ESTIMATION OF SEA LEVEL RISE IN KOTA KINABALU

LOOI KAI XIANG

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ABSTRACT

The increasingly rising trend of sea level is an issue that raise global considerable concern. Due to the limited data and research available in this area, the study will carried out to estimate the sea level rise in Kota Kinabalu by using correlation analysis. The estimation of sea level rise upon the coastal plain of Kota Kinabalu Sabah are examined by identifying the trend analysis of tide gauge pattern, precipitation pattern and temperature within the range of 10 years data, from 2005-2014. The rate of sea level rise for the study area was estimated at an annual rise of 9.172 mm/year for the past 10 years. By the year of 2100, the sea level is projected to be rise by an additional of 0.789 m in Kota Kinabalu based on the linear equation obtained from annual sea level rise trend. The changes in percentage of sea level, temperature and precipitation in Kota Kinabalu for the past 10 years are also calculated to show their changes as compared to last year to have a better understanding on their fluctuation of values. Correlation of the relationship between sea level, temperature and precipitation are considered weak and insignificant. Responding to sea level rise in the most economically efficient manner will challenge humans to learn and adapt over a long period of time.
ABSTRAK

ANGGARAN KENAikan PARAS AIR Laut DI KOTA KINABALU

Trend paras laut yang semakin meningkat adalah satu isu yang menimbulkan kebimbangan besar di peringkat global. Oleh sebab data dan penyelidikan yang terdapat di kawasan ini terhad, kajian akan dijalankan untuk menganggarkan kenaikan aras laut di Kota Kinabalu dengan menggunakan analisis korelasi. Kadar peningkatan aras laut ke atas zon persisiran pantai Kota Kinabalu Sabah telah dikaji dengan menganalisis trend pasang surut air laut, trend hujan dan suhu sepanjang tempoh 10 tahun bermula tahun 2005-2014. Kadar kenaikan aras laut bagi kawasan kajian dianggarkan mengalami kenaikan tahunan sebanyak 9,172 mm / tahun untuk 10 tahun yang lalu. Pada tahun 2100, paras air laut dianggarkan meningkat sebanyak 0.789 m di Kota Kinabalu berdasarkan persamaan linear yang diperolehi dari trend kenaikan paras laut tahunan. Perubahan peratusan paras laut, suhu dan hujan di Kota Kinabalu sejak 10 tahun yang lalu juga dikira untuk menunjukkan perubahan mereka berbanding tahun lepas supaya mempunyai pemahaman yang lebih baik mengenai nilai turun naik mereka. Hubungan korelasi antara aras laut, suhu dan hujan adalah dianggap lemah dan tidak penting. Tindak balas kepada kejadian kenaikan paras laut dengan cara yang paling cekap dari segi ekonomi akan mencabar manusia untuk belajar dan menyesuaikan diri bagi tempoh masa yang panjang.
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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Globally, human populations along the world's coasts are at a historic high and there were no signs of a slackening in growth. Trends in the population distribution of many nations by the end of this century promise to yield spatial demographics showing a large percentage of the total population living near the coast (Martinez et al., 2007). The increase in coastal populations worldwide is alarming for many reasons, not least for what it portends for the quality of the coastal environment, which is already threatened by high levels of eutrophication and toxic materials, over-fishing and habitat destruction.

However, the prospect of an accelerating rise in global sea levels has captured international attention due to the magnitude of the hazards posed and their economic, social and political consequences. The existence of sea level rise is undeniable. The oceans have the potential to increase in height at the coast at an accelerated rate during this century and thereafter, due to the impacts of increased greenhouse gas concentrations responsible for global warming. Global warming is the main contributor to the rise in global sea level since the Industrial Revolution. Human activities such as burning coal and oil and cutting down tropical forests increase atmospheric concentrations of heat-trapping gases (Hansen et al., 2010). Besides, the associated melting of polar and alpine glaciers and changes in ocean currents also contributes to sea level rise (IPCC, 2007). Accelerated sea level rise will have far-reaching impacts on low-lying coastal regions around the world. In the case of the Maldives, the continued existence of the nation-state is at risk (Titus, 1989).
IPCC Fourth Assessment Report (AR4) estimated a global sea level rise of 18 to 59 cm from 1990 to the 2090s (Rahmstorf, 2010). These ranges are narrower than in the IPCC Third Assessment Report, mainly because of improved information about some uncertainties in the projected contributions (Solomon et al., 2007). However, the global mean sea level rise will not be uniform around the world since the local change in sea level at any coastal location depends on the sum of global, regional, and local factors, which is termed as relative sea level change.

On the other hand, the response of coastal ecosystems to climate change and rising sea level is strongly influenced by continuing developments such as developments that in many cases lead to overexploitation of resources, pollution, sediment starvation and fragmentation of ecosystems through urbanization and development of infrastructure (World Coast Conference, 1993). These developments will, on an increasing scale lead to a decrease in the resilience of coastal systems in coping with natural climate variability. Moreover, these developments adversely affect the natural capability of the systems to adapt to changes in climate and eventually lead to the increased hazard potential for coastal population, infrastructure and investments.

Therefore, the assessment of impacts of climate change in coastal areas involves the estimation of the additional risk that is posed by climate change to systems that already are under significant stress (Bijlsma, 1997). Thus, predictions of changes in coastal ecosystem boundaries, in response to projected relative rising sea level enables advanced planning appropriate for specific sections of coastline. This predictions facilitate in minimize and offset anticipated losses besides reduce threats to coastal development and human safety (Gilman et al., 2007).

Although sea level rise is generally considered a relatively slow process on human time scales (Cronin, 2012), it has a very significant long-term impact, influencing the dynamics of coastal erosion, groundwater salinization and change in natural ecosystems (Nicholls and Cazenave, 2010). In view of the high and increasing population density and of the numerous coastal areas potentially vulnerable to flooding, erosion and loss of wetlands (Nicholls et al., 1999) in the coastal region, the problem of future sea level rise is particularly felt. In key zones, future sea level rise
will exacerbate existing human pressure, will impact the development of tourism (Cori, 1999) and will influence the migration fluxes.

Over time choices may change as sea level rise forecloses certain options or new solutions for building resilience emerge. Mankind will also develop a deeper understanding of the risks and tradeoffs in the path of confronting climate change. In weighing the best options for each unique coastal community, we will also need to share experiences and coordinate policies and actions across local, state, regional, and national jurisdictions. However, even as we work to adapt to unfolding climate change, deep reductions in our global warming emissions remain one of the best ways to limit the magnitude and pace of sea level rise and cut the costs of these adaptations.

1.1.1 Importance of Research

Studies to estimate the sea level rise between year 2005 and 2014 using correlation analysis is vital to determine the rate of increase of sea level rise along the coastline of Kota Kinabalu. This is crucial as it can provide information about the profile changes that occur in the surrounding respective area. This is based on the trend of sea level rise which is seen as an old issue that raise global considerable concern. This study also allows the initial expectations about the relationship between climate change factors which is precipitation and temperature with sea level rise to be observed for the purpose of designing effective alternative in the study area. Furthermore, this study is important in order to examine knowledge of global issues of sea-level rise, and as a first step for assessing the risk of coastal areas in this study, which is Kota Kinabalu being flooded in the future.

1.1.2 Research Scope

The research scope gives focus on the climate change factors that affect sea level rise on coastal areas in Kota Kinabalu, Sabah. First of all, the trend of increasing sea level is studied using data from year 2005 to 2014 with the application of statistical
methods such as Microsoft Excel. The data used are the latest secondary data applied from respective Malaysia Meteorological Department and National Hydraulic Research Institute in Malaysia. The data applied are annual and monthly tidal gauge data, precipitation pattern and temperature data of Kota Kinabalu, Sabah for the past 10 years from 2005 to 2014.

1.1.3 Problem Statement

Kota Kinabalu, a major coastal city in Malaysia, had been experiencing relatively slow sea level rise during the past decades due to several climate change factors such as global warming. Nowadays, there is a serious yet growing concern on the Impact of sea level rise towards social and economic activities especially in densely populated areas such as Kota Kinabalu. Due to the limited data and research available in this area, the study will carried out to estimate the sea level rise in Kota Kinabalu with correlation analysis using Microsoft Excel.

1.1.4 Significance of Study

The research study should provide information on the issues of climate change factors particularly on tidal pattern, precipitation pattern, temperature and their relationship with sea level rise in the city of Kota Kinabalu. This study will also be a review of the accelerating rate of sea level rise in Malaysia, particularly in the coastal areas of Kota Kinabalu. Furthermore, this study would be beneficial to the people living in the city of Kota Kinabalu as this study enhance the knowledge of the people about the sea level rise issues which is a major global environmental concern. Moreover, this study would provide the necessary information on the risk of flooded coastal areas in Kota Kinabalu in the near future. This would expectedly heighten the awareness of the people regarding the threat of sea level rise by projecting sea level rise in the future. To the future academicians and researchers, this study can provide baseline information and data on the sea level rise matter in Kota Kinabalu.
1.2 RESEARCH OBJECTIVE

The objective of the research is shown as below:

a. To determine the rate of sea level rise using data collected at the study site.

b. To identify the relationship between precipitation, temperature and sea level rise.
CHAPTER 2

LITERATURE REVIEW

2.1 Geography of Malaysia

Malaysia is a coastal nation situated in the centre of South East Asia. The country had divided into two parts. Peninsular Malaysia, commonly known as West Malaysia, comprise of the long fringe of land, stretching down from South East Asia that connects Singapore and Thailand. The mainland is divided by the South China Sea from the less inhabited East Malaysian provinces of Sabah and Sarawak. Malaysia contains an estimated land area of 329,847 km$^2$ and a coastline stretching 4800km long where the coastal section spreading a land area of about 4.43 million hectares or 13% of the sum land mass in Malaysia. The coastal could be additionally separated into 1.18 million hectares in Peninsular Malaysia, 1.00 million hectares in Sabah and 2.25 million hectares in Sarawak, considering for 9%, 13% and 18% correspondingly of the land area in these regions. 27% coastal land had been previously predicted to be used for agriculture while forest and urbanized area covers 69% and 4% respectively (Cetdem, 2010).

2.2 Global Climate Change

Climate can be defined as the average weather or the statistical description in terms of the mean and variability of relevant quantities over a period of time, ranging from months to thousands or millions of year (IPCC, 2008). From the definition of the United Nations Framework Convention on Climate Change (UNFCC) in its Article 1, climate change is 'a change of climate which is attributed directly or indirectly to
human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods’ (IPCC, 2008).

In fact, the earth’s climate is dynamic and always changing through natural cycle. However, the variability in climate may be due to natural internal process or external forcing within the climate system, or to persistent anthropogenic changes in the composition of the atmosphere or in land use (Houghton et al., 2001). Thus, UNFCC makes a distinction between climate change that can be attributed to human activities altering the atmospheric composition, and climate variability that can be attributed to natural causes. Climate change will primarily lead to changes of physical nature such as sea levels, temperature, precipitation and occurrence of extreme weather and as a result it impacts the social, economic and ecological system (Anja & Salik, 2009).

2.3 Sea Level Rise Scenario

The International Panel on Climate Change (IPCC, 2012) reported that the global mean surface air temperature has increased by 0.5°C in the 20th century and was projected to increase further in between 1.5 to 4.5°C in this century. These temperature changes will have many negative effects such as greater frequency of heat waves, increased intensity of rain events, floods, drought, spread of diseases and rising sea levels (McLean, 2009). Sea level rise poses a particularly ominous threat because 10% of the world’s population lives in low-lying coastal regions within 10 m elevation of sea level.

Sea level, or referred as the Mean Sea Level, is the average height of the surface of the ocean. As the average height increases, it causes major implications to coastal vulnerability, especially in the sense of seizing land area. However, sea level variation differs between global and regional measurements, as there are some regions where sea level seems to be falling due to land uplift, such as the Gulf of Alaska (Gornitz, 1990). Therefore, to measure sea level variations regionally, both sea level and vertical land motions need to be considered. There are two types of
measurements for sea level; the first is relative sea level, and the second is absolute sea level. Relative sea level (RSL) measures sea level rate with the inclusion of vertical land motion. It is measured via tide gauges over a coastline. Hence, the apparent sea level rate at the coast of a region can be derived. Absolute sea level (ASL) measures only the sea level rate without any external effects.

There are three main factors contributing to the rising sea level which includes ocean thermal expansion; melting of the Greenland and Antarctica glacier and ice sheets; and lastly changes in terrestrial storage, with ocean thermal expansion as the dominant factor. However, new data on rates of deglaciation in Greenland and Antarctica suggests greater significance for glacial melt, and a possible revision of the upper-bound estimate for sea level rise in this century. Since the Greenland and Antarctic ice sheets contain enough water to raise the sea level by almost 70 m, small changes in their volume would have a significant effect (Dasgupta et al., 2007).

2.3.1 Global Sea Level Rise

Rising sea levels also pose a particular threat to countries around the world with high population and socioeconomic activities in the coastal regions. Church et al. (2006) predicted a sea level rise of 0-1 meter during the 21st century. Meanwhile, Bindoff et al. (2007) estimates the global mean sea level rise rate to be 1.8 ± 0.5 mm/year for the period of 1961-2003 and 1.7 ± 0.5 mm/year over the 20th century while Dasgupta et al. (2007) estimate the rate of sea level rise as 3.1 ± 0.7 mm/year, based on satellite altimetry observations for the period of 1993 to 2003.

Large variations in sea level rise were observed in the western Pacific and eastern Indian Ocean, mainly due to ocean circulation changes associated with El Nino Southern Oscillation events (Church et al., 2006). Sea level change varies spatially with some regions showing higher rates compared to the global mean sea level rise while sea level in other regions is falling, probably due to regional thermal expansion (Dasgupta et al., 2007). The increase in occurrences of extreme high water due to storm surges and variations in the extremes related to mean sea level rise in the regional climate are also evident (Bindoff et al., 2007).
2.3.2 Sea Level Rise in Malaysia

Although the global prediction for sea level rise is about 1.7 – 3.1 mm/year, the regional sea level rise in Malaysia is expected to be higher, owing to local climate and topographical conditions. Low lying areas with high population and socio-economic activities are at risk of being inundated. Malaysia has a long shoreline with most of the cities located near the coast, and NAHRIM has carried out a number of studies as our preparation to face global warming issues in terms of projections for sea level rise in Malaysia.

Sea level has not been rising uniformly around Malaysia. According to NAHRIM (2010), a study was carried out to project sea level rise in the Malaysian coast for the year 2100. Using linear trend analysis, satellite altimetry data from year 1993 to 2010 from 30 stations around Malaysia were analyzed to obtain the rate of sea level rise for Malaysia. The results showed that there is a significant increase in sea level rise trend over the recent 5 years, compared to the sea level rise trend over 20 years ago. Beside from that, the observed mean sea level rise rate along the Malaysian coast based on satellite altimetry data from 1993 to 2010 is between 2.7 -7.0 mm/year. Meanwhile, the mean sea level rise rate recorded by Kota Kinabalu on that time is around 5.25 mm/year. This ranked Kota Kinabalu sea level rise values as moderate risk based on the United States Geological Survey (USGS) definition (NAHRIM, 2010).

![Figure 2.1 NAHRIM sea level rise projection for Malaysia by 2100 (NAHRIM, 2010).](image-url)
In Peninsular Malaysia, the projected sea level rise for the year 2100 is 0.25 – 0.5 m with the maximum value occurring in low-lying areas along the northeast and west coast of the peninsular (Kelantan and Kedah). Meanwhile in Sabah, the projected sea level rise for the year 2100 is 0.69 – 1.06 m with the maximum value occurring in low-lying areas, river mouths and estuaries in the East coast (Tawau, Semporna, Lahad Datu, Sandakan and Kudat). The sea level of Kota Kinabalu is expected to rise by 0.698 m in 2100 as shown in Figure 2.1. For Sarawak, the projected sea level rise for the year 2100 is 0.43 – 0.64 m with maximum value occur in low lying areas, river mouths and estuaries in the Southwest coast (Meradong). The results obtained from NAHRIM showed that Sabah is suffering from greater risk of sea level rise if compared to peninsular and Sarawak (Figure 2.1).

2.4 Impacts of Sea Level Rise in Malaysia

Flooding of coastal regions particularly low-lying coastal areas could become increasingly likely and serious because of sea level rise and elevation in the incidence of drastic high water phenomenon associated to high tides, storm surges and flooding rivers (Nicholls, 2004). Flooding and loss of land may cause noteworthy effects on humans, economy, fauna and even ecosystems. Susceptibilities of economic sectors and related source of income, water capital, national defense, energy, transportation, investments in homes and the well-being of a various assemble of people living in coastal regions constitute to the socioeconomic vulnerability of the coastal region because of sea level rise (Nicholls, 2002; Burkett & Davidson, 2012). A coastal country such as Malaysia would encounter a handful of impacts via the rise of sea level.

Severe erosion issue had been faced by our country for a number of years where 1400 km (30%) of the 4800 km coastline is prone to varying level of erosion. The southern states of Malaysia such as Selangor, Negeri Sembilan, Melaka, Pahang and Johor are regularly flooded. It was estimated that 9% of the land area in Malaysia is susceptible to flooding affecting up to 3.5 million people. Sea level rise could increases the flood proneness of these states (ICZM, 1999).
The emerging in the consequences of sea level rise could bring much higher economic impact. An average of RM 100 million losses was recorded by our country annually due to floods (Baharuddin, 2007). Inundation or abrasion during the floods in Johor causes a revealed RM 46 million loss of agricultural output for Western Johor Agricultural Development Project area (Cetdem, 2010). Interventions of economic pursuits, mostly agriculture production, along vulnerable extensions of coastline are the lead reasons of economic loss as an effect of immediate inundation in the occurrences of bund breach. According to Chamhuri et al. (2009), climate change may influence food output adversely caused by yield changes in agriculture and geographical alteration, depletion in the amount of water accessible for irrigation and misplacement of land via sea level rise and related salinization. A 5.75 billion US$ PPP could be required by Malaysia as an extra economic cost annually for sea level rise by the year 2030 (Climate Vulnerability Monitor, 2010).

Though it is hard to compute the social influence of sea level rise but it is assumed that large number of people of the coastal region would be relocated and their source of income could be affected (Pernetta, 1992). Sea level rise will inundate land as Malaysia has a long coastline of 4800 km and people of the low lying areas need to be displaced. It has been estimated that 2500 people may be affected and 450 km² of extra land will be perished of Malaysia annually because of sea level rise by 2030 (Climate Vulnerability Monitor, 2010).

### 2.5 Adaptations to Sea Level Rise

Adaptation action are demanded to lower the adverse effects of sea level rise and to safeguard the resources and livelihood of our coastal zone. It is inarguable that certain cost was required for adaptation measures but could be less than the expenses of sea level rise without adaptation. Modification measures should be made to consider the sizeable unpredictability concern on future climate and numerous other factors, so there is a necessity for a risk and uncertainty based manner rather than searching for deterministic answers (Nicholls, 2003). Thus, government should play a key role in developing arranged adaptation measures (Nicholls, 2003). There
are plenty of adaptation approaches which can be involved in the lessening of effects of sea level rise.

Structural measures like seawalls and dikes are a reactive approach to defend people, belongings and infrastructure from sea level rise. This has been the conventional approach to deal with sea level rise in many parts of the globe (Bijlsma et al., 1996; Klein et al., 2001; Arlington Group Planning, 2013). Such measures vary from large-scale general plan to small-scale efforts by independent property holders. Benefits of non-structural preventive measures such as beach nourishment and coastal wetland reconstruction are also in growing concern. These measures could be administered as sea level rises which would supplement structural protection and strengthen the natural flexibility of the coastal region. They can be cheaper than structural protection, which will head to undesirable impact on erosion and sedimentation arrangement if implemented improperly (Arlington Group Planning, 2013).

Meanwhile, retreat is regarded as any strategic resolution to displace, remove or evacuate public or private belongings at threat because of coastal hazards. This adaptive plan is aim to restrict the operation of structural protection, design for the eventual displacement of Infrastructure to regions with lower uncertainty and discourage development in zones prone to sea level rise. All natural system impacts are granted to happen and human effects are lessened by pulling back from the coast in this approach (Bijlsma et al., 1996; Klein et al., 2001).

Accommodation is another adaptive approach that permits extended occupation of coastal region while changes are made to human activities or infrastructure to alter to sea level rise (Arlington Group Planning, 2013). This required retrofitting a construction and making it more flexible to the impact of sea level rise. Other accommodation measures would contain liability depletion like a covenant indemnifying governments from the impact of coastal threats irrespective of protection works that are handled. All natural system influence was authorized to take place and human consequences are lessened by regulating human use of the coastal region under the condition of this approach (Bijlsma et al., 1996; Klein et al., 2001).
In practice, it is impossible to curb sea level rise by using a single approach of adaptation. Hence, various and hybrid reaction require to effectively decrease the adverse effects of sea level rise. All the reaction may be mainstreamed with local policy, strategy and resilience-building plans even though most assessments of adaptation regarding mixtures of retreat and protection solely where the accommodation choice remains mostly non-accessible.

2.6 Impact of Climate Change on Sea Level Rise

Climate change is recognized as one of the notable problems confronted by Mother Earth and mankind nowadays. Changes in climatic forms such as the elevation in mean temperature, rise in sea level and mighty downfall of rain could head to climatic changes. There is scientific evidence that the concentration of greenhouse gases in the atmosphere, global mean temperature and mean sea level are rising. In addition to changes in sea surface temperature, rainfall in certain areas may contribute significantly to sea level variations (Camfield & Morang, 1996).

Natural sources including continental drifts, volcanic eruptions and the earth’s incline and anthropogenic root or man-made activities such as land clearing, industrial development and production of greenhouse gases are basically the two major sources of climate change. These man-made activities may be affected by global, national and local feature. One of the global factors which were global warming is trans-border in nature whilst industrialization, clearing of land for agriculture and encroachment of fragile ecosystem are examples of national and localized factors (Baharuddin, 2007).

2.6.1 Impact of Temperature on Sea Level Rise

Climatologists believe that there has been a slight, but steady rise in air temperature since the 1800s when reliable temperature records first became available (Aung et al., 1998). This phenomenon is known as global warming, the increase of average global air temperature. Over the last hundred years (1906-2005), the average global


Cetdem. 2010. *Socio-Economic Impacts of Climate Change in Malaysia*. Centre for Environment, Technology and Development Malaysia.


