SEASONAL VARIATIONS OF SEA LEVEL AND THE TRENDS IN JOHOR BAHRU

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ABSTRACT

Sea level rise has become the issue that everyone is discussing about in this 21st century. This was induced by the ongoing climate change issue where visible effects of these such as hot weathers are being experienced by everyone. Although globally, many scientist have started looking into this issues, locally this is sadly very much understudied. In order to be able to actually determine the effects of sea levels on each local areas, local sea level studies must be carried out as global sea level rates cannot help us at all. This study was done to determine the sea level trends in Johor Bahru for over a period of 28 years. The yearly, monthly and daily sea level data's were obtained from Permanent Service for Mean Sea Level (PSMSL) and also University of Hawaii Sea Level Centre (UHSLC). This data was then analyzed separately through time series and linear regression analysis to produce a sea level trend. The cumulated Sea Level Trend analysis was then carried out to determine if the sea level trends were stable for future sea level projection in Johor Bahru. The results from this study was that sea levels in Johor Bahru have risen 89 mm in the last 28 years and will continue to rise at a rate of 3.18 mm per year, almost double the global sea level trends. Monthly sea level anomaly was also observed and then correlated with the formations of El-Niño and La niña events. The results of this study can help the local residents, town planning committee and state government of Johor to carry out proper coastal managements and mitigative steps to prevent beach erosions and land losses.

ABSTRAK

Pada abad ke-21 ini, isu peningkatan paras laut semakin menjadi isu yang dibincang oleh semua orang. Isu ini dibangkitkan akhir-akhir ini kerana kesan daripada pemanasan global seperti peningkatan suhu semakin dirasai oleh semua pihak. Walaupun pada peringkat global, isu ini banyak dikaji oleh para saintis, namun pada peringkat tempatan isu ini sangat kurang dikaji. Untuk membolehkan kesan kesan peningkatan paras laut dipastikan, kajian tempatan tentang hal ini perlu dilakuan kerana kadar peningkatan paras laut global langsung tidak boleh mendatangkan sebarang manfaat kepada kita. Kajian ini dilakukan untuk memastikan kadar peningkatan paras laut berdasarkan 28 tahun data. Data tahunan, bulanan and harian ini diperoleh daripada Permanent Service for Mean Sea Level (PSMSL) dan juga University of Hawaii Sea Level Centre (UHSLC). Data yang diambil ini terus dikaji melalui regrasi linear untuk mendapatkan kadar kenaikan pada setiap tahun. Kajian untuk kadar peningkatan paras laut kumulatif dilakukan untuk memastikan bahawa kadar paras laut menigkat untuk masa depan boleh ditentukan. Hasil daripada kajian ini menunjukan bahaea paras laut di Johor Bahru telah meningkat sebanyak 89 mm pada 28 tahun yang lalu, dan akan terus meningkat pada kadar 3.18 mm setiap tahun. Kadar peningkatan ini adalah dua kali ganda kadar peningkatan yang telah dikemukakan oleh saintis untuk kadar peningkatan global. Perbezaan peningkatan paras laut bulanan juga dikaji dan dikaitkan dengan fenomena El-Niño dan La niña sejauh mana yang boleh. Hasil daripada kajian ini juga membolehkan penduduk tempatan and kerajaan Johor Bahru untuk menentukan cara pengurusan pantai dan langkah-langkag pencegahan untuk memastikan hakisan pantai dan kehilangan tanah tidak berlaku.

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LIST OF SYMBOLS

mm / yr	millimetre per year
mm / mth	millimetre per month
mm	millimetre
cm	centimetre
m	metre
km	kilometre
km^2	kilometre square
hPa	hectoPascal
$\bar{x}$	mean value
no.	Number
c	y-axic intercept
m	gradient
Σx	sum of sample x
ΣXY	sum of X and Y
n	number of sample
°C	degree celcius
°	degree
±	standard deviation
%	percentage

LIST OF FORMULA

LIST OF ABBREVIATIONS

BOM	Bureau of Meteorology
CSIRO	Commonwealth Scientific and Industrial Research Organisations
DSMM	Department of Survey and Mapping Malaysia
DSMM	Department of Survey and Mapping Malaysia
E	East
ENSO	El Niño Southern Oscillation
EPU	Economic Planning Unit
GMSL	Global Mean Sea Level
IPCC	Intergovernmental Panel on Climate Change
MSL	Mean sea level
N	North
NAHRIM	National Hydraulic Research Institute of Malaysia
PSMSL	Permanent Service for Mean Sea Level
SOI	Southern Oscillation Index
SSH	Sea Surface Heights
UHSLC	University of hawaii Sea Level Centre

CHAPTER 1

INTRODUCTION

1.1 Sea Level Rise

Sea-level rise was one of the issues that first triggered widespread concern about the potentially adverse effects of anthropogenically-induced climate change (Nicholls, 2002). Sea level is a measured water height from a reference level, the results of all relevant influences which affect the height of the sea surface (Aung *et al.*, 2013). Sea level is constantly changing both globally and locally due to tides, meteorological influences, thermal effects, seismic effects, oceanographic influences and vertical land movement.

The 2007 assessment report of the IPCC-Intergovernmental Panel on Climate Change (IPCC AR4, 2007) has given new sea level rise estimates that range between 18 and 59 cm up to the end of next century. This report corrected the previous one (IPCC TAR, 2001) which showed a higher uncertainty with a range of 9 to 88 cm. However, because of uncertainties about the response of ice sheets to warmer temperatures and future increases in emissions of enhanced greenhouse gases, there is a possibility of getting higher values then predicted.

Rising of sea levels becomes a threat especially to the residents living in coastal areas. Low-lying areas are more susceptible to frequent flooding and the danger of being submerged completely. Growing populations and development along these coastal areas increase the vulnerability of coastal ecosystem to sea level rise. Wetlands would no longer function as natural buffers to flooding because they would not be able to receive enough sediment to keep up with the rising seas. Other buffers like mangrove forests and coral reefs would also be harmed due to rise in sea level.

Rise in sea level would also cause salt water intrusion into aquifers and this could harm aquatic plants and animals with low salinity tolerence level. To be able to reduce all these negative impacts, sea-level measurements are being taken primarily using the tide gauge, and over the past decade, using altimetry satellites.

1.2 Problem Statement

According to a media report in the Berita Harian dated May 20th 2011, Prof Ir Dr Abdul Aziz Abdul Samad, vice chancellor of Universiti Tun Hussein Onn Malaysia (UTHM), stated that based on sea level analysis done by Dr Tan Lai Wai, a lecturer in that university, they found that sea level in Malaysia is rising at a rate of 10 cm per year since 2004. However, shortly after that report was brought to our attention, another media report regarding this issue was seen on MyNewsHub on July 6th 2011. In this report, the Ministry of Natural Resources and Environment said that the 10 cm per year increase in sea levels that the Tun Hussein Onn University stated was not accurate. This then brings us to the question: Which of these two reports should Malaysians believe in?

Narrowing down to the situation in Johor Bahru, based on a study by the Drainage and Irrigation Department in 2006, the New Straits Time (July 23rd 2010) reports that Tan Sri Joseph Kurup, Deputy Minister of the Natural Resources and Environment stated that sea levels in Johor would go up by 13 cm in the next 100 years. He also stated that 6 per cent of Malaysia's coastline was being eroded by the sea and this puts the economy under threat.

Because of these contradicting reports, each giving a different opinion on the sea level rise issue in Malaysia, this study in being carried out. With sufficient data (more than 18.6 years to complete a nodal cycle), this study aims to analyse to actual situation of the Johor Bahru sea level and determine its trends. To be able to determine this trend, the annual, monthly and daily sea level time series needs to be done, so that the regression analysis can be carried out.

1.3 Study Area

Johor Bahru (JB), is the capital city of Johor in southern Malaysia, which is north of Singapore. Johor Bahru is the southernmost city in Peninsula Malaysia. This area is selected as a study area because of its coastal areas being densely populated with humans which leads to much of the development taking place in these areas. This makes the study area highly susceptible to the effects of sea level rise. As of 2010, this city has a population of 1,334,188 people and a population density of 7,409/km^{2}. (Department of Statistics Malaysia, 2010).

1.4 Objectives of Study

- To examine mean sea level (MSL) in Johor Bahru.
- To analyse yearly, monthly and daily sea level data for seasonal variations.
- To calculate sea level trends in Johor Bahru.
- To decide the variation in trends of sea level rise in Johor Bahru over the past 28 years, if they are stable for future sea level projection.

1.5 Hypotheses

- There is a significant difference between the yearly, monthly and daily variation of sea level in Johor Bahru depending on the climate phenomena.
- There is a general increase in mean sea level in Johor Bahru areas as there is in other parts of the world.
- The calculation of local sea level trends in Johor Bahru yields a positive trend of sea level rise, higher than the global average.

1.6 Significance of Study

Being a maritime nation with a coastline (not including the smaller islands) of 4,809 km (Economic Planning Unit (EPU), 1985), it is essential that Malaysians know the dangers and threats of the sea level rise issue. Many of us do know that there is this problem of sea level rise, but since we are not actually presented with local data's proving this point, we dismiss it as something insignificant, oblivious to its detrimental effects.

Globally, there are many studies being done on this issue and people have even started looking for ways to reduce the negative impacts. However locally, there are not many studies being done to prove whether sea levels in this region are also rising. Therefore, the primary aim of this study is to answer the question: Is sea level really rising in Johor Bahru? The results of this study would then indicate the threats that we may have to face in the future (if there is a rise in sea level) or steps that can be taken to make sure it remains this way (if there is no rise in sea level).

Nicholls (2002) stated that many countries are aware of sea-level rises, but yet chooses to ignore it in their long-term coastal planning, which resulted in disastrous effects for its inhabitants. Hence, we do not want to wait till it is too late before we decide to act.

CHAPTER 2

LITERATURE REVIEW

2.1 Sea Level

Global sea levels have on average risen by approximately 21 cm over just the last 130 years (Church and White, 2011) and this value is predicted to rise continually at an accelerated rate throughout and beyond the 21st century (Meehl *et al.*, 2007), even if somehow the emissions of greenhouse gases are controlled. Hence this is the reason why there are so many researches and studies being done currently by many scientists regarding the sea level rise issue.

According to the Intergovernmental Panel on Climate Change (IPCC, 2007), some 125,000 years ago, during the last interglacial period, sea level was likely 4 m to 6 m higher than it was during the 20th century. It also continues by saying that 4 m of this rise was likely from the Greenland Ice Sheet, and maybe a little contribution from the Antarctic Ice Sheet. IPCC also stated in their report that sea level has risen by more than 120 m about 20,000 years ago, when the last glacial maximum occurred. This is largely due to the loss of mass from present and earlier ice sheets, which elevates global sea level at locations far away from the main glaciations centre.

At the end of the last glacial maximum, sea level rose at an average of 1 m per century, with the highest rates of 4 m per century (Fairbanks, 1989). When many coastal cities became established in the last 2000 years, sea level rise was only on average approximately 0.2 mm per year. But the rates began rising from the 19th to the 20th century when it reached an average of 1.7 mm per year. From 1961 to 2003, the average rate of sea level rose to 1.8 ± 0.3 mm per year. With the aid of altimetry satellite measurements, sea level showed an increase of 3.1 mm per year from 1993 to 2003.

Although many studies strongly suggest a rising trend in sea levels, there are still some scientist who thinks that there is no rise in sea levels at all (Pirazzoli, 1986; Mörner, 2004, 2007, 2010, 2011). Professor Nils-Axel Mörner stated that one of the keepers of the satellite record told him that the record has been interfered with to show a rise in sea levels, because the raw data obtained showed no increase at all in global sea level. The raw data was collected from the TOPEX/POSEIDON (from 1993 to 2000), showed only a slight uptrend in sea level. However Professor Mörner said that after the exclusions of distorting effects of the Great El Niño Southern Oscillation of 1997/1998, a naturally-occurring event, the sea-level trend is zero. Then there is the GRACE gravitational-anomaly satellites, which are able to measure ocean mass, from which sea-level changes can be calculated. This GRACE data showed that sea level fell slightly from 2002 to 2007. Therefore Professor Mömer concluded that using two distinct satellite systems with different measurements methods, where both produced raw data reaching identical conclusions must only prove one thing – sea levels are barely rising (Mörner, 2007, 2010).

In conclusion, though there may be arguments among scientists with regards to the rising of sea levels, they all mostly agree on one fact: a rise in global sea levels does not necessarily indicate a rise in local sea levels. As the Commonwealth Scientific and Industrial Research Organisation (CSIRO) puts it, "the ocean is NOT like a bathtub - that is, the level does not change uniformly as water is added or taken away. There can be large regions of ocean with decreasing sea level even when the overall Global Mean Sea Level (GMSL) is increasing."

2.2 Variations in Sea Level

In the Intergovernmental Panel on Climate Change's Fourth Assessment Report (2007), it is stated that the ocean thermal expansion and melting of non-polar glaciers and ice caps are the biggest contributors to the recent sea-level rise. Both of these factors mentioned are due to the rise in global temperatures mainly as a result of greater enhanced greenhouse gas emission. During the 20th century, greenhouse gas concentrations increased significantly due to the burning of fossil fuels, which contributed to a global temperature rise of about 0.6°C. This led to a rise in global sea levels of about 20-30 cm (Houghton *et al.*, 2001). There are also regional factors like the El Niño-Southern Oscillation or meteorological impacts like storm surges that causes sea level rise.

Over the last 50 years, observations have pointed out that the global ocean warmed significantly, although not uniformally (Levitus *et al.*, 2005). Ocean thermal expansion has contributed about 0.4 mm per year to the global mean over the past 50 years (Antonov *et al.*, 2005). Later, during the satellite era, this rate accelerated to between 1.2 mm per year (Antonov *et al.*, 2005) and 1.6 to 1.8 mm per year (Lombard *et al.*, 2005). Although there has been a significant increase in the rate of sea levels due to thermal expansion during this past decade, it is not the only factor involved. Sea level rise that cannot be explained by thermal expansion, may be caused by melting of non-polar glaciers and ice caps.

Advances and retreating of ice sheets is another important process affecting sea level rise, but only when considering long-term time periods. The Greenland and Antarctica ice sheets hold the vast mass of Earth's fresh water. During 1961 to 2000, the melting of the Antarctic ice sheets resulted in a 0.14 mm per year rate of sea level rise and a 0.05 mm per year rise for the smaller Greenland ice sheet. The observations for the later decade of this period, 1993 to 2003, showed estimates of 0.21 mm per year in terms of sea level rise for each ice sheet's melting (IPCC, 2007). Alpine glaciers and ice caps are estimated to have contributed to a 0.5 mm per year rise in sea level from 1961 to 2003 and 0.77 mm per year during the last decade of that period (Reeh *et al.,* 1999).

Changes in sea levels and vertical land movements may also result in the varying of relative sea levels, as sea level is observed relative to the fixed bench mark located on land. One good example would be in the Scandinavia regions, due to isostatic rebound of land – rising of land masses due to melting of glaciers, succeeding the last glaciations have caused mean sea levels in those areas to fall by 10 cm per year. Therefore, mean sea level rises does not occur the same way in every region (Yanagi & Akaki, 1994). Because the change in relative sea levels differs according to each particular location, different mitigation and adaptive measures are needed for each location.

Finally, there is increasing scientific eveidence that the rise in sea level observations are associated with anthropogenic effects like emission of enhanced greenhouse gasses which leads to climate change (Houghton *et al.*, 2001). This human influence on climate is expected to intensify during the 21st century as there would be growing populations in coastal areas (Nicholls, 1995; Nicholls and Small, 2002). While mitigation is needed to avoid the worst impacts of the sea level rise issue, currently planned adaptive measures are essential. This is due to the fact that planned adaptive measures are more cost effective that responses to impacts in the future.

2.3 Length of Sea Level Data

The point that has been repeatedly stressed on is the importance of having long term sea level data for a more reliable sea level trend analysis. The widely accepted fact is that for a reliable sea level analysis, 18.61 years of data is necessary. This is because the time taken for a full rotation of the Moon's orbital plane around the ecliptic, also known as the nodal tide cycle is 18.61 years (Woodworth, 2012). The ecliptic is the plane of the apparent path of the Sun on the celestial sphere, and is coplanar with both the orbit of the Earth around the Sun and the apparent orbit of the Sun around the Earth. This cycle of the lunar node is important because it plays a huge part in determining tides in the atmosphere and oceans. The atmospheric tides then affect rainfall which in turn affects the sea levels (Tomes, 2005).

2.4 Measuring Sea Level

Over the last decade, our knowledge of sea level has improved considerably. These sea level measurements that we hear and read about are derived from either the tide gauge observations or the satellite altimetry measurements (Nerem *et al.*, 2006). The primary source of sea-level information over the past century is from tide gauge measurements. The tide gauge measures water-level heights with respect to the zero mark on a tide staff as a vertical reference. However, this becomes a disadvantage as it would be affected by the vertical land motions unrelated to climate-driven sea level variations. A good example of a tide gauge record that has been contaminated by vertical land movement, in this case the sinkage of land, is the record for Manila in the Philippines as shown in Figure 2.1. The rise between 1970 and 2010 is not because of sea level, it is the result of sinking land at the place where the tide gauge is deployed.

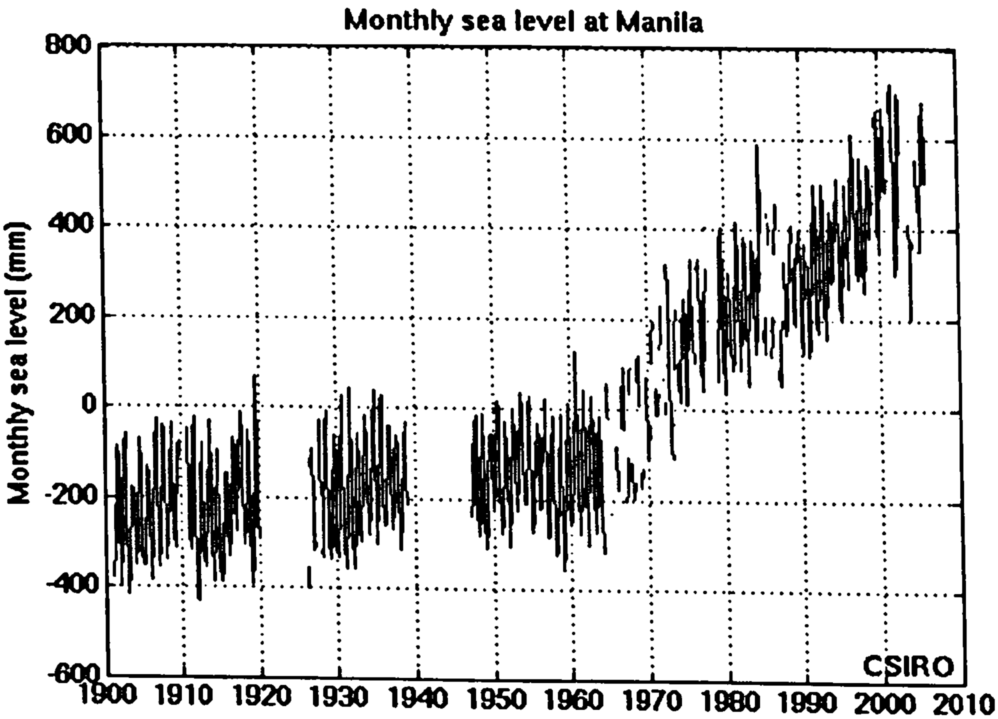

Figure 2.1 Monthly Sea Level in Manila from 1900-2010 (Source : CSIRO, 2010)

An alternative to overcome the inaccuracies of the tide gauge is to measure sea levels from space, that is through the satellite altimetry technique. Sea levels measured from the satellites are known as sea surface heights (SSH). Early missions (e.g. Seasat mission of 1978) measured SSH with an accuracy of tens of metres. However, with recent high quality satellite altimeters such as the TOPEX/Poseidon (launched in August 1992 and its mission endured till October 2005) and its successors, Jason-1 (launched in December 2001) and Jason-2 (launched in June 2008), SSH is measured to an accuracy of just a few centimetres (CSIRO, 2010). Although the satellite altimetry records are still quite short when compared to the tide gauge data sets, this technique still appears to be quite promising as it minimises errors and provides measurements with a very good coverage (Cecile *et al.*, 2001). The altimetry satellites are suitable in determining global sea levels as it is able to measure an amazing 66°N to 66°S latitudes (Nerem *et al.*, 2006), which is a near-global coverage.

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