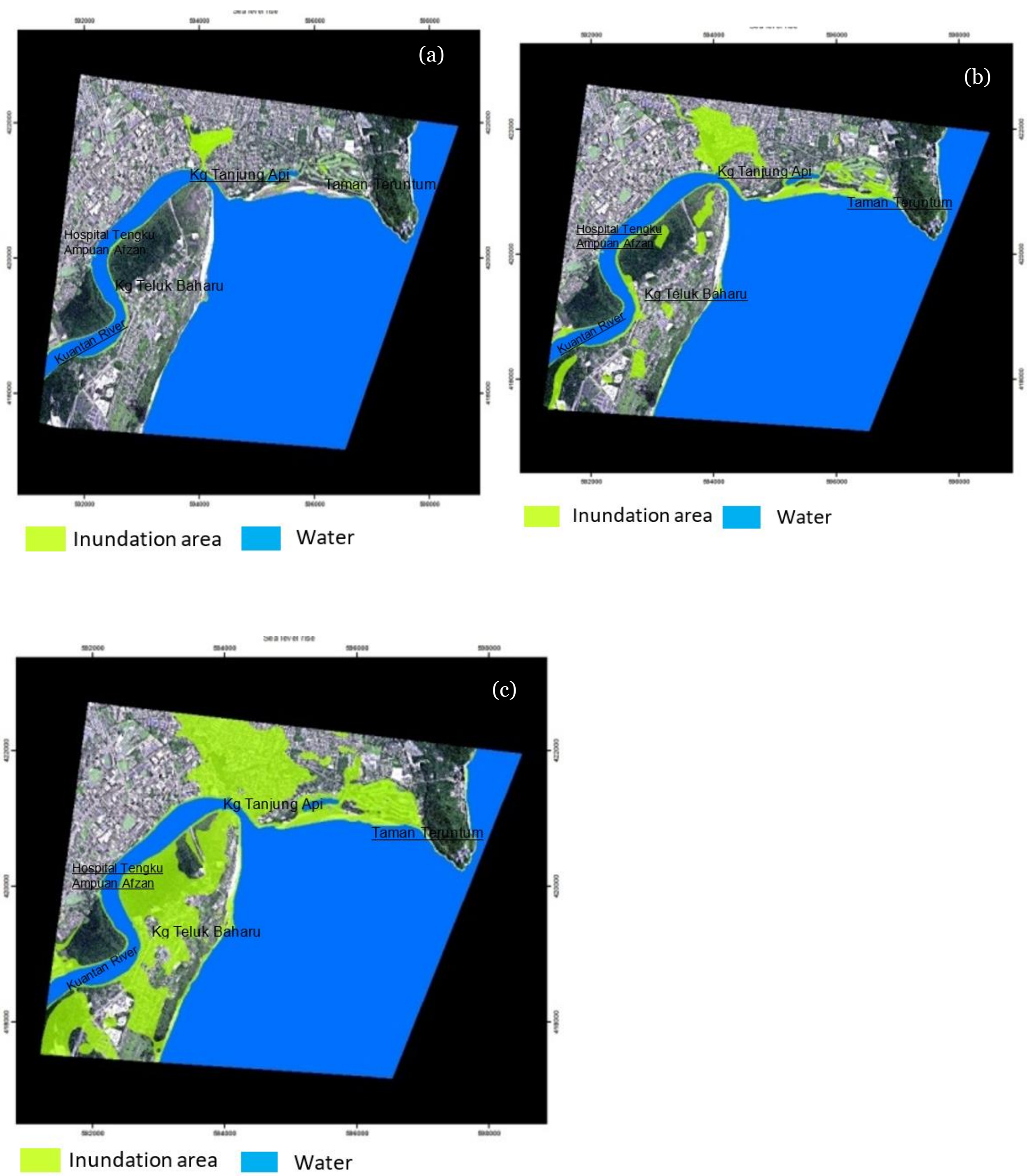


Figure 4. Simulation of 1m (a), 2 m (b) and 3 m (c) inundation area based on 2.64 mm/year SLR (Din et al., 2012) in Kuantan.

3.1.4 Inundation Area of Kota Tinggi Based on 1- 3 m SLR

Johor is Malaysia's third biggest state economy, with a GDP of RM104.4 billion, accounting for 9.4% of Malaysia's GDP (Ehsan et al., 2019). Ismail et al. (2018) stated that the physical vulnerability index at Kota Tinggi is low, with a 21.51 index. The Kota Tinggi area is only 13 km^2, consisting of mangrove forests, aquaculture activities and village areas. Din et al. (2012) estimated the SLR is 1.83mm/year. Based on this value, the SLR is projected to increase at 1 m, 2 m and 3 m by 2553, 3100 and 3646 respectively (Table 2).

An inundation area for 1 m water level will affect 1.01 km^2 (10%) out of 13 km^2 of the Kota Tinggi area. The affected area is adjacent to the Sg. Sedili Besar and the aquaculture activities in Kota Tinggi (Figure 5a). In 3100, the inundation area will be 3.46 km^2 (34%), flooding the Kuala Sedili Forest Reserve, part of Kg. Tanah Puteh, Kuala Sedili Jetty when the SLR increases to 2 m (Figure 5b). The SLR will affect about 22% of 5.68 km^2 of the study area when increased to 3 m. This will affect the Kg. Tok Jeri (Figure 5c). Fisheries and tourism are the primary economic resources in Kota Tinggi. The coastal communities from Kg. Wakap, Kg. Ramunia, Kg. Gambu, Kg. Pungal, Kg. Setajam, Kg. Tanjung Balau, Kg. Tanjung Sedili, Kg. Tai Hong, Kg. Lipat Kajang and Kg. Baru Sungai Mas contributes to fisheries. Tourism activities are in Tanjung Balau, Pantai Teluk Mahkota and Pantai Teluk Ramunia (ESI, 2010).

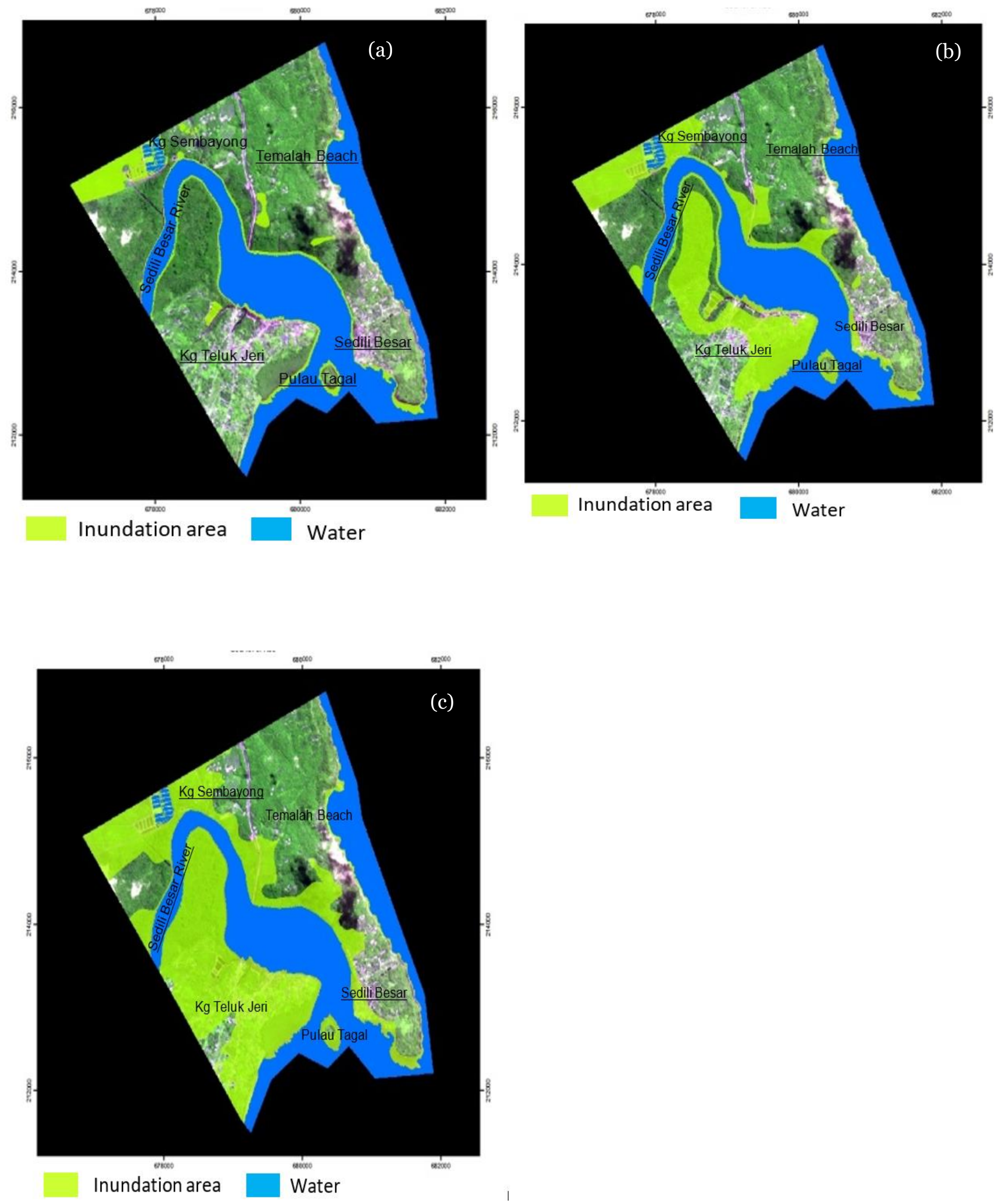


Figure 5. Simulation of 1m (a), 2 m (b) and 3 m (c) inundation area based on 1.83mm/year SLR (Din et al., 2012) in Kota Tinggi.

4.0 Conclusion

Most of the major towns on the East Coast of Peninsular Malaysia are in the low-lying area. The inundation area depends on the SLR level and the study area's contour. This assessment is based only on tidal data from the nearest tidal stations where the projection of SLR at 1 m, 2 m, and 3 m will occur between 2319 and 3741. The highest percentage of inundation area is in Kota Bharu (15%) if SLR increases to 1 m. The inundation area will spread further inland and along the Kelantan riverbank when the water level rises to 2 m. Kota Bharu is known as Kelantan Delta, and the landform feature is mainly in low-lying areas. The delta is protected by sand spits and sandbars that probably bring much faster destruction to the low-lying area. This town will be 60% inundated if the sea level increases to 3 m. The inundation percentage of Kuala Terengganu, Kuantan, and Kota Tinggi areas is between 4 % and 10 % of the study area, which is a 1 m rise. The percentage of the inundated area will be more than triple if the SLR increases to 2 m. The impacted land area will be between 41 % and 56 % if at a 3 m rise.

The SLR simulation at different water levels identified inundation areas within a few kilometres inland. However, extreme events or/and human activities contribute to coastal erosion and loss of natural coastal defence, such as mangroves, that accelerate the inundation area over a short time. The findings provide insight into adaptation options and mitigating against vastly dynamic catastrophic floods that usually cause significant loss of life, health hazards and risks, damage of properties, and economic losses. Among adaptation options is shifting new buildings and infrastructures to less flood-prone areas due to SLR. The information on SLR projection at the local level is part of the future coastal management and town development. It is prudent for policymakers to develop guidelines and adaptation options to lessen the risk of SLR, especially in sensitive areas.

Acknowledgements

We thank MOSTI through its E-Science fund project (Vot. Number 52061) and the Ministry of Higher Education Malaysia through the MyBrain Scholarship. We also offer special thanks to the Borneo Marine Research Institute (BMRI), UMS.

References

Awadalla, S., & Noor, I. M. (1991). Induced climate change on surface runoff in Kelantan, Malaysia: A preliminary assessment. *International Journal of Water Resources Development*, *7*(1), 53-59.

Cayan, D., Tyree, M., Dettinger, M., Hidalgo, H., Das, T., Maurer, E., ... & Flick, R. E. (2009). Climate change scenarios and sea level rise estimates for the California 2009 climate change scenarios assessment. California Climate Change Center CEC-500-2009-014-D.

Church, J. A., Gregory, J. M., Huybrechts, P., Kuhn, M., Lambeck, K., Nhuan, M. T., ... & Woodworth, P. L. (2001). Changes in sea level. In: *JT Houghton, Y. Ding, DJ Griggs, M. Noguer, PJ Van der Linden, X. Dai, K. Maskell, and CA Johnson (eds.): Climate Change 2001: The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel* (pp. 639-694).

Church, J. A., & White, N. J. (2006). A 20th-century acceleration in global sea-level rise. *Geophysical Research Letters*, *33*(1).

Din, A. H. M., Omar, K. M., Naeije, M., & Ses, S. (2012). Long-term sea level change in the Malaysian seas from multi-mission altimetry data. *International Journal of Physical Sciences*, *7*(10), 1694-1712.

DSMM. (2008). Department of Survey and Mapping Malaysia, User Manual.

Economic Planning Unit (EPU). (1985). National Coastal Erosion Study, Phase I. Report by Stanley Consultants, Inc., Jurutera Konsultant (S.E.A.) Pte. Ltd. and Moffatt and Nichols, Engineers to the Government of Malaysia, Prime Minister's Department, September 1985.

Ehsan, S., Begum, R. A., Nor, N. G. M., & Maulud, K. N. A. (2019). Current and potential impacts of sea level rise in the coastal areas of Malaysia. In *IOP Conference Series: Earth and Environmental Science* (Vol. 228, No. 1, p. 012023). IOP Publishing.

ESI. (2010). Environmental Sensitivity Index 2010 for Kelantan, Terengganu, Pahang and Johor. Universiti Malaysia Terengganu.

Faour, G., Fayad, A., & Mhawej, M. (2013). GIS-based approach to the assessment of coastal vulnerability to sea level rise: Case study on the Eastern Mediterranean. *Journal of Surveying and Mapping Engineering*, *1*(3), 41-48.

Grinsted, A., Moore, J. C., & Jevrejeva, S. (2010). Reconstructing sea level from paleo and projected temperatures 200 to 2100 AD. *Climate Dynamics*, *34*, 461-472.

Hamid, A. I. A., Din, A. H. M., Hwang, C., Khalid, N. F., Tugi, A., & Omar, K. M. (2018). Contemporary sea level rise rates around Malaysia: Altimeter data optimization for assessing coastal impact. *Journal of Asian Earth Sciences*, *166*, 247-259.

Heberger, M., Cooley, H., Herrera, P., Gleick, P. H., & Moore, E. (2009). The impacts of sea-level rise on the California coast. Pacific Institute.

Ho, J. C. (2009). Coastal flood risk assessment and coastal zone management: A case study of Seberang Perai and Kuantan Pekan in Malaysia. Master Thesis, University of Southampton.

IPCC. (2013). Climate Change: The Assessment Reports of the Intergovernmental Panel on Climate Change: Cambridge University Press Cambridge, UK.

IPCC. (2007). Climate change 2007: Impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the Intergovernmental Panel on Climate Changed M L Parry et al. (Cambridge: Cambridge University Press) p976.

Ismail, I., Abdullah, W. S. W., & Zakaria, S. M. M. R. (2018). Physical impact of sea level rise to the coastal zone along the east coast of Peninsular Malaysia. *Marang*, *5*, 12-82.

Ismail, I., Husain, M. L., & Saleh, E. (2020). Penilaian Indek Kerentanan Sosio-Ekonomi Terhadap Kenaikan Paras Laut Sepanjang Pesisir Pantai Timur Semenanjung Malaysia. *Malaysian Journal of Social Sciences and Humanities (MJSSH)*, *5*(10), 21-33.

Kont, A., Ratas, U., & Puurmann, E. (1997). Sea-level rise impact on coastal areas of Estonia. *Climatic Change*, *36*, 175-184.

Mimura, N. (1999). Vulnerability of island countries in the South Pacific to sea level rise and climate change. *Climate Research*, *12*(2-3), 137-143.

Mimura, N. (2013). Sea-level rise caused by climate change and its implications for society. *Proceedings of the Japan Academy, Series B*, *89*(7), 281-301.

Mohd, F. A., Maulud, K. A., Karim, O. A., Begum, R. A., Awang, N. A., Hamid, M. A., ... & Abd Razak, A. H. (2018, June). Assessment of coastal inundation of low lying areas due to sea level rise. In *IOP Conference Series: Earth and Environmental Science* (Vol. 169, No. 1, p. 012046). IOP Publishing.

MOSTE (Ministry of Science, Technology and the Environment), (2000). *Malaysia Initial National Communication*. Submitted to the United Nations Framework Convention on Climate Change. http://unfccc.int/resource/docs/natc/malnc1.pdf

NAHRIM & CHRL. (2010). The study of the impact of climate change on sea level rise in Malaysia (Final report), National Hydraulic Research Institute of Malaysia (NAHRIM) and California Hydrologic Research Laboratory (CHRL), pp 172.

Awang, N. A., & Hamid, M. A. (2013). Sea level rise in Malaysia. *Sea level rise adaptation measures. Hydrolink*, *2*, 47-49.

Omar, K., Ses, S., Naeije, M., & Mustafar, M. (2006). The Malaysian seas: Variation of sea level observed by tide gauges and satellite altimetry. In *Proceedings of the SEAMERGES Final Symposium, Bangkok, Thailand* (Vol. 28).

Pfeffer, W. T., Harper, J., & O'Neel, S. (2008). Kinematic constraints on glacier contributions to 21st-century sea-level rise. *Science*, *321*(5894), 1340-1343.

Rahmstorf, S. (2007). A semi-empirical approach to projecting future sea-level rise. *Science*, *315*(5810), 368-370.

Rowley, R. J., Kostelnick, J. C., Braaten, D., Li, X., & Meisel, J. (2007). Risk of rising sea level to population and land area. *Eos, Transactions American Geophysical Union*, *88*(9), 105-107.

Warrick, R., & Oerlemans, J. (1990). Sea level rise. In: Climate Change, The IPCC Scientific Assessment (Eds. Houghton, J. T., Jenkins, G. J. and Ephraums, J. J.): Cambridge University Press, 263-281.

Yoskowitz, D. W., Gibeaut, J., & McKenzie, A. (2009). The socioeconomic impact of sea level rise in the Galveston Bay Region. *Corpus Christi, TX: A Report for the Environmental Defense Fund. Harte Research Institute for Gulf of Mexico Studies, Texas A&M University*.