CLIMATE CHANGE IMPACTS ON SEA LEVEL RISE IN SMALL ISLANDS OF EAST COAST SABAH

TAN ZHONG QING

FACULTY OF SCIENCE AND NATURAL RESOURCES
UNIVERSITI MALAYSIA SABAH
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CLIMATE CHANGE IMPACTS ON SEA LEVEL RISE IN SMALL ISLANDS OF EAST COAST SABAH

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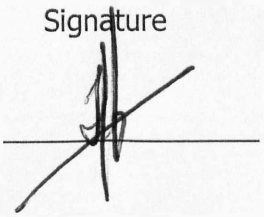

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Tan Zhong Qing
11 Oct 2016

ABSTRACT

Within the Coral Triangle, the islands and their surrounding in the East Coast of Sabah are known as the most biologically diverse and ecologically rich regions on earth. The considerably low-lying area of the coastal setting makes it vulnerable to the impact of sea level change due to its major climate change-related impacts in coastal ecosystems. Thus, it is an indication of urgency to investigate the impacts of climate change and sea level change on coastal inundation and the ecosystem at the coastal areas. Using the statistical downscaling method, the establishment of the statistical relationship between the predictand (sea level) and the predictors (climate variables) allows the estimation of regional climate change by statistical means through the application of regression models to the corresponding output of GCM simulations. By the end of century, based on the worst-case scenario of RCP 8.5, almost 1 hectare (2.5 acres) of coastal land is expected to be lost due to 879 mm and 823 mm of sea level rise in Selingan and Sibuan Island respectively. About 12.3 % of Selingan Island will be inundated while 6.7 % of the Sibuan Island will be submerged due to inundation. A rise of 823 mm of sea level is estimated to submerged about 1.83 hectare (4.5 acres) or 15.3 % of the total land in Sipadan Island. The sand beaches and some vegetated areas would be considered the most vulnerable due to sea level rise. Coastal ecosystems, terrestrial and marine is potentially affected due to the changes of coastline landscape. The submergence of natural turtles nesting ground especially in Selingan Island, saltwater intrusion into groundwater reservoir of the islands and degradation of coral reefs around the island constitute the potential consequences of sea level rise. The high vulnerability of the ecologically sensitive island ecosystem and potentially high risk of coastal inundation may warrant implementation of specific combination of adaptation strategies to ensure sustainability of the island ecosystem.

ABSTRAK

KESAN PERUBAHAN IKLIM KEPADA KENAIKAN ARAS LAUT DI PULAU-PULAU KECIL DI PANTAI TIMUR SABAH

Dalam kawasan Inisiatif Segi Tiga Terumbu Karang, pulau-pulau dan persekitarannya di Pantai Timur Sabah dikenali sebagai kawasan yang paling kaya dengan kepelbagaian dari segi biologi dan ekologi di bumi. Kawasan yang rendah di persekitaran pantai menjadikannya terdedah kepada kesan perubahan paras laut akibat daripada perubahan iklim yang membawa kesan terhadap ekosistem di pantai. Oleh itu, ia adalah satu petunjuk kecemasan untuk mengkaji kesan perubahan iklim dan perubahan paras laut terhadap kebanjiran pantai dan ekosistem di kawasan persisiran pantai. Dengan menggunakan kaedah penskalaan statistik, pembentukan hubungan statistik antara predictand (aras laut) dan predictor (pembolehubah iklim) membolehkan anggaran perubahan iklim serantau melalui statistik dengan penggunaan model regresi untuk data yang sepadan simulasi GCM. Pada akhir abad, berdasarkan senario kes terburuk RCP 8.5, hampir 2.5 ekar tanah pantai dijangka akan hilang akibat daripada 879 mm dan 823 mm kenaikan aras laut di Selingan dan Pulau Sibuan masing-masing. Lebih kurang 12.3 % di Pulau Selingan and 6.7 % di Pulau Sibuan akan tenggelam disebabkan banjir pantai. 823 mm kenaikan paras air laut dijangka akan tenggelamkan kira-kira 4.5 ekar atau 12.3 % daripada keseluruhan tanah di Pulau Sipadan. Pantai-pantai pasir dan beberapa kawasan tumbuh-tumbuhan dianggapkan sebagai kawasan yang paling terdedah kepada ancaman disebabkan oleh kenaikan aras laut. Ekosistem pantai, sama ada darat dan laut adalah berpotensi terjejas disebabkan oleh perubahan landskap pantai. Kawasan penetasan telur penyu semula jadi yang tenggelam di Pulau Selingan, pencerobohan air masin ke dalam takungan sumber air bawah tanah di setiap pulau dan kemusnahan terumbu karang di sekeliling pulau merupakan ancaman yang berpotensi disebabkan daripada kenaikan aras laut. Ancaman yang menjejaskan ekosistem pulau yang sensitif dari segi ekologi dan risiko banjir pantai yang berpotensi tinggi menggalakkan implementasi pelbagai gabungan strategi adaptasi yang khusus untuk memastikan kelestarian ekosistem pulau.

TABLE OF CONTENTS

		Page
TITLE		i
DECLARATION		ii
CERTIFICATION		iii
ACKNOWLEDGEMENT		iv
ABSTRACT		v
ABSTRAK		vi
TABLE OF CONTENTS		vii
LIST OF TABLES		x
LIST OF FIGURES		xi
LIST OF ABBREVIATIONS		xv
LIST OF SYMBOLS		xvi
LIST OF APPENDIXES		xvii
CHAPTER 1: INTRODUCTION		1
1.1	Introduction	1
1.2	Scope of Study	4
1.3	Problem Statements	4
1.4	Objectives	6
CHAPTER 2: LITERATURE REVIEW		7
2.1	Sea Level	7
	2.1.1 The Measurement of Sea Level	8
2.2	Coastal and Small Island Regions Around the World	9

Page

2.3 Factors Affecting Sea Level Changes 12
2.3.1 Thermal Expansion 12
2.3.2 Melting of Land Ice 13
2.3.3 Tectonic Land Movements 13
2.3.4 Other Possible Factors 14
2.4 Variability of Climate and Sea Level Change 14
2.5 The Vulnerability of Low Lying Coastal and Small Islands Due to Sea Level Rise 17
2.5.1 Inundation and Erosion 17
2.5.2 Contamination of Freshwater Resources 18
2.5.3 Degradation of Coastal Ecosystems 18
2.6 Future Projections and Sea Level 19
2.7 Global Climate Models 22
2.7.1 Special Report on Emission Scenarios (SRES) and Representative Concentration Pathway (RCP) 23
2.8 Statistical Downscaling 27

CHAPTER 3: METHODOLOGY 30
3.1 Background of Study Areas 30
3.1.1 Selingan Island 31
3.1.2 Sibuan Island 32
3.1.3 Sipadan Island 32
3.2 Research Framework 33
3.3 Observed Climate Datasets 34
3.3.1 Tidal Datasets 34
3.3.2 Climate Reanalysis Data 35
3.4 Modelled Global Climate Datasets 36
3.5 Establishment of Statistical Approaches in the Observational Records and the Projections of Sea Level 37
3.5.1 Observed Data Analysis 37
3.5.2 Sea Level Projections 38

		Page
3.6	Mapping of Inundation and Vulnerable Areas	39
	3.6.1 Base Map and Land Cover Profiling	39
	3.6.2 Inundation Coverage and Vulnerable Areas Due to Sea Level Rise	43
CHAPTER 4: RESULTS AND DISCUSSIONS		44
4.1	Observational Sea Level and Reginal Climate in East Coast Sabah	44
	4.1.1 Climatic Variables in East Coast Sabah	45
4.2	Relationship of Climate Variables and Sea Level	47
	4.2.1 Sea Level Pressure	48
	4.2.2 Sea Surface Temperature	49
	4.2.3 Wind Variations	51
4.3	Reconstruction of Sandakan and Tawau Sea Level	54
4.4	Projections of Future Sea Level Rise	57
	4.4.1 Selingan Island in Sandakan	57
	4.4.2 Sibuan and Sipadan Island in Tawau	58
	4.4.3 Discussions of Sea Level Projections in East Coast Sabah and Other Studies	59
4.5	Projected Inundation and Vulnerable Areas	63
	4.5.1 Selingan Island	63
	4.5.2 Sibuan Island	66
	4.5.3 Sipadan Island	68
	4.5.4 Summary	70
CHAPTER 5: CONCLUSION		71
5.1	Summary of Finding	71
5.2	Significance of Study	72
5.3	Limitation and Future Research Work	73
REFERENCES		75
APPENDIX		93

LIST OF TABLES

		Page
Table 2.1:	Brief descriptions of SRES storylines	25
Table 2.2:	Brief descriptions of scenario RCP	26
Table 3.1:	Climate variables been used in the analysis for Sandakan and Tawau	36
Table 3.2:	List of global climate models	37
Table 4.1:	Correlation coefficient, r between observed and reconstructed sea level	56
Table 4.2:	Projections of Sea Level Rise by 2100	61
Table 4.3:	Projected Rate of Sea Level Rise by 2100	61
Table 4.4:	Summary of rate of sea level rise by the end of century	62
Table 4.5:	Sandakan sea level rise projection	62
Table 4.6:	Tawau sea level rise projection	62
Table 4.7:	Average sea level rise and inundated land area on each island by the end of century	70

LIST OF FIGURES

		Page
Figure 1.1:	Sea level projection based on IPCC from 1990 to 2100 for different emission scenarios (coloured lable on right). The grey indicates additional uncertainty in the projections	2
Figure 2.1:	Mean sea level geographical distribution of (a) short term (1993-2003) based on satellite altimeter, (b) long term linear trends (1955-2003) based on past sea level reconstruction with tide gauges and altimetry data	9
Figure 2.2:	Coastal and small island regions that vulnerable to sea level rise.	11
Figure 2.3:	Projection of future global mean sea level rise	21
Figure 2.4:	Regional sea level change projection for RCP scenarios (a) 2.6, (b) 4.5, (c) 6.0 and (d) 8.5 between 1986-2005 and 2081-2100.	22
Figure 2.5:	Illustration of four SRES storylines	24
Figure 2.6:	Representative Concentration Pathways (RCPs)	26
Figure 2.7:	Comparison of RCPs and SRES scenarios	27
Figure 3.1:	Sabah and location of the Selingan, Sibuan and Sipadan Island	30
Figure 3.2:	Selingan Island at 6.18° N, 118.06° E	31
Figure 3.3:	Sibuan Island at 4.65° N, 118.66° E	32
Figure 3.4:	Sipadan Island at 4.12° N, 118.63° E	33
Figure 3.5:	Research framework for the investigation of Climate Change impacts on Sea Level Rise in the East Coast of Sabah	34

		Page
Figure 3.6:	Tidal station – a. Sandakan (1994-2013), b. Tawau (1988-2013)	35
Figure 3.7:	Selingan, Eroded remains of coral reefs	40
Figure 3.8:	Selingan, Turtles nesting site	40
Figure 3.9:	Selingan, Turtles hatching site	41
Figure 3.10:	Selingan, Large boulders as wave breaker and erosion prevention	41
Figure 3.11:	Selingan, Flat sandy area facing southern direction	41
Figure 3.12:	Sibuan, Flat and low-lying landscape	42
Figure 3.13:	Sibuan, Eroded limestone rocks at northern part of the island	42
Figure 3.14:	Sibuan, Long sandy area at southern part of the island	42
Figure 3.15:	Sibuan, Low-lying sandy beach	43
Figure 3.16:	Sibuan, Sea gypsies (Bajau laut)	43
Figure 4.1:	Tidal level in Sandakan and Tawau	44
Figure 4.2:	Sea level anomaly of (a) Sandakan and (b) Tawau	45
Figure 4.3:	Anomaly of (a) mean sea level pressure, (b) sea surface temperature, (c) zonal wind and (d) meridional wind between 1994 and 2013.	46
Figure 4.4:	Anomaly of (a) mean sea level pressure, (b) sea surface temperature, (c) zonal wind and (d) meridional wind between 1988 and 2013.	47

		Page
Figure 4.5:	Correlation of sea level and sea surface temperature	48
Figure 4.6:	Anomaly of mean sea level pressure and Sandakan and Tawau sea level anomaly	49
Figure 4.7:	PC of mean sea level pressure and Sandakan and Tawau sea level anomaly.	49
Figure 4.8:	Correlation of sea level and sea surface temperature in Sandakan and Tawau.	50
Figure 4.9:	Anomaly of sea surface temperature and Sandakan and Tawau sea level anomaly.	50
Figure 4.10:	PC of sea surface temperature and Sandakan and Tawau sea level anomaly.	50
Figure 4.11:	Correlation of sea level and zonal wind (u-wind) in Sandakan and Tawau.	51
Figure 4.12:	Anomaly of zonal wind (u-wind) and Sandakan and Tawau sea level anomaly.	52
Figure 4.13:	PC of zonal wind (u-wind) and Sandakan and Tawau sea level anomaly.	52
Figure 4.14:	Correlation of sea level and meridional wind (v-wind) in Sandakan and Tawau.	53
Figure 4.15:	Anomaly of meridional wind (v-wind) and Sandakan and Tawau sea level anomaly.	53
Figure 4.16:	PC of meridional wind (v-wind) and Sandakan and Tawau sea level anomaly.	53
Figure 4.17:	Comparison of Sandakan Sea Level and Reconstructed Sea Level.	55
Figure 4.18:	Comparison of Tawau Sea Level and Reconstructed Sea Level.	55

Page

Figure 4.19: Sandakan's future average sea level projections under scenario a) RCP 4.5, b) RCP 6.0 and c) RCP 8.5 58

Figure 4.20: Tawau's future average sea level projections based on under scenario a) RCP 4.5, b) RCP 6.0 and c) RCP 8.5 59

Figure 4.21: Inundated area in Selingan Island 65

Figure 4.22: Inundated area in Sibuan Island 67

Figure 4.23: Inundated area in Sipadan Island 69

LIST OF ABBREVIATIONS

AOGCMs	-	Atmospheric-Ocean Global Circulation Models
CMIP5	-	Coupled Model Intercomparison Project Phase 5
ECMWF	-	European Centre for Medium-Range Weather Forecasts
ENSO	-	*El Nino* Southern Oscillation
EOF	-	Empirical Orthogonal Function
GCM	-	Global Climate Model
GIA	-	Glacial Isostatic Adjustment
GrADS	-	Grid Analysis and Display System
IPCC	-	Intergovernmental Panel on Climate Change
MSLP	-	Mean Sea Level Pressure
NAO	-	North Atlantic Oscillation
PCA	-	Principal Component Analysis
PCMDI	-	Programme of Climate Model Diagnosis and Intercomparison
PDO	-	Pacific Decadal Oscillation
PSMSL	-	Permanent Service for Mean Sea Level
RCM	-	Regional Climate Model
RCP	-	Representative Concentration Pathway
SRES	-	Special Report on Emission Scenarios
SST	-	Sea Surface Temperature
U	-	Zonal wind
V	-	Meridional wind
WCRP	-	World Climate Research Programme

LIST OF SYMBOLS

%	-	Percentage
cm	-	Centimeter
ha	-	Hectare
K	-	Kelvin
km	-	Kilometer
km^2	-	Square kilometer
m	-	Meter
ms^{-1}	-	Meter per second
mm	-	Millimeter
mm/year	-	Millimeter per year
Pa	-	Pascal

LIST OF APPENDIXES

		Page
Appendix A	Sandakan (1994 – 2013) and Tawau (1988 – 2013) sea level and *El Nino* Index	85
Appendix B	Anomaly of climatic variables in Sandakan. (a) mean sea level pressure, (b) sea surface temperature, (c) zonal wind and (d) meridional wind	87
Appendix C	Anomaly of climatic variables in Tawau. (a) mean sea level pressure, (b) sea surface temperature, (c) zonal wind and (d) meridional wind	88
Appendix D	Reconstructed Sandakan sea level based on the predictors. (a) MSLP only, (b) MSLP + SST, (c) MSLP + SST + U	89
Appendix E	Reconstructed Tawau sea level based on the predictors. (a) MSLP only, (b) MSLP + SST, (c) MSLP + SST + U	90
Appendix F	Future sea level in Sandakan waters based on scenarios RCP 4.5. (a) CSIRO-MK 3.6.0, (b) GISS-E2-H, (c) MPI-ESM-MR and (d) MRI-CGCM3	91
Appendix G	Future sea level in Sandakan waters based on scenarios RCP 6.0. (a) CSIRO-MK 3.6.0, (b) GISS-E2-H and (c) MRI-CGCM3	92
Appendix H	Future sea level in Sandakan waters based on scenarios RCP 8.5. (a) CSIRO-MK 3.6.0, (b) GISS-E2-H, (c) MPI-ESM-MR and (d) MRI-CGCM3	93
Appendix I	Future sea level in Tawau waters based on scenarios RCP 4.5. (a) CSIRO-MK 3.6.0, (b) GISS-E2-H, (c) MPI-ESM-MR and (d) MRI-CGCM3	94
Appendix J	Future sea level in Tawau waters based on scenarios RCP 6.0. (a) CSIRO-MK 3.6.0, (b) GISS-E2-H and (c) MRI-CGCM3	95
Appendix K	Future sea level in Tawau waters based on scenarios RCP 8.5. (a) CSIRO-MK 3.6.0, (b) GISS-E2-H, (c) MPI-ESM-MR and (d) MRI-CGCM3	96

CHAPTER 1

INTRODUCTION

1.1 Introduction

Climate system is an intricate yet interactive system that consists of five natural components which are the atmosphere, hydrosphere, lithosphere, cryosphere and biosphere. The atmospheric components of the climate system are most obviously characterizing the climate. Climate usually described as weather that can be identified by the changes in the mean and/or the variability of its properties, and that persists for an extended period, typically 30 years or longer whether it is due to natural variability or as a result of human activities (IPCC, 2007b). The climate around the world differ by the geographical location, geomorphological properties, elevation as well as water bodies. Long periods of time enable researchers to observe the most important internal cycles and define a baseline measure from which to distinguish the signal of a changing climate against the statistical noise of natural climate variability. However, climate phenomena take time to show its effects due to the energy needed to be distributed around the planet through the ocean. The delay of the energy distribution in the climate system leads to implications where it adds a degree of determinism and predictability as over a long period of time, the energy will manifest in the climate system which gives rise to weather that people experience.

The temporal lags imply that the full warming from the current concentrations of greenhouse gases has yet to be realized where there is an obvious argument between the emission of anthropogenic greenhouse gases today and the timescales on which the consequences of those actions will be realized. Studying anthropogenic climate change impacts over such long timeframes is complicated as huge social economic changes have occurred over the past 100 years, making it difficult to distinguish what effects has had in that time range. However, the widespread

warming of the atmosphere and the ocean, together with loss of ice mass has been observed for the past fifty years, corroborate the statement that it is likely climate change of the past half century is influenced by external forcing and it is not due to known natural causes alone (Nicholls, 2010).

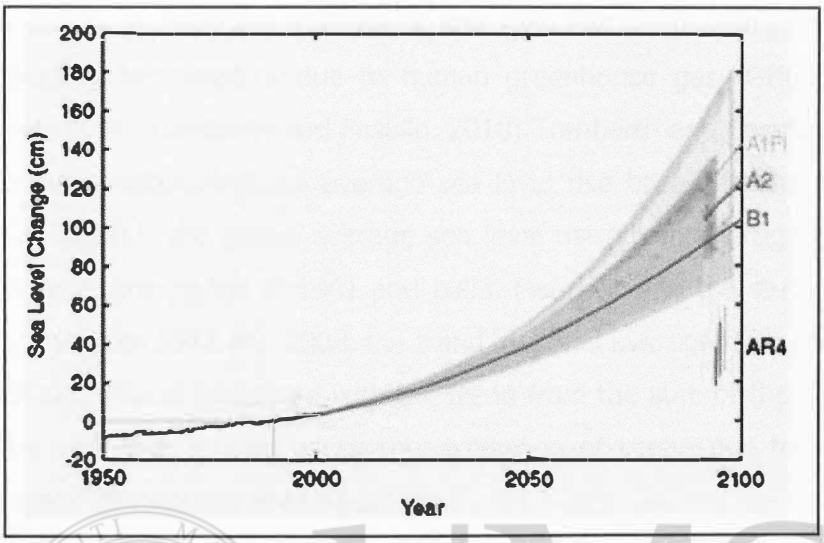

Figure 1.1: Sea level projection based on IPCC from 1990 to 2100 for different emission scenarios (coloured label on right). The grey indicates additional uncertainty in the projections.

Source : Vermeer and Rahmstorf (2009)

IPCC had reported that during the 21st century, projected sea level will rise another 0.18 m to 0.59 m (IPCC, 2007b). US National Research Council had published a literature assessment showing a different and much higher sea level projection ranged (Figure 1.1) based on same period as IPCC (Vermeer and Rahmstorf, 2009; National Research Council, 2010). All of these projections are considerably larger than the sea level rise estimates by 2100 provided in IPCC AR4, which did not account for potential changes in ice sheet dynamics and are considered conservative. Though, according to Nicholls *et al.* (2011) in AR4 projection, 66 % significant portion of the sea level rise is contributed by thermal expansion and the contributions from ice sheets are considered to be small. In addition, IPCC (2007b) excluded the uncertainty due to lack of understanding on process that control the flow rate of ice sheet losses. Some information of primary processes and feedbacks between local climate and ice sheets is too limited to provide the best estimation or the maximum range of sea

level rise. While these high end scenarios may be relatively unlikely, their potential impacts make them highly significant in terms of climate risk (Keller *et al.*, 2008).

Sea level rise and its impacts to the environments have caught the attention of many researchers since the emergence of concern on human-induced global warming in 1980s. In fact, the increase of sea level has been associated with the raising of ocean's temperature due to human greenhouse gas (GHG) emissions (Levitus *et al.*, 2001; Trenberth and Fasullo, 2010; Trenberth and Fasullo, 2011). In terms of the observational global average sea level rise based on the analysis of Nicholls *et al.* (2011), the global average sea level rise at an average rate of 1.8 mm/year between the period of 1961 and 2003. Meanwhile in the study of Church *et al.* (2011) between 1972 and 2008, the trend in global average from the tide data of 1.8 ± 0.2 mm/year is compared with the trend from the sum of the contribution of 1.8 ± 0.4 mm/year, among which the expansion of ocean due to increase of temperature and glaciers are the largest.

Since IPCC Third Assessment Report (TAR), the understanding of the implication of climate change for coastal system and low lying areas has increased substantially. Coastal regions are highly sensitive to the change of climate, which impose substantial costs on coastal societies. Large populations of people at the coastal regions are exposed to impacts of climate change, which vulnerable to coastal hazards such as cyclones, storm surge, coastal erosion and submergence. From the report published by IPCC, it states that South East Asia is highly vulnerable to adverse impacts of climate change due to the geology and geography of the coastal areas, growing population density in the coastal zone (IPCC, 2007b). Coastal areas in countries like Bangladesh, Philippines, Thailand and Malaysia, sea level rise is the most major climate change-related impact on coastal ecosystem. Islands have characteristics which makes them very vulnerable to the impacts of climate change. The increase of sea level will exacerbate inundation, erosion, cause degradation of coastal ecosystem especially wetlands and coral reefs as well as terrestrial habitat such as turtles nesting area.

1.2 Scope of Study

This study focuses on the vulnerable areas of the island based on the projections future sea level rise and coastal inundation in the selected islands of Sandakan (Selingan Island) and Tawau (Sibuan and Sipadan Island). Besides that, the contributions of climatic factors such as sea level pressure, sea surface temperature, wind variations of zonal wind and meridional wind on sea level change are studied.

1.3 Problem Statements

Malaysia has a land area of 329,847 km^2 and a coastline of about 4800 km where the coastal area covers land area of about 4.43 million hectares or 13% of the total land mass in Malaysia. Out of the total coastal land area in Malaysia, Sabah has 1.00 million hectare of coastal land, accounting for 13% of the land area in Sabah (Md. Sujahangir *et al.*, 2014). It has been a long history for Sabah of setting aside important natural areas for conservation of its unique and rich flora and fauna. Variety categories of protected areas form a crucial part of the nature conservation in Sabah such as terrestrial parks and marine parks. Sabah have 3 terrestrial parks and 5 marine parks under the Parks Enactment, 1984. Three marine parks are found in East Coast Sabah where Turtle Islands Park is located in Sandakan District, while Tun Sakaran Marine Park and Sipadan Island Park are located in Tawau District. Marines parks can play an essential role in addressing the impacts of climate change and ecosystem resilience. Aside from ecological and conservation value, the marine parks also play an important position in tourism to increase local people's income and national revenue. While they have the responsibility to provide lasting protection and minimize some local disturbance to the ecosystems, they remain vulnerable to large scale disturbances originating outside their boundaries, particularly those associated with climate change. Climate change and sea level rise would be expected to hamper the economy, trade, tourism, biodiversity and livelihood of the island.

Due to the low lying characteristic of the islands and the geographical location situated in the open sea without natural or artificial protections, these small islands are most exposed to the external impacts. Increase of storm surge events due to climate change and rise of sea level will destroy the coastal areas and increase coastal erosion especially on sandy beach coast. Beside coastal erosion, inundation is another

major threat of sea level rise. Coastal inundation will submerge the low-lying coastal area and destroy the terrestrial and marine ecosystem on the island. Based on Tegart and Seldon (1993), due to low lying coastal plain, a rise of about 0.35 m mean sea level will lead to almost 1 km of landward advance of sea water. The sea level and inundation will lead to landward migration of mangrove due to shrinking of the island. Moreover, the low temperature tolerance and slow growth rate characteristic of coral reefs will contribute the degradation of coral reefs due to climate change and sea level rise. Furthermore, sea level rise and inundation will lead to saltwater intrusion, contamination of surface water and groundwater quality. The over-exploitation of groundwater activities will decrease the freshwater lens underneath the island and exacerbate the impacts to islands (Church *et al.*, 2006). Impacts to the small island due to rise of sea level and inundation will also severely affect the tourism industry.

Generally, the application of global climate models is for the purpose of future climate scenarios study. Since the global climate models are lack of sufficient fine resolution to focus on the islands, the projections are usually given over ocean surfaces instead of over small area of land and less efforts have been applied for downscaling these coarse resolution climate model to the small islands so that the projections on regional or local scale can be made. The downscaling can be conducted using either dynamical or statistical method. However due to the limited substantial computational resources, the more convenient statistical downscaling method would be best alternative method to implement this analysis. The information and details of both dynamical and statistical downscaling will be discussed in next chapter. Regardless on the analysis methods, there is indication of urgency to begin the adaptation and mitigation of sea level rise especially when the target is protected area. Thus, the research questions for this study are:

i. What are the magnitude of sea level rise in small islands of East Coast Sabah namely Selingan Island, Sibuan Island and Sipadan Island under different climate scenarios?
ii. How significant are the impacts of coastal inundation to the coastal areas due to climate change?
iii. How vulnerable are the three islands to the sea level rise and coastal inundation?