METHOD TO ESTIMATE THE LAND LOSS FROM SEA LEVEL RISE DUE TO GRADUAL WARMING IN KOTA KINABALU, SABAH

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ABSTRACT.*Debateshave been going on for several years regarding the issue of global warming and subsequent sea level rise. Are humans one of the contributing factors to the warming of the Earth's temperature? Or is it just a natural phenomenon and there is nothing to be worried about? Whatever it is, global warming, the increase of average global air temperature, is one of the most talked about and of high concern issues today, not just amongst the scientists, but also the general public. The rise of air temperature and subsequent increase in sea surface temperature (SST) will raise the sea level due to thermal expansion. These changes in water temperature could affect the health of many aquatic species, in addition to causing land loss and beach erosion. For the past 10 years (2000 until 2009), the average air temperature change in Kota Kinabalu, Sabah is approximately 0.10°C and according to these trends for the next eleven years (until 2020), the projection of air temperature change will be approximately0.21°C. When this happens, average sea surface temperature (SST) will also increase due to the relationship between air temperature and water temperature, though the change in SST may not be as large as the air temperature increase. The empirical relationship obtained in this study for air temperature and SST is SST = 0.241T + 22.6, with air temperature, T. As a rule of thumb, an increase of 1°C in SST can raise sea level by approximately 1 cm.. Using the SST data for the last eleven years, the change of SST is also calculated, as well as the projected SST changes for the next decade. Based on the last decade's data, SST in Kota Kinabalu has increased 0.26 °C and it will increase another 0.24 °C by 2020. Sea level in Kota Kinabalu has also increased by 2.6 mm inthe last 11 years. Projections show that sea level in Kota Kinabalu will increase another 2.4 mm by 2020. Using the estimated value of sea level rise due to SST increase, land loss is also estimated for the coastal areas in Kota Kinabaluandthe calculation is explained.*

KEYWORDS. Air temperature, beach angle, beach loss, sea level rise, sea surface temperature

INTRODUCTION

Since the last ice age, which is approximately 18000 years ago, the global temperature trend has been generally upward. This may not raise much concern, as it is normal for Earth's temperature to fluctuate slowly over time. However, what is deeply concerning is the rate of this increase. Studies have shown that the rate of this increase has only recently accelerated (Garrison, 2005). Most scientists believe that twenty thousand years ago, at the peak of the last ice advance, the global temperature was about 5°C lower than it is today. Climatologists also 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. Debates have been going on for several years about what is causing global warming. Are humans to blame? Or is it just another natural occurrence and there is actually nothing to be worried about?

According to Garrison (2005), the rapid increase in global warming is mostly caused by the enhanced greenhouse effect, where heat is trapped inside the Earth's atmosphere. Hence, the more greenhouse gases, such as carbon dioxide, water vapour, methane and Chlorofluorocarbons (CFCs) there are in the Earth's atmosphere, the more heat will be absorbed, causing the air temperature to increase more. According to Vitousek (1994), the recent increase of carbon dioxide, after the 19^{th} century, is substantial and is five to ten times more rapid than any of the sustained change in ice core records (prior to the 19^{th} century) due to human demands for quick energy to fuel massive industrial growth. Carbon dioxide is now being produced at a higher rate than the rate it can be absorbed by the ocean (Vitousek, 1994; Garrison, 2005). Problems that may arise if global warming were to persists includes shifting the strength and position of surface currents, increase in acidity of the ocean as more carbon dioxide are dissolved in the sea water and also increase in global sea level.

According to Aung*et.al* (1998) and Peltier&Tushingham (1989), sea level has risen, approximately at the rate of 1 to 2 mm per year (globally) over the last 100 years. Half of this rise in sea level is contributed from the thermal expansion of the ocean's surface layers due to increase in global air temperature and another half is due to the addition of mass to the ocean from the melting of land ice (glaciers).

The ultimate aim of the paper is to highlight the simple methodology of estimating the sea level rise in any area using available environmental parameters. This study will focus mainly on the land loss due to increase of sea level in Kota Kinabalu and surrounding areas, as a result of air temperature rise and subsequent water temperature rise. Due to the relationship between air temperature and water temperature, sea surface temperature (SST) will increase as global air temperature increases, though the change may not be as big as the air temperature rise. When SST increases, sea level will also increase due to thermal expansion of ocean waters. Coastal flooding, beach and land loss as well as beach erosion are just some of the problems that may arise if sea level continues to increase. Other than that, the changes in water temperature could also affect the health of many aquatic species as not many species are able to tolerate even small changes in temperature.

Study Area

The area chosen for this study is Kota Kinabalu, Sabah, Malaysia. Kota Kinabalu the capital city of Sabah, and is located at the west coast of Sabah with latitudes 05° 58' N until 06° 06' N and longitudes 116° 04' E until 116° 16' E (Figure 1). Kota Kinabalu, Sabah is separated from Peninsular Malaysia by the South China Sea and is sheltered by islands including Gaya and Sepanggar.

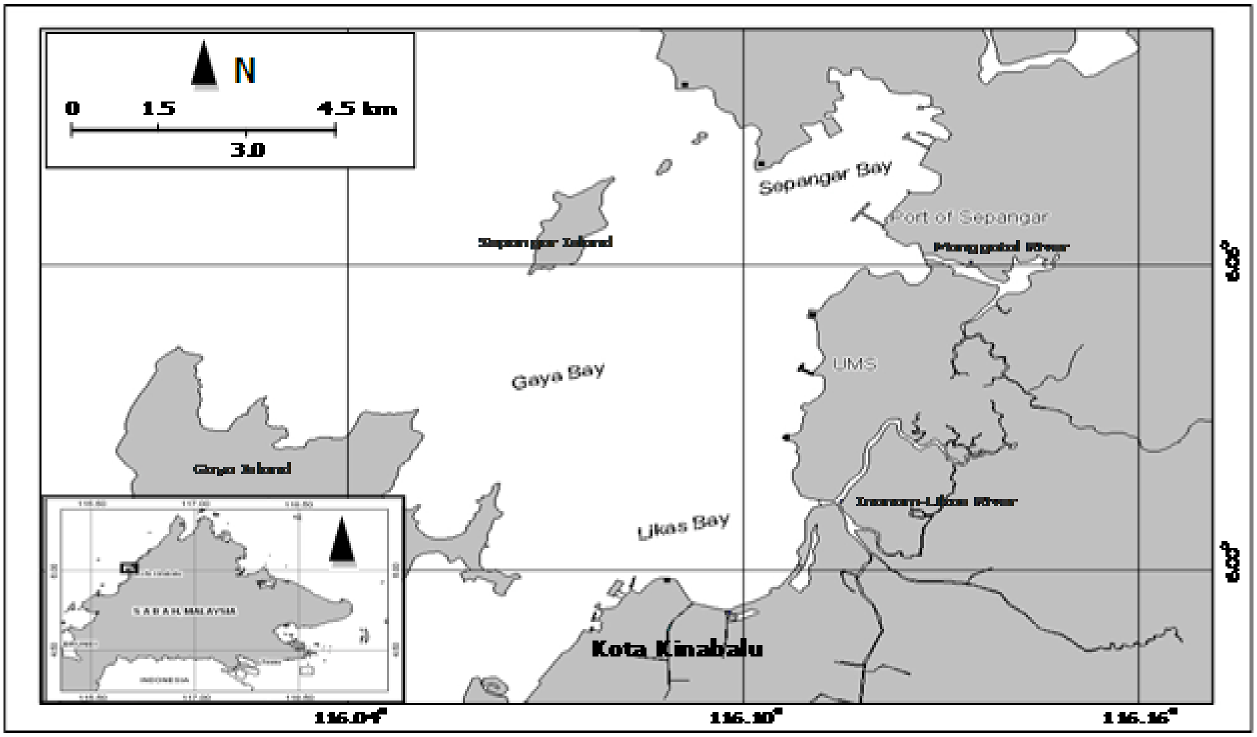

Figure 1. Map showing the study area Kota Kinabalu in Sabah, Malaysia.

Generally, Kota Kinabalu experiences uniform temperature throughout the year, with high humidity and abundant rainfall. Wind flow in Sabah is generally light and variable, and seasons here can be categorized into four: the southwest monsoon (later half of May or early June until September), northeast monsoon (early November until March) and two shorter periods of inter-monsoon seasons (MMD, 2010). Seasonal wind flow patterns, combined with the local topographic features, will determine the rainfall distribution over the country. Being an equatorial country, Malaysia, and therefore Kota Kinabalu, experience uniform temperature throughout the year with average temperature of 27°C (although may range from 26°C to 32°C). The annual variation of temperature is less than 2°C. However, daily temperature changes are relatively large: 5°C to 10°C in coastal areas and 8° C to 12°C in inland areas (MMD, 2010).

MATERIALS AND METHODS

Data Collection

Data for air temperatureand SST were obtained from Kota Kinabalu Meteorological Department. These meteorological data were acquired for a 10-year period (from 2000 until 2009) for air temperature and 11-year period for SST (from 2000 until 2010). After all the desired data have been collected, a trendplot for air temperature and SST for Kota Kinabalu were developed, and changes within the study time frame were observed and calculatedfor the projection.

Effect of Air Temperature on Water Temperature

Generally, an increase of 1 °C of air temperature will raise approximately 0.6 °C to 0.8 °C of water temperature(if it is still water). But sea water temperature is heavily depending on many other factors (such as currents and upwelling) since it is in constant motion.

Thermal Expansion of Sea Water

Solids, liquids and gases expand when they are heated. Unlike solids, gases and liquids do not have well defined shapes. Therefore, the volume expansion for gases and liquids needs to be considered. The change of volume, ΔV, due to temperature change, ΔT, can be given as follows:

$$\Delta V = \beta V_0 \Delta T$$

Where:

V_0 = initial volume

β = coefficient of thermal expansion

If we consider the upper layer of approximately 30 m to 40 m for any area (since heat transfer does not penetrate up to the deep water), A, the initial volume of sea water $V_0 = 35A$. The coefficient of thermal expansion of standard seawater under normal condition, β, is approximately 300×10^{-6} °C^{-1} and temperature change, $\Delta T = 1$ °C. Taking all these values into account, the following result is obtained:

$$\Delta V = 300 \times 10^{-6}\ °\mathrm{C}^{-1} \times 35A \times 1$$

If we consider the same surface area, A, the change in volume due to local thermal expansion, ΔV, can be described as follows:

$$\Delta V = A\,\Delta h$$

Where:

Δh = change in height (or sea level change)

$$\therefore \Delta h = 1.05 \times 10^{-2}\ \mathrm{m} = 1.05\ \mathrm{cm}$$

Therefore, it can be concluded that 1°C temperature increase over the upper layer of approximately 30 m to 40 m will raise the sea level by approximately 1.05 cm (or 1 cm, as it is generally assumed).

Effect of Atmospheric Pressure on Sea Level

As a simple methodology it is worthwhile to include the effect of atmospheric pressure on sea level (although we did not analyse the pressure data in this study due to some technical difficulties in obtaining the data on time). It was evidenced that pressure changes during ENSO period could be significant. Due to the 1997-98 strong El Niño, the whole western Pacific region experienced higher pressure and sea level was depressed up to ~30 cm for several months through 1998-1999 (Singh and Aung, 2005). Although the effect was not permanent, it could not be simply ignored.

Generally, a change of 1 hPa of barometric pressure may cause approximately 1 cm variation in sea level. This can be explained from the example below:

$$\text{Atmospheric pressure change, } \Delta P = 1 \text{ hPa [hPa = hectoPascal]}$$

This pressure change is acting upon the sea surface. Therefore, the following relationship can be used for the variation of sea level:

$$\Delta P = \Delta h \, \rho g$$

Where:

ρ = density of sea water
Δh = sea level change due to atmospheric pressure difference
g = acceleration due to gravity

Using the typical values for the equation above:

$$1 \text{ hPa} = 1 \times 10^2 \text{ Pa} = 100 \text{ N m}^{-2}$$

$$\Delta h \times 1026 \text{ kg m}^{-3} \times 9.8 \text{ m s}^{-2} = 100 \text{ N m}^{-2}$$

$$\therefore \Delta h = \sim 10^{-2} \text{ m} = 1 \text{ cm}$$

This effect is known as the inverted barometric pressure. Inverted barometric effect is the depression of the water surface under high atmospheric pressure and elevation of water surface under low atmospheric pressure. Water level does not adjust itself immediately to a change of atmospheric pressure, and will respond to the average change in pressure over a considerable area. Changes in sea level that are caused by variations in atmospheric pressure rarely exceed ~30 cm. However, the effect is important as it is associated with those caused by wind setup, since winds are driven by pressure gradient.

Land Loss Due to Sea Level Rise

Coastal erosion is the wearing away of land or the removal of beach or sediments by wave or current actions, sediment deficiencies (sand mining, harbor or navigational channel construction etc) and sea level rise. This paper will focus solely on the effect of sea level rise on land or beach areas.

Beach profiling and shoreline position data areessentialto provide a baseline for geometric evaluation of coastal or beach areas.From beach profiling, slope or angle of a beach can be found. Take for example, for a particular area, sea level has risen 1 cm after a certain time as shown in Figure 2.

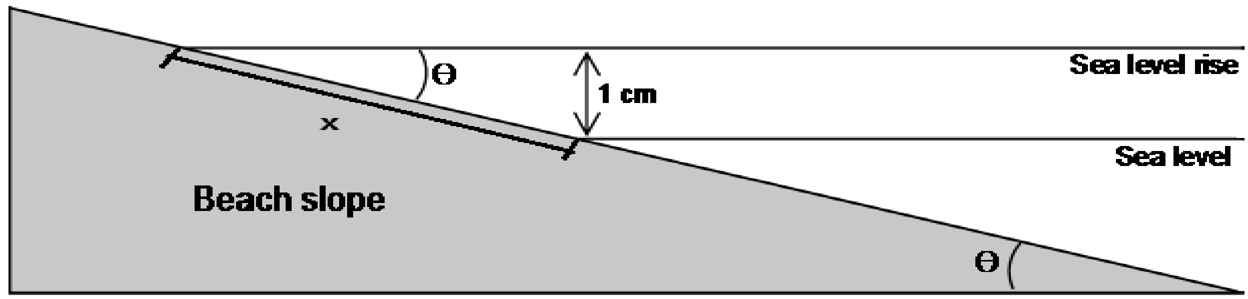

Figure 2.Schematic diagram showing land loss due to sea level rise of 1 cm.

To find land loss due to sea level rise, *x*, the following formula is used:

$$\sin\theta = \frac{1\,cm\ (sealevelrise)}{x}$$

$$x = \frac{1}{\sin\theta}\,\text{cm}$$

Where:
θ = beach angle
x = land loss due to sea level rise

Using different values of beach angles (as shown in Table 1), land loss due to 1 cmsea level rise for each anglecan be calculated:

Table 1.Prediction of land loss due to sea level rise with different beach angles.

$\boldsymbol{\theta}$ (Beach angle)	x (Land loss due to sea level rise)
1°	57.3 cm
2°	28.7 cm
3°	19.1 cm
4°	14.3 cm
5°	11.5 cm
10°	5.8 cm
15°	3.9 cm
20°	2.9 cm
25°	2.4 cm
30°	2.0 cm

From Table 1, it can be seen that the smaller the beach angle, the bigger or more the land loss will be. Beach or coastal areas in or located nearby Kota Kinabalu such as TanjungAru beach and TanjungLipat beach are popular destinations for many people for recreational activities. These areas may be affected by sea level rise. Therefore, understanding and predicting the effect of sea level rise towards these beaches is important.

RESULTS AND DISCUSSION

Air Temperature

From the data for the last decade, the average air temperature for Kota Kinabalu during the study period of 10-year is 27.34 °C. Between 2000 and 2009, air temperature ranges from 26.0 °C to 28.6 °C. Figure 3 shows the fluctuations of monthly average of air temperature in the study area from 2000 until 2009.

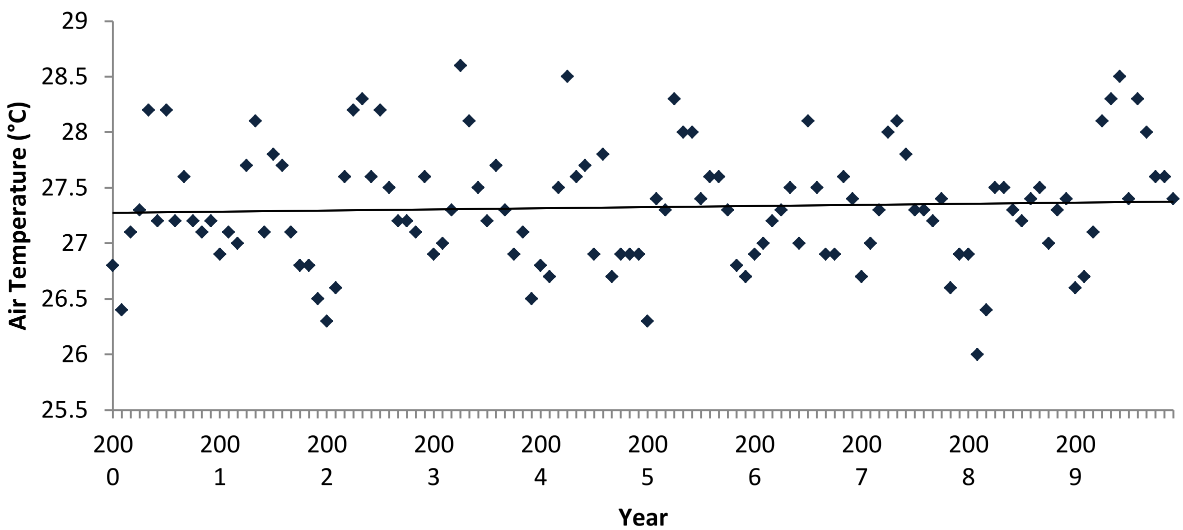

Figure 3.Monthly average of air temperature in Kota Kinabalu (from 2000 until 2009).

As shown in Figure 3, for the past 10 years, air temperature in Kota Kinabalu showed a slight but gradual increase, with an increase of approximately 0.847×10^{-3} °C per month. Empirical relationship obtained from the variations of air temperature in Kota Kinabalu from 2000 until 2009 is $T = 0.000847t + 27.275$ with air temperature, T and number of months, t. From 2000 until 2009, average air temperature in Kota Kinabalu has risen 0.10 °C. According to these trends, for the next eleven years (until 2020), the projection of air temperature increase will be approximately 0.11 °C, assuming business as usual. From 2000 until 2020, air temperature in Kota Kinabalu will have increased 0.21 °C.

SST

Results showed that the average SST during the study period is 29.2 °C. SST ranges from 27.0 °C to 32.0 °C between 2000 and2010. Figure 4 shows the fluctuations of monthly average of SST in the study area from 2000 until 2010.

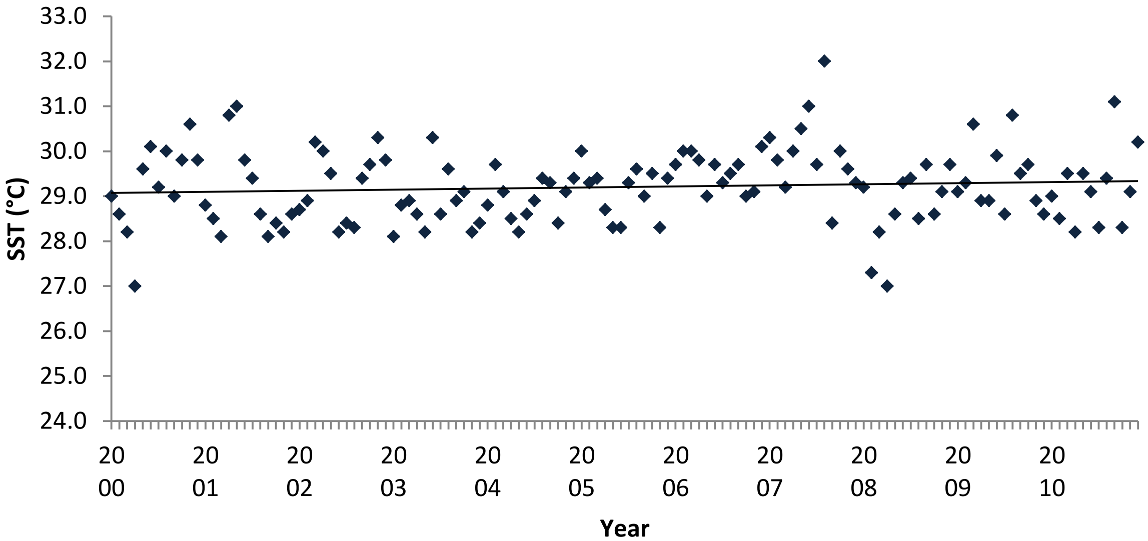

Figure 4.Monthly average of water temperature in Kota Kinabalu (from 2000 until 2010).

Based on Figure 4, SST in Kota Kinabalu showed a continuous increase through the study period, with an increase of approximately 0.002°C monthly. From that value, SST in Kota Kinabalu has increased 0.26 °C over the past 11 years. The linear correlation relationship obtained from the increase of SST in Kota Kinabalu from 2000 until 2010 is $SST = 0.002t + 29.069$ with the number of months, t.From the projection done in this study, SST will increase another 0.24°C until the year 2020, again, assuming business as usual. Therefore, from 2000 until 2020, SST in Kota Kinabalu will have increased 0.50 °C.

It is significant to note that SST increase is much higher than air temperature increase. During the last decade, there are fourEl Niño episodes,although the usual frequency is 3-7 years. As expected, stronger warm pool in the western Pacific region is believed to influences the water temperature in the study area.

Relationship between Air Temperature and SST

As an additional analysis, relationship between air temperature and SST is also briefly considered in this study using the decade long data.Figure 5 shows the relationship between air temperature and SST in Kota Kinabalu. The empirical relationship obtained for air temperature and SST is $SST = 0.241T + 22.6$, with air temperature, T. From the figure, it is found out that SST is always higher compared to T, air temperature (but only applicable with validity range until SST-22.6 = 0.241T, with 0.241, the slope of the relationship between air temperature and SST, and 22.6, the value of SST that intercept the y-axis).

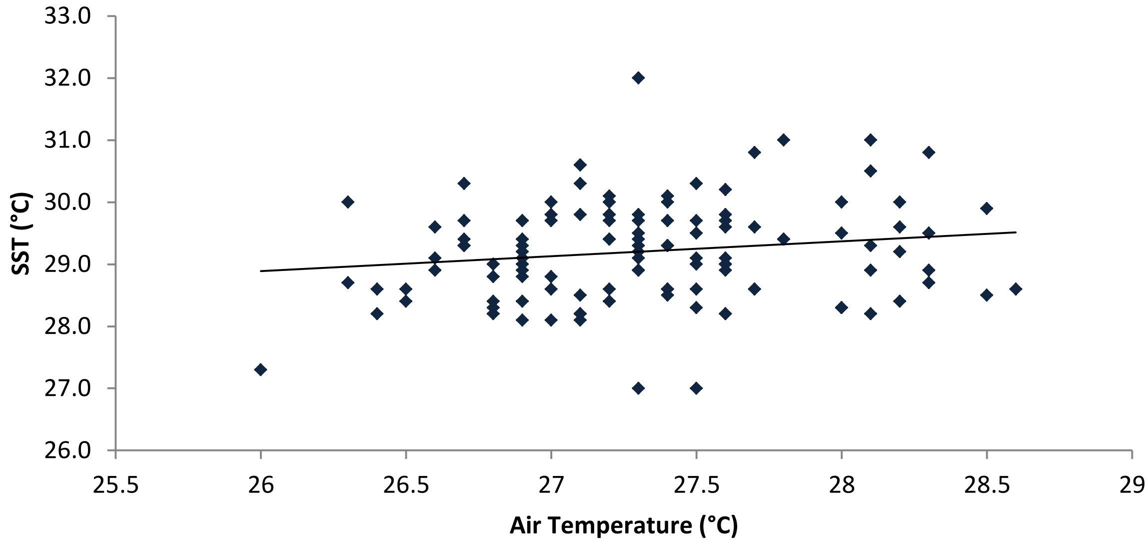

Figure 5.Relationship between air temperature and water temperature (2000 until 2009).

It is interesting to note that the result is somehow the opposite of the common perception by many people, as it is always assumed that sea water is colder than the surrounding air temperature. This can be explained when considering the effect of thermal inertia of seawater: tendency of seawater to resist a change in temperature with the gain or loss of heat energy. Higher value of specific heat capacity of seawater is a key property of seawater that acts to moderate changes in its temperature. Water temperature rises as the Sun's energy is absorbed and then changed to heat. However, due to water's very high specific heat capacity, its temperature will not rise very much even if a large quantity of heat is added (Garrison, 2005). The same goes for loss of heat from seawater, making the temperature of seawater to not decrease significantly.

Air temperature is able to fluctuate more easily, as the atmosphere is more dynamic than the ocean and the specific heat capacity of air is much smaller than that of water. Water are evaporated from the ocean surface, and then moved by wind. This mass movement of air helps to minimize worldwide extremes ofsurface temperature. Rain also helps in maintaining or decreasing surface air temperature as it provides moisture (Garrison, 2005).

Sea Level Rise Due to Temperature Increase

Temperature increase of 1 °C over the upper layer of the ocean(approximately 30 m to 40 m) will raise the sea level by 1 cm. Therefore, from calculations done in this study, sea level in Kota Kinabalu has risen 2.6 mm for the last 11 years (approximately 0.24 mm per year). Sea level will continue to increase another 2.4 mm by 2020. Sea level in Kota Kinabalu will have increased 5.0 mm from 2000 until 2020.

Past changes in sea level records includes an average rate of 0.5 mm per year over the last 6000 years and 0.1-0.2 mm per year over the last 3000 years (based on geological data). Records also showed that in the 20th century, sea level has risen at an average rate of 1-2 mm per year (based on tide gauge data), with no significant acceleration in the rate of sea level increase in the 20th century has been detected. However, it is found out that average rate of sea level rise in the 20th century was higher than it is in the 19th century (Church*et al*., 2001).

Rate of sea level rise in Kota Kinabalu (0.24 mm per year) is much lower than the IPCC global average rate of 1-2 mm per year (IPCC, 2007). Calculated rate of annual sea level rise in the study area is also lower than that in Nauru area, a small island nation in the Pacific Ocean (4.4 mm per year), based on the study conducted by Hussein *et al*. (2010). AOGCM (Atmosphere-Ocean General Circulation Models) simulations result in rates of thermal expansion of 0.3 to 0.7 mm per year in the 20th century (Church *et al*., 2001), which is also higher than the calculated value of sea level rise in the study area. Lower rate of sea level rise in Kota Kinabaluissimplydue to the reason that the calculated and projectedsea level rise for Kota Kinabalu area is based on changes in watertemperature alone. No otheroceanographic effects such as ENSO phenomena, waves, currents or sedimentstransportandmelting of glaciersare taken into account.

As suggested by Hussein *et al*. (2010), threat of sea level rise problem must be taken into consideration when making plans or policies for future development in Kota Kinabalu area. Although we may not encounter severe problems such as coastal flooding and land loss due to sea level rise in the near future, actions need to be taken accordingly to prevent any unwanted problems that may arise in the distant future.

Land Loss Due to Sea Level Rise

Coastal or beach erosion can be defined as the loosening and transporting of sand by moving agents such as waves and currents to other places. As mentioned earlier, coastal erosion is caused by several factors, such as sea level rise, wave or current actions, as well as sediment deficiencies, which includes sand mining and dune grading, among others.

As shown previously in Table 1, the smaller the beach angle, the bigger or more the land loss will be. To calculate the total area of land loss due to sea level rise, the stretch of the beach must be taken into account as well, not just the loss of beach in landward direction alone.

Sandy beaches are one of the favourite places for people to relax and enjoy. Unfortunately, because of beach and coastal erosion due to natural factors (wave and current actions), combined with insufficient planning from previous generations, our sandy beaches have been deteriorating. It is impossible to stop the natural process that causes beach erosion. What can be done is to make appropriate planning and take necessary action in the hope of minimizing these effects on our beaches. Development of seawalls, wave breakers, groins, among others can help in preserving beaches from further erosion. Restoration of already deteriorated beaches is another option that can also be taken.

From the results obtained and based on the calculations done in this study, air temperature in Kota Kinabalu has increased 0.10 °C since 2000 until 2009. Projection showed that air temperature in the study area will continue to increase by another 0.11°C by 2020, assuming business as usual. Results showed that SST was always higher compared to air temperature. For SST in Kota Kinabalu, since 2000 until 2010, it has increased 0.26 °C and based on projection done in this study, it will increase another 0.24°C by 2020. Subsequently, sea level in Kota Kinabalu has also increased by 2.6 mm for the last 11 years. Again, assuming business as usual, sea level in the study area will continue to increase 2.4 mm for the next 10 years: sea level in Kota Kinabalu would have risen 5.0 mm by 2020. To calculate the total amount of land loss due to sea level rise, the total length of the beach along the coastlinemust be taken into account when doing the calculations, not just the loss of beach in landward direction alone. It can be concluded that the amount of beach loss due to sea level rise is very much dependant on the slope of the beach: the smaller the beach angle, the bigger or more the land loss will be. It is vitally important to use a longer term data in this method of analysis in science and the longer the data length is, the more reliabletheresults will be. In this brief study, we are very much inclined to report the simple methodology using a short term data set as an example. Our results and projections will be highly controversial from the scientific point of view however the dissemination of simple method is still appreciable to many who are interested in the sea level rise and land loss issues.

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