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Current and potential impacts of sea level rise in the coastal areas of Malaysia

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Abstract. Sea level rise is one of the most concerning and costly effects of climate change that impacts the sustainable development of coastal areas. Malaysia, representing 13% of the total land area within 5 km of a coast, is threatened by the devastating impacts of sea level rise. This study attempts to highlight the current and potential impacts of sea level rise in several high risk coastal areas of Malaysia. Currently, coastal erosion and coastal flooding are the major effects of sea level rise impacting the important coastal infrastructure. The coast of Selangor and Batu Pahat experienced severe coastal erosion recording the total eroded area of 1878.5 hectares and 415.47 hectares respectively. Likewise, the coastal flooding in Johor coastal flood was damaging an estimated RM 0.35 billion worth of infrastructure and RM 2.4 billion of economic losses. In addition, one meter rise in sea level is expected to cause the loss of 180,000-hectare of agricultural land, 15%-20% of mangrove forests loss along the coastline. Among the selected high risk areas along the coast of Malaysia, Batu Pahat is estimated to experience 100% loss of the development area followed by Port Klang (40.67%), Kedah (38.57%), Kuala Terengganu (4.86%), Kota Kinabalu (4.46%) and Kuching (2.64%). The potential sea level rise will amplify the existing impacts and create new risks for coastal population and development. Thus, proper adaptation measures are necessary in order to reduce the adverse impacts and economic costs of sea level rise in Malaysia.

1. Introduction

The global climate is changing at rates unprecedented in recent human history [1]. Sea level rise is one of the most concerning and costly effects of climate change, which has four major impacts in coastal areas: coastal flooding, coastal inundation, coastal erosion, and saltwater intrusion. While these impacts already exist in coastal regions, sea level rise intensifies their severity [2]. It addition, it will cause changes in the intensity and frequency of extreme events from combined effects of high spring tides, storm surges, surface waves and river flooding [3].

These pose major threat to the sustainable development of coastal areas as they directly impact the physical property, important coastal infrastructure including transport network and utility infrastructure, production process, natural and cultural resources, and indirectly, impacts the ecosystem, economic activities, income, wealth, public health, safety, and overall social well-being of the coastal community. For instance, sea level rise directly affects the design and structural stability of the existing infrastructure such as coastal roads, revetment, groin, breakwater, coastal tide gates, ports, fishing pier, beach and also commercial and residential buildings [4] in several ways such as accelerated degradation and greater likelihood of cascading failures (e.g. failures or destruction of critical infrastructure, immobilization due to transportation system breakdown, blackouts due to power grid failures, and catastrophic saltwater contamination of water supplies) [5]. Below figure 1 illustrates the climate change process and major impacts of sea level rise in the coastal areas.

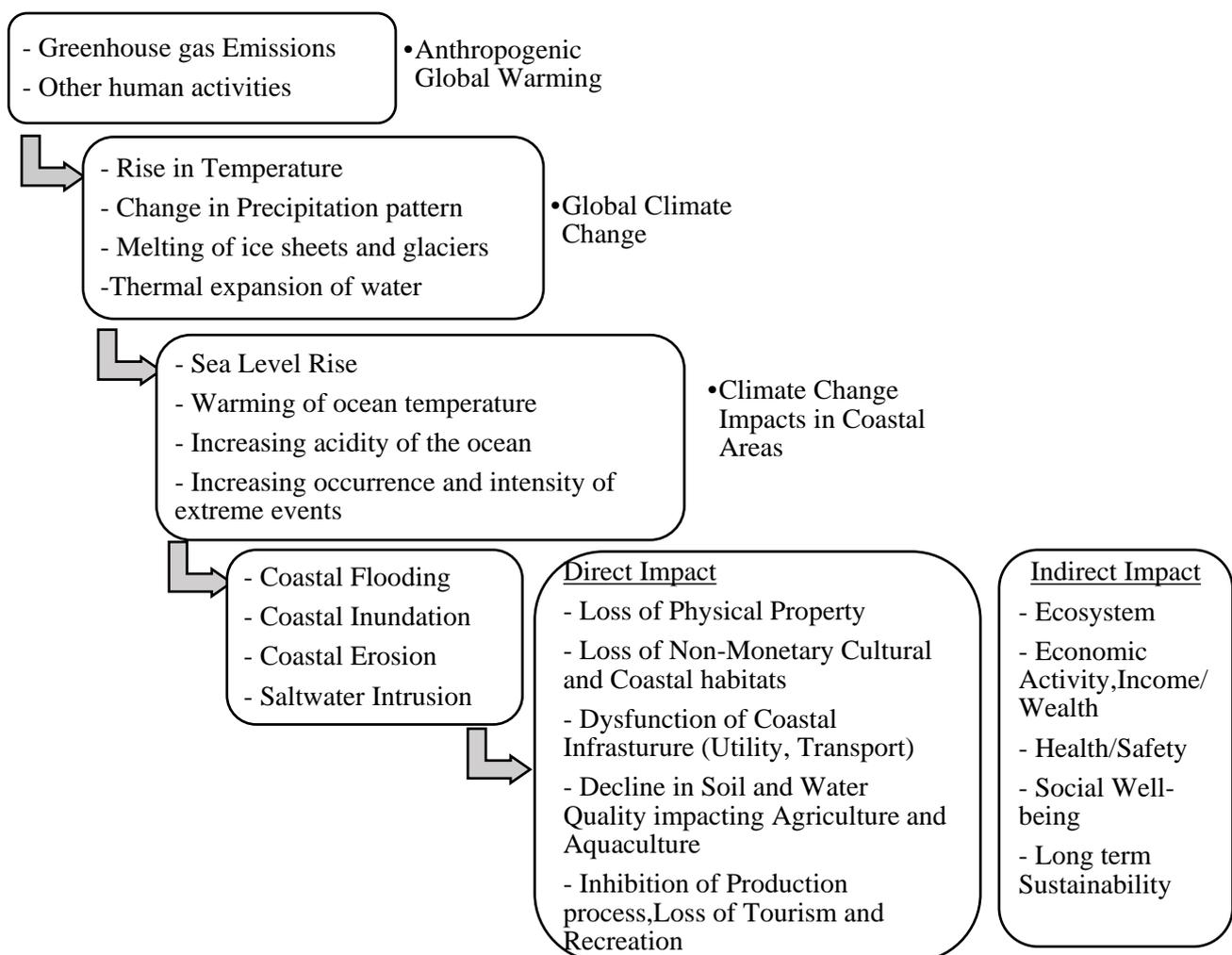


Figure 1. Sea level rise and its impacts in the coastal areas

The rising sea levels phenomena have significant long term impacts on the coastal area and their severity depends on the extreme, exposure and vulnerability of coastal areas [6]. Low-lying coastal areas are particularly susceptible to storm surge and flooding, and the effects on communities can be catastrophic. In the future, such effects will be intensified by rising sea levels [7] and may lead to prolonged disruption of economic activities, livelihoods, and long term sustainability of the coastal

communities. Sea level rise threatens a significant number of people and assets in coastal areas. This study will highlight the sea level rise trend and the current and potential impacts of sea level rise in the coastal areas of Malaysia.

2. Coastal areas of Malaysia

The coastal zone in Malaysia is broadly defined as the areas where terrestrial and marine processes interact such as coastal plains, deltaic areas, coastal wetlands, estuaries and lagoons. Malaysia, with a land area of 330,000 km² and a coastline of 4800 km and its coastal areas occupies a total land area of 4.4 million hectares representing 13% of the total land area within 5 km of a coast, approximately 1.2 million hectares of the coastal areas are found in Peninsular Malaysia, 1 million hectares in Sabah and 2.2 million hectares in Sarawak. About 70% of the total population live in the coastal zones. There are 22 urban settlements and 12,400 rural settlements, 28 industrial estates and 54 ports located in the coastal zone of Peninsular Malaysia. Moreover, the development along the coasts and surrounding areas has been extensive such as agricultural development (especially rubber, coconut, paddy, and oil palm plantation), fisheries and aquaculture, manufacturing industries, transportation and communication, oil and gas reserves, mineral resources e.g. tin, gold, platinum, chromite etc, natural habitat and tourism resources [8].

3. Sea level rise (SLR) trend in Malaysia

Sea level has shown a rising trend that has been observed globally and along Malaysian coastline. For instance, according to Intergovernmental Panel on Climate Change (IPCC) [1], globally sea level has risen by 2.4 mm to 3.8 mm (per year). On the other hand, the study about the impact of sea level rise in Malaysia on year 2010 by National Hydraulic Research Institute of Malaysia (NAHRIM) reported the average rise in sea level along 30 stations in Malaysia from 1993 to 2010 as 2.73 mm to 7.0 mm (per year) and found that there has been an important increase in SLR trends over the last 5 years compared to SLR trends over 20 years ago [9]. Table 1 shows the observed and projected SLR Trend around the global and in Malaysia.

Table 1. The observed and projected SLR Trend (Global vs Malaysia)

Sea Level Rise (SLR) Rate (mm/year)	Global IPCC (AR4 2007)	Malaysia NAHRIM (2010)	
Observed	2.4 – 3.8*	2.73 – 7.0* (1993-2010)	
		West	East
Projected by 2100	2.6 – 5.9	2.5 – 5.2	4.3 – 10.6

*measured by Satellite Altimeter

In addition, IPCC [10] has recently revised the potential SLR and estimated that global sea level rise may range from 0.3 m to approximately 1 m by 2100 based on a better understanding of glacial and ice sheet input. Consequently, climate change caused by the enhanced greenhouse impact will most likely accelerate the rise in sea levels in the future.

Similarly, NAHRIM predicted the rates of future SLR for 30 stations along Malaysia's coast using linear analysis and observation data from altimetry satellite (figure 2) that shows the SLR projection for the year 2100 which is estimated to be 0.25 - 0.5 m with maximum value occurring in low-lying areas along the Northeast coast (Kelantan State) and West coast (Kedah State) of Peninsular Malaysia. The maximum value of SLR in Sabah on year 2100 is estimated as 0.690 – 1.06 m occurs at Tawau, Semporna, Lahad Datu, Sandakan and Kudat as known as low-lying areas, river mouths and estuaries of the East coast; and in Sarawak, the maximum value of the SLR projection on year 2100 is 0.43 - 0.64 m occurs at Southwest coast consists of Meradong, Batang Iagan and Batang Rajang [9].

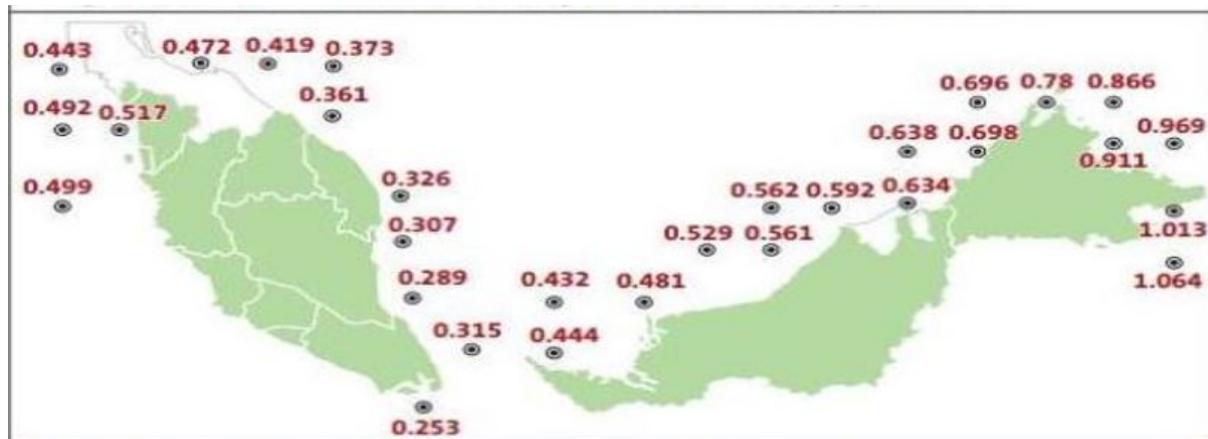


Figure 2. Projected sea level rise for Malaysia coastlines by year 2100 (Adapted From [9])

4. Current impacts of SLR in Malaysia

Coastal land is a valuable resource that has important economic, social, cultural and ecological values. However, several impacts sea level rise are already being experienced by the coastal communities of Malaysia mostly due to coastal erosion and coastal flooding putting millions of lives and billions of dollars' worth of property and infrastructure at risk.

4.1 Coastal erosion

Selangor, one of the major states on the west coast of Peninsular Malaysia is the largest economy in Malaysia in terms of gross domestic product (GDP) with RM 239.968 billion in 2015, making up 22.6% of the total GDP of Malaysia [11]. This state is also the most developed in Malaysia with good infrastructure such as highways and transport, has the largest population with a high standard of living and the lowest poverty rate in the country [12]. However, the coast of Selangor measuring 276 km is threatened by the climate change impact. For instance, the shoreline has been changed during 1984-2013 recording the total eroded area of 1878.5 hectares and total accretion area of 2447.4 hectares. The coastal area of Kapar, Kelang, Jugra, Telok Panglima Garang and Kelanag in Kuala Selangor and Klang districts are among the highest eroded areas [13]. At the coast of Selangor, the monitoring carried out proves that strong ocean currents, waves and winds damages the infrastructure near the coastal area. Figure 3 illustrates the effects of coastal erosion at Bagan Pasir, Selangor.



Figure 3. Impact of coastal erosion to the residential property at Bagan Pasir, Selangor (Adapted from [13])

In addition, Johor, the third biggest state economy in Malaysia with GDP of RM104.4 billion, which accounted for 9.4% of Malaysia's GDP is also threatened by the adverse impacts of sea level rise. Batu Pahat is one of the small districts of Johor state located at the south of Malaysia. A study was conducted

by Khairul Nizam and Roshana (2015) found that Batu Pahat experienced severe coastal erosion. This area experienced 415.47 hectares of erosion and 68.52 hectares sedimentation over 3 years from 2011 to 2013. Based on their research, it is clear that 85.84 percent of Batu Pahat is extremely experiencing erosion phenomena occurred only within 3 years [14]. Figure 4 shows the phenomenon of coastal erosion and its impacts to the infrastructure damage occurring in Batu Pahat coastal areas.



Figure 4. Coastal erosion and its impact to the coastal infrastructures at Batu Pahat, Johor
(Adapted from [14])

4.2 Coastal flooding

Impacts of sea level rise to the coastal communities due to coastal flooding has also become a serious issue in Malaysia. Floods are the most disastrous natural hazard in Malaysia. Even though, most floods occurred in Malaysia as a result of cyclical monsoons bringing heavy and regular rainfall and inadequate drainage system to curb with the excessive rainfall intensifying flooding problem [15], a series of flood seen in Johor state of Malaysia in 2006-2007 are believed to be extraordinary events that are closely related to global climate change and sea level rise impacts [16]. The coastal flooding in Johor during 2006-2007 with the worst case in Kota Tinggi and Segamat was caused due to the heavy rainfall within a long period of time, which occurred in the low area and the condition of the shallow river and high tide impacts from sea level rise [17]. Figure 5 illustrates coastal flooding and its impact to the coastal infrastructures.



Figure 5. Coastal flooding and its impact to the coastal infrastructures at Johor 2006-07
(Adapted from [18])

The impacts of the coastal flood was devastating and affected more than 100,000 victims in two separate events [18], damaging an estimate of RM 0.35 billion worth of infrastructure and RM 2.4 billion of economic losses [19]. In another study, the damage cost of 2006- 2007 Johor flood was estimated at RM1.5 billion [20]. In addition, an estimate of RM84 million of agriculture produce were damaged or losses affecting 7000 farmers. The loss of agricultural production due to inundation of erosion during the floods, in Johor signified RM 46 million for western Johor Agricultural Development Project Area [21]. Moreover, estimated cost to repair the transport infrastructure (road and bridges) was RM147

million by Public Work Department (PWD) and hydraulic structures was RM260 million by Department of drainage and Irrigation (DID) [18].

In addition, another climate change impacts related to sea, which causes coastal flooding in low lying coastal areas is known as La Nina phenomena. According to the Malaysian Meteorological Department, La Nina is caused by cooling of Pacific Ocean and causing higher rainfall compared to normal weather [22]. In 2011 and 2012, coastal flooding due to La Nina phenomena caused floods in Johor -the four worst affected areas were Segamat, Batu Pahat, Kluang and Muar [23]. One of the major impacts of this flooding was the effect to the palm oil production. Ayat K et al. (2012) estimated the potential income losses to the palm oil production at RM155.10 million and RM168.22 million during the two years [24]. In addition, flood affected estates had spent RM25.80 million and 26.48 million respectively to repair the infield roads.

Moreover, coastal flooding as a result of high tides meeting high water flow is prevalent at coastal cities such as Klang, Teluk Intan and several places in Penang [15]. For instance, 'king tides', the higher than normal waves that threaten low lying areas damaged coastlines in Penang, Kedah, Perak, Selangor, Negeri Sembilan, Melaka, Johor in 2016. Many of these coastal areas are densely populated and rich coastal infrastructures such as Penang is an area with the most intense coastal population (e.g. 860 people per square kilometer) [25]. However, coastal flooding severely impacts many aspects of these low lying coastal areas. Therefore, sea level rise may reduce the size of these coastal areas and its' infrastructure; worsen inundation, erosion, and other coastal hazards; threaten vital infrastructure, and thus compromise the socio-economic wellbeing of the island communities [26].

5. Potential impacts of SLR in Malaysia

Numerous areas in Peninsular Malaysia, especially coastal areas are at risk of being eroded, flooded and inundated if the ice coating in Greenland is fully melted. Several studies estimated the likely impact of sea level rise in Malaysia. For instance, Nicholls and Mimura (1998) has concluded that one meter increase in sea level rise will cause 700 square kilometer (2.1%) of land loss and displaces more than 0.3% of the population in Malaysia [27].

Moreover, one meter rise in sea level will also cause the loss of 180,000-hectare of agricultural land, 15%-20% of mangrove forests loss along the coastline, and possible relocation of shore-based power stations [28]. Besides, there are studies that focuses on the potential sea level rise impacts to the most vulnerable coastal areas in Malaysia. For example, according to the National Coastal Vulnerability Index Study [29], an average of 30% land loss is estimated at Langkawi Island and Tanjung Pia in Malaysia based on one meter sea level rise scenario.

In addition, based on the SLR projections NAHRIM carried out desktop studies on selected high risk areas along the coast of Malaysia e.g. mud-flat area at Batu Pahat (Sg. Senggarang to Sg. Punggur), active development and high population area at Kelang, Selangor, Kedah Estuary, Terengganu Estuary, Kota Kinabalu, and Kuching [30]. Utilizing numerical modelling suite and GIS software, potential SLR inundation maps were produced to assess the SLR towards population, development, mangrove area and paddy field that exist within these areas. Table 2 describes the potential impact of SLR in vulnerable areas in Malaysia.

With the potential 1 meter increase in sea level rise, Batu Pahat is estimated to experience 100% loss of the development area followed by Port Klang (40.67%), Kedah (38.57%), Kuala Terengganu (4.86%), Kota Kinabalu (4.46%) and Kuching (2.64%). In addition, a significant number of population are threatened to be inundated due to 1 meter sea level rise, e.g. 22000 in Port Klang, 12000 in Kedah, 5735 in Batu Pahat, 5000 in Kuala Terengganu, 2000 in Kuching, 1000 in Kota kinabalu are at risk due to future sea level rise. Similarly, all the mangrove areas are also likely to be inundated in Batu Pahat and Kedah.

Table 2. Potential impact of SLR in vulnerable areas (adapted from [30])

Study Area (Km ²)		Impact of Sea Level Rise (Inundation)			
		Development Area (Km ²)	Population	Mangrove Area (Km ²)	Paddy (Km ²)
Batu Pahat (Existing)	46	6.28	5,735	0.8	
0.253m SLR ¹	9.2 (20%)	0.884 (14.08%)	600 (10.46%)	0.716 (89.87%)	
0.5m SLR	22 (47.83%)	3.933 (62.62%)	3,080 (53.7%)	0.8 (100%)	
1m SLR ²	46 (100%)	6.28 (100%)	5,735 (100%)	0.8 (100%)	
Port Klang (Existing)	360	107	49,000	161	
0.5m SLR ¹	17.14 (4.7%)	2.28(2.13%)	4,000(8.16%)	14.27(8.8%)	
1m SLR ²	87.6 (24.4%)	14.36 (13.4%)	13,000 (26.5%)	37.56 (23.8%)	
2.2m SLR ³	146.42 (40.67%)	31(29%)	22,000 (44.9%)	116.97 (72.8%)	
Kedah (Existing)	70	28.77	22,000	0.6	47.84
0.5m SLR	12.51 (17.87%)	2.53 (8.79%)	4,000 (18.18%)	0.6 (100%)	9.38 (19.61%)
1m SLR	27 (38.57%)	7.06 (24.54%)	12,000(54.55%)	0.6 (100%)	16.78 (35.08%)
Kuala Terengganu (Existing)	147	36.87%	36,000		
0.5m SLR	3.46 (2.35%)	3.26 (8.84%)	4,000 (11.11%)		
1m SLR	7.15 (4.86%)	6.81 (18.47%)	5,000 (13.89%)		
Kota Kinabalu (Existing)	32.71	17.3	9,000		
0.5m SLR	0.36 (1.1%)	0.09 (0.52%)	<1,000 (<11.11%)		
1m SLR	1.46 (4.46%)	0.41 (2.37%)	1,000 (11.11%)		
Kuching (Existing)	576	72.57	88,000		
0.5m SLR	14.09 (2.45%)	4.07 (5.61%)	1,000 (1.14%)		
1m SLR	15.2 (2.64%)	4.53 (6.24%)	2000 (2.27%)		

Note: 1 refers to the mean SLR in year 2100, 2 refers to the sensitivity SLR, 3 refers to the max SLR in year 2100.

6. Adaptation measures to reduce the impacts of SLR

The potential sea level rise impacts reflect that rising sea level in Malaysia and around the world will amplify these existing impacts and create new risks for coastal population and development. Therefore, the economic cost of sea level rise along the coast of Malaysia without any adaptation measures could be huge as the previous studies found out in the other coastal areas of the world. For instance, the

economic cost of US\$20.4 billion for the coast of United States [31], US\$23 million for the coast of Montevideo, Uruguay [32], and US\$30 billion for the total cost of land loss for the coasts in Poland [33]. MOSTE (2000) estimated the economic costs from socio-economic impacts based on the high rate of sea level rise (0.9 cm/yr) in Malaysia which projected the agricultural production loss at RM46 million from eroded/inundated lands in Western Johor Agricultural Development Project area, which accounts for about 25% of the national drainage areas. In addition, long-term annual flood damage estimated at about RM88 million in Peninsular Malaysia and RM12 million for Sabah/Sarawak based on 1980 price level, which will be increased by 1.67 times if the flood frequency is doubles. Similarly, loss of fisheries production is estimated at RM300 million based on 2% loss of mangrove resulting in a loss of about 70,000 tonnes of prawn production values at RM4,500/ tonne [28]. Therefore, in order to offset the damage due to climate change, adaptation strategies are necessary measures which refers to any adjustments to human activities that reduce the vulnerability of humans and ecosystems to climate change impacts [1].

Over the last decades, adaptation has become one of the central approaches to reduce the adverse impact of changing global climate, has had a widespread benefit in reducing society's vulnerability to coastal hazards [34] and enables coastal communities to reduce its detrimental impacts by averting or reducing the potentially negative consequences, while benefiting for potentially positive consequences [35]. There are several coastal adaptation measures such as protection approaches to defend vulnerable areas using seawalls, sea dikes, storm surge barriers and closure dams and land claim etc.; accommodation approaches to occupy vulnerable areas but accepting the greater degree of flooding by changing land use, construction methods and improving preparedness such as flood-proofing, wetland restoration, floating agricultural systems, flood hazard mapping, flood warnings etc.; and retreat approaches to abandon currently developed areas, resettle inhabitants such as managed realignment and coastal setbacks. Figure 6 illustrates adaptation strategies in coastal areas [36].

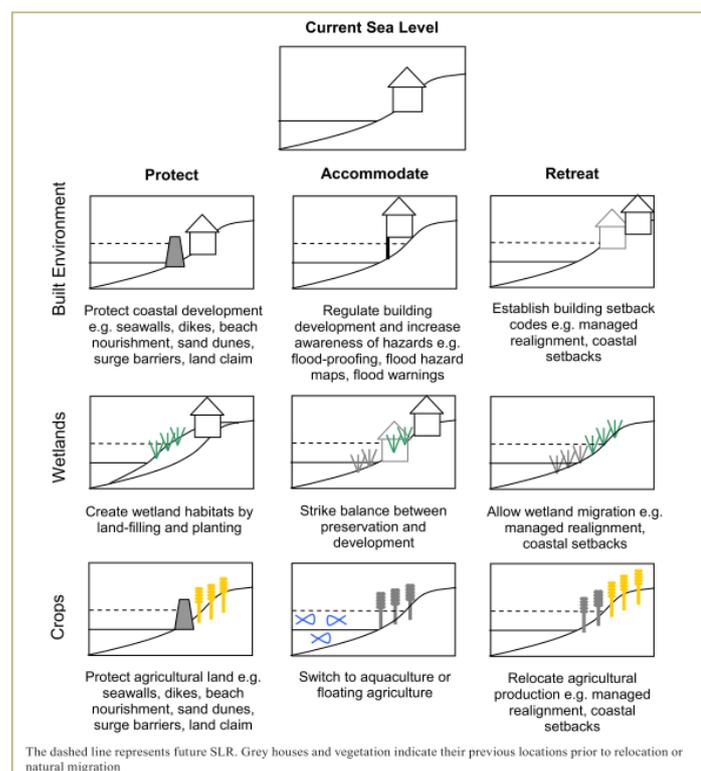


Figure 6. Coastal adaptation measures (Source: Adapted from [36])

7. Concluding Remarks

Climate change in coastal areas such as sea level rise, increased occurrence and intensity of storms and high tide poses major concern as they result in coastal erosion, flooding, salt water intrusion and inundation which in turn impacts the important infrastructure, physical property, production processes and wetland services. The economic cost of current and potential SLR in Malaysia is enormous. Nevertheless, noted in Malaysia's Second National Communication (NC2) to the United Nations Framework Convention on Climate Change (UNFCCC), there is renewed interest in climate change adaptation needs for Malaysia [37]. Similarly, the Malaysian Second National Communication and Fourth Assessment Report of Intergovernmental Panel on Climate Change (IPCC) stressed on research gaps and needs in terms of socio-economic impacts and response as well as comprehensive estimation of adaptation costs and benefits [38] due to its importance in decision-making on economic viable adaptation option, future investment decision, fund disbursement and negotiations at the global level. Therefore, cost-efficient and location specific appropriate adaptation measures for the coastal community are necessary to reduce the cost of climate change among the prevalent adaptation measures such as sea wall, living shoreline, road elevation, house elevation, investment avoidance and public purchases.

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