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Abstract: Sea level rise (SLR) due to global warming would severely affect the coastal areas of many countries of the world through inundation of coastal areas and islands, shoreline erosion, and destruction of important ecosystems such as wetlands and mangroves. A significant increase of sea level would hamper the economy, trade, tourism, biodiversity and livelihood. This article attempts to highlight a snapshot of physical, economic and social impacts of SLR and adaptation measures needed in Malaysia. In Malaysia, the total mangrove would be lost with 90 cm rise in the sea level and destruction of coastal bunds could inundate 1000 km² agricultural lands. Malaysia would be needing 5750 million US$ PPP additional economic cost for SLR in 2030. In addition, Malaysia would lose 7000 km^2 land area and more than 0.05 million population would be displaced by 1 m SLR in 2100 if no adaptation measures are taken. The country's total cost of SLR with and without adaptation would be 160.92 and 655.09 million US$/year respectively under A2 scenario. Thus, adaptation measures are necessary to reduce the possible impacts of SLR in coastal zones. Adaptation measures such as coastal defenses, beach nourishment, offshore barriers, flood gate, mangrove creation etc. should be taken to limit the negative impact of SLR in Malaysia. These adaptation measures and responses should be mainstreamed with local policy, planning and resilience-building strategies.

Key words: Sea level rise, impacts, adaptation measures, Malaysia.

Introduction

Sea level rise would be one of the most significant potential impacts of climate change if the current trend of sea level rise (SLR) due to global warming continues to increase for the upcoming decades. SLR would severely affect the coastal areas of many countries of the world through inundation of coastal areas and islands, shoreline erosion, and destruction of important ecosystems such as wetlands and mangroves. Moreover a significant increase of sea level will hamper the economy, trade, tourism, biodiversity, and livelihood and so on. SLR due to climate change is a serious threat to countries with heavy concentrations of population and economic activity as well as ecosystem in coastal regions (Sachs et al., 2001; Nicholls et al., 2011). In 1990, it has been estimated that 23% (1.2 billion) of the world's population lived in the near-coastal zone where population density is about three times higher than the global mean (Nicholls and Small, 2002; Small and Nicholls, 2003). Coastal populations are also growing more rapidly than the global mean, due

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to net coastal migration (Nicholls, 2003). Therefore, human and economic exposure to SLR is significant and growing.

A number of studies have shown that the rate of SLR is increasing over the decade. Global sea levels rose 10 to 25 cm over the last century and are expected to rise about 0.5 m by 2100, equivalent to a 2- to 5-fold acceleration (Warrick et al., 1996). The rate of global sea level rise was faster during 1993 to 2003, about 3.1 mm per year, as compared to the average rate of 1.8 mm per year during 1961 to 2003 (IPCC, 2007). Interestingly Malaysian SLR scenario is comparatively lower than the global average scenario. Based on a longer tidal data record, observed sea levels at the two tidal stations in Malaysia have been estimated 1.3 mm and 1.0 mm per year in Tanjung Piai, Johor and Teluk Ewa, Langkawi respectively. Table 1 shows the observed and predicted SLR at Malaysian (local) scenario with the global scenarios.

Several studies have been tried to quantify the impacts of SLR through a number of issues such as (1) increased risk of flooding (Nicholls, 2004), (2) wetland loss (Nicholls, 2004), (3) loss of rice production (Hoozeman et al., 1993), (4) cost of protection and dry land loss (Fankhausar, 1995; Tol, 2002a and 2002b; Nicholls and Tol, 2006) and (5) the number of people who would be forced to migrate (Tol, 2002a and 2002b). Human health is another sector where the indirect effects of sea-level rise could be significant. So a variety of impacts would arise due to SLR in the coastal regions. This article reviews the types of impacts and adaptation measures due to SLR in Malaysia.

Geography of Malaysia

Malaysia is a coastal nation located in the heart of South East Asia. The country has two distinct parts. Peninsular Malaysia, which is also known as West Malaysia, constitutes the long fringe of land, extending down from South East Asia that borders Thailand and Singapore. The South China Sea separates the mainland from the less populated East Malaysian provinces of Sabah and Sarawak. Figure 1 shows that Malaysia is a land area of 329,847 km^2 and a coastline of about 4800

Table 1: Observed and predicted sea level rise at local level in Malaysia with global scenario

		Predicted sea levels		
SLR scenarios	*Rate of SLR*	*Year 2000*	*Year 2050*	*Year 2100*
Observed at local (Tanjung Piai, Johor)	1.3 mm/year	0.0 m	0.065 m	0.13 m
Observed at local (Teluk Ewa, Langkawi)	1.0 mm/year	0.0 m	0.050 m	0.10 m
Global-Low	3.0 mm/year	0.0 m	0.15 m	0.30 m
Global-Average	5.0 mm/year	0.0 m	0.25 m	0.50 m
Global-High (Worst case)	10.00 mm/year	0.0 m	0.50 m	1.00 m

Source: DID, 2007

Some indicators of Malaysia	
Indicators	*Volume*
Total area (km^2)	3,29,847
Coastal area (% of total area)	13
Total coastline (km^2)	4800
Total population (million)	28.86
Coastal population (% of total population)	23.5
SLR (mm/yr) at Tanjung Piai, Johor	1.30

Figure 1: Malaysia map with geography and coastal indicators.

Source: www.mapsopensource.com; DID, 2007; UNDP, 2010.

km where the coastal zone covers a land area of about 4.43 million hectares or 13% of the total land mass in Malaysia. The coastal can be further divided into 1.18 million hectares in Peninsular Malaysia, 1.00 million hectares in Sabah and 2.25 million hectares in Sarawak, accounting for 9%, 13% and 18% respectively of the land area in these regions. It has been estimated that 27% coastal land is used for agriculture while forest and urban and residential area covers 69% and 4% respectively (Sulaiman, 2012).

Impacts of Sea Level Rise

Flooding of coastal areas especially low-lying coastal areas will become more common and severe due to SLR and increase in the occurrence of extreme high water events related to storm surges, high tides, and flooding rivers (Nicholls, 2004). Flooding and loss of land would have significant impacts on humans, economy, wildlife, and entire ecosystems. Socioeconomic vulnerability of the coastal area due to SLR is comprised of the vulnerabilities of economic sectors and associated livelihoods, water resources, energy, transportation, national defense, investments in homes and other buildings, and the health and well-being of a diverse concentration of people living in coastal zones (Nicholls, 2002; Burkett and Davidson, 2012). Malaysia is a coastal nation which could be faced several impacts with the rise of sea level. A range of potential physical, economic and social impacts due to SLR in Malaysia has been discussed in the following sub-sections.

Physical Impacts

Malaysia is already facing serious erosion problem where out of the 4800 km coastline, 1400 km (30%) of the coastline is subject to varying degrees of erosion. Floods frequently happen in the southern states of Malaysia, including Selangor, Negeri Sembilan, Melaka, Johor and Pahang. About 9% of the land area in Malaysia is vulnerable to flooding affecting 3.5 million people. The flood proneness of these states could be increased due to SLR. Three SLR scenarios of 20 cm, 50 cm and 90 cm during the year of 2100 were examined to measure the biophysical impact in Malaysia. The biophysical impacts were assessed based largely on existing studies, but updated where relevant and aggregated to the national level (INC, 2000).

The likely biophysical impacts are classified into four broad categories: tidal inundation, shoreline erosion, increased wave action, and saline intrusion (INC, 2000) as summarised in Table 2. As a result of 90 cm of SLR, a sizeable proportion of the coastal polder land of about 1200 km in Peninsular Malaysia alone would be submerged subsequent to bund failure, if the bunds are not shored up. Along sandy coasts, sea level rise-induced shoreline retreat, as predicted by the Bruun Rule, may add another 30% to the rate of existing shoreline erosion (INC, 2000). There is also emerging salinity intrusion problem in Malaysia as of consequences of SLR.

Economic Impacts

The economic impacts could be much higher resulting in the consequences of SLR. Malaysia lose average RM 100 million per year (conservative estimate) due to floods (Baharuddin, 2007). The loss of agricultural production due to inundation (or erosion) during the floods in Johor signified RM 46 million for Western Johor Agricultural Development Project area (Cetdem, 2010). SLR by 1 m can flood and inundate about 100,000 ha of land planted with oil palm and 80,000 ha of land under rubber production (Chong, 2000). The main economic loss is projected to be the interruption of economic activities, principally agriculture production, along vulnerable stretches of coastline as a result of direct inundation in the event of bund breach.

The potential loss in terms of fisheries resources is related to a 20% loss of mangrove areas, which serve as habitat for fish juveniles (INC, 2000). Hence, the impact on fisheries reported in Table 3 refers to that resulting from the loss of habitat, and not as a direct result of SLR. According to Chamhuri et al. (2009), climate change could influence food production adversely due to geographical shifts and yield changes in agriculture, reduction in the quantity of water available for irrigation and loss of land through sea level rise and associated salinization. Malaysia will be needing 5750 million US$ PPP as an additional economic cost per year for SLR in 2030 (Climate Vulnerability Monitor, 2010). Table 3 shows some sort of economic impacts resulting from SLR in Malaysia.

Social Impacts

Though it is difficult to measure the social impact of SLR but it is believed that many people of the coastal area would be displaced and their livelihood would be impacted. This study has considered land loss and population displacement as social impact that would be a certain phenomenon due to SLR. As Malaysia has a long coastline of 4800 km, some degree of SLR would inundate land and people of the low lying areas need to be shifted. It has been projected that 2500 people will

Table 2: Biophysical impacts resulting from SLR

Type of bio-physical impact	*Sea level rise scenarios (Year 2100)* 20 cm (or 0.2 cm/yr)	50 cm (or 0.5 cm/yr)	90 cm (or 0.9 cm/yr)
Tidal inundation			
(a) Mangrove fringed mudflats			
i. Bunded	Insignificant as bunds will be raised	Insignificant as bunded	Perhaps 300 m strip may be lost (retreat bund)
ii. Unbunded	Insignificant as bunds are likely to be built	Insignificant as bunds are likely to be built and topped up	Perhaps 300 m strip may be lost (retreat bund)
(b) Sandy shores	Insignificant as existing ground level is higher	Insignificant as existing ground level is higher	Insignificant as existing ground level is higher
(c) Increased flooding	Reduced drainage efficiency of tidal control gates	Reduced drainage efficiency of tidal control gates	Tidal gates rendered non-operational and replaced by pumped drainage
Shoreline erosion			
(a) Sandy shoreline	Insignificant	Insignificant	Insignificant
(b) Mangrove loss	Vertical accretion rate able to keep pace	Vertical accretion rate able to keep pace	Total mangrove loss
Increased wave action	Insignificant	Reduced factor of safety, but consider refurbishment if necessary	Taken into account during refurbishment
Saline intrusion	Unlikely to be of concern due to a shift towards reservoir development		

Source: MOSTE, 2000; INC, 2000.

Table 3: Economic impacts resulting from SLR

Type of impact	*Socio-economic impacts based on high rate of sea level rise (0.9 cm/yr)*
Loss of agricultural production from eroded/ inundated lands	RM46 million for Western Johor Agricultural Development Project area. This project area accounts for 25% of the national drainage areas
Displacement and relocation of flood victims with associated disruption of business/economic activities resulting from increased flooding	Long-term annual flood damage estimated at about RM88 million for Peninsular Malaysia and RM12 million for Sabah/Sarawak based on 1980 price level. If the flood frequency is doubled, the annual flood damage will increase by 1.67 times
Loss of fisheries production due to mangrove loss	RM300 million loss based on 20% loss of mangrove resulting in a loss of about 70,000 tonnes of prawn production valued at RM4500/tonne
Interruption of port operation	May see some improvement due to reduced siltation

Source: MOSTE, 2000.

be affected and 450 km^2 additional land will be lost of Malaysia every year due to SLR by 2030 (Climate Vulnerability Monitor, 2010). Table 4 shows that with an 1 m rise in the sea level, Malaysia will lose 7000 km^2 land area and population less than 0.05 million (1990s population) will be displaced if no adaptation measure is taken (Nicholls et al., 1995). A quantitative assessment of erosion on the mud coasts in Malaysia is beyond existing knowledge, but the nature of the impacts is expected to be severe. Destruction of coastal bunds could inundate 1000 km² of agricultural land (Midun and Lee, 1995). Nicholls et al. (1995) projected that Bangladesh would be affected by 20.7% land and 13.5% population while World Bank (2000) study estimate 17.5% of land (25,000 km^2) for Bangladesh due to 1 m rise in the sea level. Toms et al. (1996) shows that Vietnam would lose 12% of its land where 17% population would be affected (Table 4). Another study estimated that 10.8% of Vietnam's population would be impacted by a 1 m SLR (World Bank, 2007). Indonesia

Table 4: Land loss and population displaced (1990s population) in some Asian countries with a rise of 1 m sea level

Country	*SLR scenario (cm)*	*Land loss*		*People displaced*	
		km²	*%*	*millions*	*%*
Bangladesh	100	29,846	20.7	14.8	13.5
Indonesia	100	34,000	1.90	2.0	1.1
Malaysia	100	7000	2.1	>0.05	>0.03
Vietnam	100	40,000	12.1	17.1	23.1

Source: Nicholls et al., 1995, Vietnam from Toms et al., 1996.

is projected to be highly affected by coastal flooding, with nearly 5.9 million people expected to experience flooding annually in 2100 assuming no adaptation while 0.24 million population would be affected in Malaysia (Mcleod et al., 2010).

Adaptations to Sea Level Rise

Adaptation measures are necessary to reduce the adverse impacts of SLR and to protect the resources and livelihood of the coastal region in Malaysia. Of course there is some costs for adaptation measures but this would be less than the cost of SLR without adaptation. According to Mcleod et al. (2010), the cost of SLR for Malaysia with and without adaptation would be 160.92 and 655.09 million US$/year in 2100 under A2 scenario[1]. But the adaptation measures must be made to consider the larger uncertainty about future climate (and many other factors), so there is a need for a risk- and uncertainty-based manner rather than looking for deterministic solutions (Nicholls, 2003). Therefore, all levels of government have a key role in developing planned adaptation measures (Nicholls, 2003). There are several adaptation approaches that could be employed to minimize the impact of SLR.

Protection: Protection is a reactive approach to protect people, property and infrastructure from sea level rise. Protecting the coastline through structural measures such as dikes and seawalls has been the traditional approach to dealing with SLR in many parts of the world (Bijlsma et al., 1996; Klein et al., 2001; Arlington Group Planning, 2013). Such measures range from large-scale public projects to small-scale efforts by individual property owners. There is also a growing concern of the benefits of non-structural protection measures, including beach nourishment and coastal wetland restoration and creation. These measures can be implemented as sea level rises, and may complement or supplement structural protection. These non-structural adaptations can enhance the natural resilience of the coastal zone and can be less expensive than structural protection, which can lead to unwanted effects on erosion and sedimentation patterns if not properly implemented (Arlington Group Planning, 2013).

Retreat: Retreat is considered any strategic decision to withdraw, relocate or abandon private or public assets at risk due to coastal hazards. This adaptive strategy is designed to limit the use of structural protection, discourage development in areas subject to SLR, and plan for the eventual relocation of buildings and infrastructure to areas with no risk or a lesser risk. In this approach, all natural system effects are allowed to occur and human impacts are minimised by pulling back from the coast (Bijlsma et al., 1996; Klein et al, 2001).

Accommodation: Accommodation is an adaptive strategy that allows continued occupation of coastal areas while changes are made to human activities and/or infrastructure to adapt to SLR (Arlington Group Planning, 2013). This involves retrofitting a building or making it more resilient to the consequences of sea level rise. Other accommodation measures may include liability reduction such as a covenant indemnifying governments from the consequences of coastal hazards regardless of protection works that are undertaken. Under the circumstances of this approach, all natural system effects are allowed to occur and human impacts are minimised by adjusting human use of the coastal zone (Bijlsma et al., 1996; Klein et al, 2001).

In practice, it is not possible to tackle SLR by taking a single approach of adaptation. So multiple and hybrid responses need to effectively reduce the adverse impacts of SLR. All the responses should be mainstreamed with local policy, planning and resilience-building strategies.

[1] A2 is one of the emission scenarios of the IPCC Special Report on Emissions Scenarios (SRES; Nakicenovic and Swart 2000). The A2 storyline assumes a socio-economically heterogeneous world and a continuously increasing global population. Global emissions increase throughout the century.

Though most assessments of adaptation only consider mixtures of retreat (or ‘do nothing’) and protection where the accommodation option remains largely unassessed. Department of Irrigation and Drainage (DID, 2007) suggested the following specific adaptation measures/responses to SLR for Malaysia:

- *Sea walls, revetments and bulkheads:* Protect inland properties from the direct effects of waves and storm tides. Building sea walls are the most common form of coastal protection around the coastline.
- *Coastal defenses:* Malaysia needs to construct or establish physical barriers to flooding and coastal erosion through coastal bunds, dikes, levees and flood walls.
- *Detached breakwaters:* A detached breakwater is a structure parallel, or close to parallel, to the coast, built inside or outside the surf zone. This structure is useful to reduce erosion and storm damage.
- *Floodgates or tidal barriers:* Establishing floodgate is another important adaptation measure for Malaysia which can prevent water entering coastal floodplain areas. Adjustable dam-like structures can be placed across estuaries to prevent upstream flooding from storm tides.
- *Beach filling and subsequent renourishment:* Replenishing beaches and dunes with sand provides an alternative and often more successful physical approach to reducing risk of SLR. Sandy beaches are particularly vulnerable to erosion and retreat. The placement of sandy material along the shore to establish and maintain the desired beach width is effective for Malaysia.
- *Wetland/mangrove creation:* Placement of fill material to appropriate elevations with subsequent planting helps to protect coastal areas. Some other measures such as planting of sea grass or seaweeds, promoting the protection of coral reefs and preventing mangrove harvesting could be useful to reduce loss of coastal wetland and erosion.
- *Infrastructure modifications:* Modifications to existing infrastructure such as drainage systems, elevation of piers, wharves, bridges, roads etc. are needed towards effective adaptation outcomes.

In addition to the above approaches/measures, the following adaptation strategies could be implemented to reduce the impact of SLR in Malaysia.

- *Planning measures:* It is also important to incorporate adaptation measures into the planning process. At the same time, some crucial planning measures such as land use planning, preparedness and emergency planning need to be taken to reduce the impacts of SLR on the people of the coastal regions.
- *Social security:* The poor are less able to cope with the risk of hazard event. They cannot afford to re-invest after a major loss due to hazard because they are less able to afford flood insurance, live in less robust houses and are less able to afford repairs. As the poor are disproportionately vulnerable to SLR so it is vital to alleviate poverty and ensure the poor people reside in well-built and well located houses (Cartwright et al., 2008). Provision of special insurance schemes for vulnerable people would be useful to promote resilience-building strategies/policies through social security, modification and development of existing responses, settlements and infrastructures.
- *Institutional measures:* Most institutional responses to SLR risk focus on increasing the capacity of people and the environment to cope with problem as a means of reducing risk. Identifying vulnerable communities and locations as well as risk mapping are useful to implement adaptation strategies successfully to minimize the impact of SLR (Cartwright et al., 2008). Several institutions of government initiate/promote awareness raising programmes, early warning system, guideline for coastal development and legislations towards integrated coastal management such as regulation of building construction, regulation of land use, declaration of buffer zone etc. which might reduce risk and increase resilience of the coastal population.

Furthermore, the above adaptation measures and responses could be useful if the following issues are taken into consideration:

- Assess public perception at the local level on adaptation needs against SLR;
- Understand the various barriers of adaptation and to generate ideas to overcome these;
- Identification of localized adaptation priorities and strategies employed; and
- Promote priority-based adaptation measures for the coastal areas and the people considering vulnerability.

Concluding Remark

Studies show that SLR would severely affect the coastal areas of Malaysia through inundation of coastal areas, shoreline erosion, and destruction of important ecosystems such as wetlands and forest. With an increase of sea level by 1 m, Malaysia will lose 7000 km^2 land area and more than 0.05 million (1990s population) will be displaced if no adaptation measure is taken. Destruction of coastal bunds could inundate 1000 km^2 agricultural land of Malaysia. The country's total cost of SLR with and without adaptation would be 160.92 and 655.09 million US$/year respectively under A2 scenario. Though SLR is a slow onset phenomena but it should not be ignored for its consequences in the long term. So the adaptation measures are useful to reduce the possible impacts of SLR in the coastal zones. The adaptation measures must be made to consider the future uncertainty of climate (and many other factors), so there is a need to link adaptation with the risk, uncertainty and vulnerability. Therefore, government and non-government organizations have to play a key role in developing planned adaptation measures that include retreat, accommodation and protection.

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