General Observations about Rising Sea Levels in Peninsular Malaysia

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ABSTRACT  Current data has shown that the sea level is increasing day by day and is never stagnant. Peninsular Malaysia is prone to affects from sea level rise, hence, it is important to investigate sea level rise in Peninsular Malaysia. We plotted time series graphs for 8 tidal stations around Peninsular Malaysia, to investigate the trend of sea level rise from 1992 to 2009. Then we projected sea level rise in each tidal station to predict the sea level rise in the year 2050 and 2100; using a deterministic seasonality model. Our data shows that the sea level is rising in each tidal station, although not all at the same rate. The study predicted that the average sea level rise is 10.79 cm and 23.94 cm in the year 2050 and 2100, respectively. Tanjung Gelang shows the highest sea level rise, with a rise of 14.42 cm and 32 cm in the year 2050 and 2100, respectively. This study will be valuable for a wide range of professionals to use as one of the guidelines for environmental planning; specifically in the coastal zones of Peninsular Malaysia.

(Keywords: Peninsular Malaysia, Sea Level Rise, Coastal Zone, Prediction, Deterministic Seasonality Model)

INTRODUCTION

Rising sea levels have been recognized as a major threat to coastal habitats and communities worldwide [1]. Sea-level rise projections using the General Circulation Models (GCMs) during the end of the 21st century range from 0.18 to 0.59 m. However, this is not assured as the Greenland and West Antarctic ice sheet contributions are uncertain [2]. The IPCC has estimated that the rise in sea level by 2100 may be 0.10–0.20 m higher than predicted, based on the uncertainties of ice sheet melt and glacier dynamics [2]. Scientists have suggested that a rise in sea level of 1–5 m by 2100 is more realistic in consideration of thermal expansion of ocean water, melting of ocean glaciers, ice sheet disintegration, and an acceleration of sea-level rise in the 20th century [3]. Measuring the exact rate of sea level rise over the recent decades and identifying its causes has attracted many people to the current debate on global climate change. This can be seen from the cover story in Time magazine [4], a documentary ‘An Inconvenient Truth’ by Al Gore (2006) [5]; as well as political debate, for example Kerry and Gingrich [6] on the sea level rise issue. Recent results based on Topex/Poseidon altimetry for the last decade showed that the rate of change of sea level shows great regional variability, with positive and negative trends amounting up to 10 times the global mean [7].

The coastal environment is highly dynamic and can cause potential harm to public safety and property damage [8]. Hazards like this are very hard to manage and may create huge problems for managing agencies. The question remains as to who would pay for all the damages done. For the past few decades, scientific research has shown that, atmospheric pollution by greenhouse gases, such as carbon dioxide (CO₂), would initiate a phenomenon known as global warming; which could cause significant changes to the earth’s temperature [9]. Coastal areas may confront impacts such as changes in storm patterns, changes in ocean temperature as well as rising sea levels which can impact a country’s economic performance as well as other aspects of human well-being [10].

For many coastal planners, one of the hindrances to managing coastal environmental change due to global warming is the uncertainty in climate predictions [11, 12]. Even though the threat due to the changing atmospheric pattern is clear, just understanding the problem is insufficient to provide definite forecasts; which are essential for developing effective adaptive strategies [13].

Climate modeling studies estimate that the global temperatures will rise a few degrees Celsius (°C) in the next few years [14]. On time scales ranging from
years to decades, the two main causes of global mean sea level changes are steric effects, which are mostly due to thermal expansion caused by global ocean warming and water mass exchange with continents [15]. Steric effects are likely an important factor of regional variability in sea level trends [15]. Whereas ocean water mass changes may quickly lead to uniform sea level changes, elasto-gravity effects on the distribution of melt water from the ice sheets, in principle, contributes to the spatially non-uniform pattern of sea level changes [15]. Some of the few sites where glacial retreats have been recorded in the last 5 years are Montana (US), Austria, Himalayas (India), and Antarctica. The melting of these glaciers adds large volumes of water to the oceans, causing sea level rise [14]. According to Sinha (2005), warmer polar ocean temperatures could also melt portions of the Ross and other Antarctic ice shelves [14]. This phenomenon could increase the rate at which ice turns into ocean in the Antarctic ice streams, whereas warmer polar air temperatures might increase the annual snowfall, which also contributes to the rise in sea level [14]. Along the United States coast, the sea level is already rising by 2.5 – 3.0 mm/year which is equivalent to 10 to 12 inches per century [14]. New results from recent research have shown that the recent increase in sea level is in response to the increased radiative forcing of the climate system; caused by natural factors as well as anthropogenic activities [16].

Sea level rise has been associated with many coastal hazards to property and public safety [17]. The emission of greenhouse gases started long before the impact of global warming was identified. In 1896, Svante Arrhenius, a Swedish scientist, had published a new idea that the burning of fossil fuels could lead to a greenhouse effect and thus increase of the planet’s average temperature [18]. Initially, greenhouse gas emission started during the First Industrial Revolution, when Europeans were racing to increase food resources to sustain the ever-increasing human populations. Since then, human activity accelerated the emission of greenhouse gases [19]. During those periods, the impacts were there, but, not as devastating as what we are experiencing nowadays. It took years for the impacts to be visible. Therefore, understanding the sea level rise phenomenon now is crucial to predict what will happen in the future. Human society is still depending on fossil fuels; their usage has been use quite rapid compared to the era of the Industrial Revolution. By understanding the phenomenon, steps could be developed which may save millions of lives from the effects of our mistakes.

In view of that, this study investigates the sea level trend in Peninsular Malaysia from 1992 to 2009, using tide gauge data. This study also endeavors to predict future sea level rise in Peninsular Malaysia for the years 2050 and 2100, using a deterministic seasonality model.

**MATERIALS AND METHODS**

**Tide Gauge Data**

The analyses were conducted by using the observed monthly mean sea level (MMSL) data from the years 1992 to 2009; which was obtained from the Department of Survey and Mapping Malaysia (DSMM). The analyses were focused on 8 tidal stations (4 in the west and east coast respectively) of Peninsular Malaysia, which are presented in Fig. 1.

A total of 1,728 (18 years x 12 months x 8 stations) data points were generated from the tide data. However, there was some missing data due to maintenance of tide gauge meters. Hence, the missing data values were estimated by using SPSS version 17.0 software; using the linear
trend at point method linear trend at point replace a missing values with the linear trend at the particular point. The existing series is regressed on an index variable scaled 1 to n where the missing values were replaced with their predicted values (IBM Corporation, 2011). Next, 3-point smoothing was conducted on the data to avoid ‘noise’ on the time series graph, during later analysis using Microsoft Excel 2007. The data was then processed using EViews 6 software, to generate a time series graph.

Future Sea Level Rise Prediction

A Deterministic Seasonality Model [20] was used to produce a fitted line graph based on the previous tide gauge data; to predict the sea level rise for the years 2050 and 2100 using this equation;

$$S_t = \alpha + \sum_{i=1}^{s-1} \beta_i D_{it}$$  

Where;

$S_t =$ Deterministic Seasonality  
$\alpha =$ Seasonality in omitted season  
$\beta =$ the difference in the seasonal component from the $s$’th period/coefficient  
$D =$ Dummy variables

If seasonality is constant and deterministic, $S_t$ is simply a different constant for each period, such as, monthly mean sea level (MMSL) data. Seasonality varies by the calendar period, for example quarter, month, week, day as well as time of the day. Deterministic seasonality $S_t$ can be written as a function of seasonal dummy variables ($D_{t1}$, $D_{t2}$, $D_{t3}$... $D_{ts}$) where $s$ is the seasonal frequency such as $s=12$. $D_{ti} = 1$, if $s$ is the first period, otherwise $D_{ti} = 0$ and at any time period $t$, one of the seasonal dummies $D_{t1}$, $D_{t2}$, $D_{t3}$... $D_{ts}$ will be equivalent to 1, others will be equal to 0 [21].

At the same time, Linear Trend analyses were performed to determine the variation of the sea level in Peninsular Malaysia using Microsoft Excel 2007. Statistical analysis was performed to determine the significance in sea level rise from 1992 to 2009. Results from both analyses were further verified with one – way ANOVA using Microsoft Excel 2007. The results from the current study with the published data were also verified using one – way ANOVA.

RESULTS AND DISCUSSION

Sea Level Rise Trends in Peninsular Malaysia

Figure 2 shows the monthly mean sea level (MMSL) from 1992 to 2009, for the 8 tidal stations. As observed from the graph, the west coast data seems to be rather noisy and inconsistent compared to the east coast data which are more consistent, smooth and in the same rhythm. Based on Ami Hassan and Kamaludin (2009), the result of the analyses lies in the fact that the west coast of Peninsular Malaysia is exposed to the narrower and shallower water of the Straits of Malacca; compared to the east coast of Peninsular Malaysia which is exposed to the wider and deeper water of the South China Sea [22]. This causes the west coast graphs to become noisy and inconsistent. Another interesting observation was found, the sea level shows an increment in each tidal station. It is worth noting that between the west and east coasts of Peninsular Malaysia, the sea level in the west coast (specifically Kukup and Port Klang) shows tremendous depth compared to the east coast. This is probably due to the location of their tide gauges, which were in deeper water compared to other stations. We also note that, 3 depth trends can be observed from Fig. 2, and we show them in Fig. 3.

The first depth trend combines both Kukup and Port Klang, which shows that both tidal stations mark the highest sea level depth compared to other tidal stations; which is in the range of 339.9 – 421.5 cm. The second depth trend comprises Pulau Tioman, Tanjung Gelang and Pulau Pinang; within the range of 238.9 – 315.1 cm and the third depth trend combines Cendering, Getting and Pulau Langkawi in the range of 191.6 – 269.9 cm.

The east coast graphs from Fig. 2 show that sea levels are increasing from 1993 to 2000, which is partly associated with the monsoon season where the rate of rainfall is high during the season. The sea levels on the east coast are increasing at the end of each year, where it is due to the monsoon season. The northeast monsoon season affecting the east coast of Peninsular Malaysia usually starts in early November and end in March [23]. Other than that, the melting of ice also plays a role in the rise of sea level. Melting from land-based ice-sheets of Greenland as well as Antarctica is very likely to have contributed to sea level rise between 1993 and 2003 [24]. However, after 2002, the sea level is decelerating slowly. The sea level starts to increase again from 2006 till 2009.

Fig. 2  Time series sea level rise graph from 1992 to 2009 for the East and West coasts of Peninsular Malaysia

Table 1. The rate of sea level rise per month in each tidal station for linear trend analysis & deterministic seasonality

<table>
<thead>
<tr>
<th>Tidal Stations</th>
<th>Linear Trend Analysis (cm)/month</th>
<th>Deterministic Seasonality (cm)/month</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulau Langkawi</td>
<td>0.0191</td>
<td>0.015451</td>
</tr>
<tr>
<td>Pulau Pinang</td>
<td>0.0242</td>
<td>0.020712</td>
</tr>
<tr>
<td>Port Klang</td>
<td>0.0274</td>
<td>0.023675</td>
</tr>
<tr>
<td>Kukup</td>
<td>0.0265</td>
<td>0.024291</td>
</tr>
<tr>
<td>Pulau Tioman</td>
<td>0.0211</td>
<td>0.020383</td>
</tr>
<tr>
<td>Tanjung Gelang</td>
<td>0.0299</td>
<td>0.029301</td>
</tr>
<tr>
<td>Cendering</td>
<td>0.0243</td>
<td>0.023918</td>
</tr>
<tr>
<td>Getting</td>
<td>0.0184</td>
<td>0.01762</td>
</tr>
</tbody>
</table>

We find it difficult to observe the results for the west coast graphs due to the inconsistency of the west coast graphs as shown in Fig. 2. However, the effect of El Nino was clearly visible on the graph where the sea level starts to fall in late 1997 and starts to increase again in the midst of 1998; which marks the end of El Nino. Based on the research done by Hashim et al. (2008), the decrease in sea level is clearly visible during El Nino years, which are parallel with our finding. After 1998, the sea level increment remains high starting from 1999 until late 2001, where the sea level decelerates very fast [25]. The effect of the Boxing Day tsunami can be seen where the sea level increases in late 2004 and decreases.
again due to the backflow of the water. After the tsunami, the sea level is increasing due to backwash-caused coastal erosion, which is similar to the effect from land subsidence. According to Hawkes et al., (2007), between 3 to 5 stratigraphic units were identified at sites situated along the Malaysia – Thailand Peninsula, where the sedimentation had one to three fining upward sequences; indicating backwash deposition [26]. However, in mid 2005, it can be seen that, the sea level is decreasing gradually and then starts to increase again from 2006 to 2009. It can also be seen that in Kukup for the year 2006 onwards, the sea level is increasing due to the fact that extreme flooding occurred in the southern part of Peninsular Malaysia. From 2006 to 2007, a series of floods occured in Malaysia starting from December 18, 2006 till January 13, 2007 due to ‘Typhoon Utor; resulting in major flooding in Johor (the southernmost state of Peninsular Malaysia) by the third week of January 2007 [27].

Future Sea Level Rise in Peninsular Malaysia

Table 1 shows the rate of sea level increment per month for 8 tidal stations, based on the linear trend analysis and deterministic seasonality model. Both analyses concluded that Tanjung Gelang recorded the highest sea level rise compared to other stations. Both analyses also show that Port Klang has the second highest sea level rise. We also noted that, the lowest sea level rise differs for both analyses. Linear trend analysis concluded that Geting has the lowest sea level rise while the deterministic seasonality model shows Pulau Langkawi has the lowest sea level rise. Both tidal stations reside in the northern part of Peninsular Malaysia. We noted that, the middle section of Peninsular Malaysia experienced the highest sea level rise while the northern part of Peninsular Malaysia has the lowest sea level rise, as summarized in Fig. 4.

One of the factors in sea level rise is the occurrence of land subsidence. Global or absolute sea level (ASL) is rising due to increasing volume and water mass of the global seas, whereas the relative sea level (RSL) indicates sea level relative to the land; as measured by tide gauges [28]. RSL is rising faster compared to ASL in land areas experiencing land subsidence [28]. The eastern coast of Peninsular Malaysia is rich in natural gas and fossil fuels and therefore oil and gas exploration is very active in the region around Tanjung Gelang. Oil and gas exploration and modern structural activities also further land subsidence [29]. Hence, those may have contributed significantly to the sea level rise in Tanjung Gelang.

It is worth noting that land subsidence is also common in areas with extensive development, such as Port Klang and the surrounding vicinity. Port Klang is the biggest port in Peninsular Malaysia. Similarly, Jakarta has developed rapidly; it is unfortunate that, the increased development introduced several environmental problems such as land subsidence [30]. Sea level rise cause coastal erosion. Rising sea levels in the vicinity of inlets such as river estuaries results in coastal erosion [31]. The pervasive urbanization in Auckland has exposed both soft and hard shoreline to coastal erosion and accretion processes [32]. This is most probably due to the occurrence of land subsidence which eventually results in sea level rise.

Results for both analyses were further verified with one – way ANOVA to determine the significance in the sea level rise data. The result from the one – way ANOVA test shows that the p–value is 0.371. Although the results from linear trend analysis revealed a higher value than the deterministic seasonality model, but there is no significance difference for both analyses as the p–values are more than 0.05.

The prediction was based on the results from the deterministic seasonality model as shown in Table 2.
We calculated the sea level rise for the years 2050 and 2100 and we observed that the sea level is increasing by 0.271 cm/year. Many studies state that sea level is rising approximately 0.2 cm/year and even though the 0.2 cm/year sea level rise seems to be relatively small, small increases in sea level would have devastating effects [33]. In Malaysia, the rise ranges from 0.121 cm/year at Pulau Langkawi and 0.302 cm/year at Kukup on the west coast of the peninsula, whereas on the east coast, the rise ranges from 0.173 cm/year at Geting and 0.32 cm/year at Chendering. Based on the current data, the highest sea level rise is in Tanjung Gelang, whereas, linear trend analysis Ami Hassan and Kamaludin (2009), suggests that Cendering has the highest sea level rise [22]. Although the results differ, it is worth noting that the two stations reside on the same coastal zone. As was explained, both stations mark the highest sea level rise due to the occurrence of land subsidence resulting from the oil and gas activities. Irregardless of that, both analyses agreed that Pulau Langkawi and Getting have the lowest sea level rise. One way ANOVA testing was carried out to verify the significance between the current study and the Ami Hassan and Kamaludin (2009) analysis; in view of our predictions for the years 2050 and 2100. The p-test values are 0.373 and 0.314 for the years 2050 and 2100 respectively. Thus, it is noted that comparison of the current study with the Ami Hassan and Kamaludin data has no significant difference.

This study predicts that the sea level would rise between 7.6 to 14.42 cm and 16.87 to 32.0 cm in the years 2050 and 2100 respectively. On average, the sea level rise in Peninsular Malaysia by the years 2050 and 2100 are estimated at 10.79 cm and 23.94 cm respectively. The Assimilated Atmosphere Ocean Global Climate Model (AOGCM), a simulation model conducted by NAHRIM [34], predicts a 25.3–51.7 cm sea level rise around the coastal zone of Peninsular Malaysia by the year 2100. One way ANOVA testing was carried out to verify the significance between the current study and the AOGCM data; but in the absence of the Port Klang data, as that data is unavailable in the AOGCM simulation model. Based on the test, both analyses show significant difference, the p-value is 0.023 which is less than 0.05. However, it is worth noting that the difference between the AOGCM simulations and our analyses is in terms of the data used; AOGCM simulations used satellite altimeter data whereas our analyses are based on tide gauge data. One of the flaws of using satellite altimetry its unsuitability to measure low depth water, which is the reason the measurement for Port Klang cannot be taken. As a result, satellite altimetry could not make a prediction for the west coastline neighboring Sumatera, particularly in the Port Klang area. Generally, the study indicates that sea level is rising from the year 1992 to 2009 for all stations. The sea level is predicted to rise by 10.79 cm and 23.94 cm in the years 2050 and 2100 respectively.

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</thead>
<tbody>
<tr>
<td>Pulau Langkawi</td>
<td>0.185412 cm</td>
<td>7.60 cm</td>
<td>5.08 cm</td>
<td>16.87 cm</td>
<td>11.13 cm</td>
<td>51.7 cm</td>
</tr>
<tr>
<td>Pulau Pinang</td>
<td>0.248544 cm</td>
<td>10.19 cm</td>
<td>7.48 cm</td>
<td>22.62 cm</td>
<td>16.38 cm</td>
<td>51.7 cm</td>
</tr>
<tr>
<td>Port Klang</td>
<td>0.284100 cm</td>
<td>11.65 cm</td>
<td>9.45 cm</td>
<td>25.85 cm</td>
<td>20.70 cm</td>
<td>NA</td>
</tr>
<tr>
<td>Kukup</td>
<td>0.291492 cm</td>
<td>11.95 cm</td>
<td>12.68 cm</td>
<td>26.53 cm</td>
<td>27.78 cm</td>
<td>25.30 cm</td>
</tr>
<tr>
<td>Pulau Tioman</td>
<td>0.244596 cm</td>
<td>10.03 cm</td>
<td>9.91 cm</td>
<td>22.26 cm</td>
<td>21.71 cm</td>
<td>28.90 cm</td>
</tr>
<tr>
<td>Tanjung Gelang</td>
<td>0.351612 cm</td>
<td>14.42 cm</td>
<td>11.09 cm</td>
<td>32.00 cm</td>
<td>24.29 cm</td>
<td>30.70 cm</td>
</tr>
<tr>
<td>Cendering</td>
<td>0.351816 cm</td>
<td>11.77 cm</td>
<td>13.44 cm</td>
<td>26.12 cm</td>
<td>29.44 cm</td>
<td>41.90 cm</td>
</tr>
<tr>
<td>Getting</td>
<td>0.21144 cm</td>
<td>8.67 cm</td>
<td>7.27 cm</td>
<td>19.24 cm</td>
<td>15.92 cm</td>
<td>47.20 cm</td>
</tr>
<tr>
<td>Average</td>
<td>0.271127 cm</td>
<td>10.79 cm</td>
<td>9.55 cm</td>
<td>23.94 cm</td>
<td>20.92 cm</td>
<td>39.63 cm</td>
</tr>
</tbody>
</table>
CONCLUSION

We concluded that the sea level is rising at all stations, although the rise is not at the same rate. The study also indicates that the middle part of Peninsular Malaysia, particularly Tanjung Gelang and Port Klang, show the highest sea level rise; while in the northern area of Peninsular Malaysia, G băng and Pulau Langkawi show the lowest sea level rise. Generally, based on the analysis done by using a deterministic seasonality model, the sea level is predicted to rise by 10.79 cm and 23.94 by the years 2050 and 2100 respectively.

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