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Trends Analysis for Tidal Level Observed at Kukup and Tanjung Keling Stations

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Abstract

Sea level rise can be affected by many significant factors and contribute several impacts directly on coastal and island regions, especially for inundation, erosion and sea water intrusion. This study analysed trend variation of rise of tidal level for two selected stations located along the Strait of Malacca based on observed long term sea level records. Man-Kendall and moving average methods were carried out to display the changes of trend over the time, and also be an aid in forecasting the rate of mean sea level rise for both stations. Results show a trend in sea level rise to be upward and mean rate of sea level rise is between 0.358 cm/yr and xxx cm/yr, and between 0.348 cm/yr and xxx cm/yr at Tanjung Keling and Kukup, respectively. The trend analysis predicted that Tanjung Keling and Kukup station will have an increasing of mean sea level approximately 13.4 cm and 34.5 cm; in 2050 and 2100 respectively.

Keywords: Sea level rise, Tidal level observation, Trend.

1. Introduction

Sea level fluctuates due to a number of factors such as change of coastal region and increasing of total water mass due to melting of land-based snow and ice, and varied greatly over geological time scales, which then lead to sea level rise (SLR) under global warming. Jevrejeva et al. (2006) estimated 2.4 ± 0.1 cm/yr increased in global sea level trend for the period from 1993 to 2000. Church and White (2011) estimated about 20 cm of global sea level rose between 1880 and 2009, and between 1972 and 2008; approximately 2 cm/decade has increased. In terms of forecasting SLR in future, IPCC (2007) has provided a trend of mean sea level rise between year 1700 and 2100 (Fig 1) to aid the researcher in estimating current MSL.

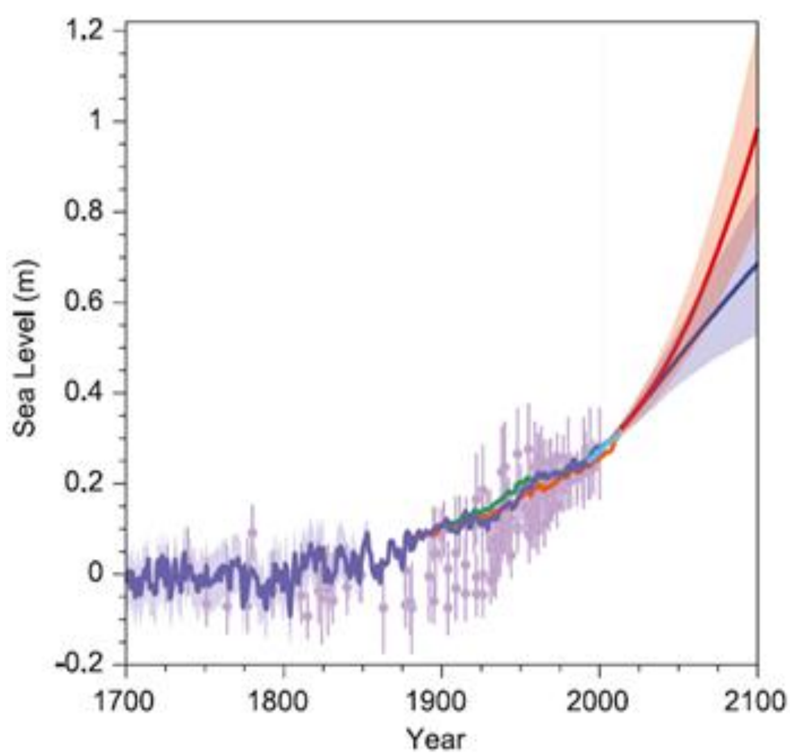

Fig-1. Rising trend of mean sea level between year 1700 and 2100 (IPCC, 2007)

They also suggest some range of MSL based on scenarios. Low (RCP2.6) and high (RCP8.5) emission of future estimation by IPCC (2013) as shown in Table 1, may threaten the survival of coastal cities and entire island nations.

Table-1. Predicted mean sea level rise based on the various scenarios (IPCC, 2013)

Scenario	Range (cm)	Mean (cm)
RCP2.6	28-61	44
RCP4.5	36-71	53
RCP6.0	38-73	55
RCP8.5	52-98	74

Study on Malay-Thai Penisular (Tjia, 1996) found 25% to 30% of estimated rate of sea-level rise may result from global warming, and suggests regional sea level may subside between 1.5 mm/yr and 2 mm/yr in future. However, Ong (2000) found the mean sea level for Malaysia decreases, 0.5 mm/yr lower than the minimum annual rate of Tjia (1996). He also reported that global tidal level is dropping at 2.4 ± 0.9 mm/yr due to changes of geological aspect, such as relative sea level in the Strait of Malacca over the last 5,000 or so years.

In July 2010, News Strait Times reported that sea levels off the west coast of Peninsular Malaysia will rise by 10 cm (Pulau Langkawi) to 13 cm (Tanjung Piai) in a century. However, finding from Jeofry and Rozainah (2013) show increment on sea level rise for the west coast, ranges between 16.87 cm (Pulau Langkawi) and 26.53 cm (Kukup). In general, sea level in Peninsular Malaysia is predicted to rise by 10.79 cm and 23.94 cm in the years 2050 and 2100 respectively.

The understanding the trend of sea level rise is crucial in managing sustainable coastal development. In view of that, this study analysed the sea level trend in South-west coast of Peninsular Malaysia from 1986 to 2012, utilizing observed long term tidal level data at two selected tidal stations. This study also endeavours to predict future sea level rise in Peninsular Malaysia for the years 2050 and 2100 using Man-Kendall and moving average methods.

2. Materials and Methods

2.1. Tidal Level Data

Tanjung Keling, Malacca and Kukup, Johor stations observed records were selected as points of sea level rise study for South-west of Malaysia, which as shown in Fig 2.

Fig-2. Map of tidal level stations in Malaysia (http://www.jupem.gov.my)

The analysis used the hourly observed tidal level records obtained from the Department of Survey and Mapping Malaysia (DSMM) for year 1986 to 2012, which are then converted into monthly-averaged of tidal level in cm. However, there exist some missing data due to maintenance of tidal gauges. Hence, missing data was treated by the estimation of mean hourly data using prior and later available record for the same tidal stations. Smoothing was conducted on the data to avoid 'noise' on the time series graph, during later analysis.

2.2. Trend Analysis Method

Trend analysis is a forecasting technique, which is good in describing long-term changes and may be used to predict future scenario by trend extrapolation. The analysis utilizes 26 years of observed records so possible error in determining certain forecasting is 6.5% based on length of assessed data (Lynch and Dent, 1990). Monthly-average, 12 month moving average and Seasonal Mann-Kendall methods were used to determine the trend of sea level variation.

The monthly average is an average tidal level for all the observations within a month. For 12-month moving average method, the average tidal level of a particular month is the average of the prior 12 months tidal level, and moving forwards by one month for the next month. The trend of sea surface fluctuation is based on the fitted linear equation on the plotted monthly averaged tidal level for each tidal station.

Mann-Kendall is a non-parametric trend test which was carried out using XLSTAT package. It accounts for the seasonality of the series. It is based on the calculation of Kendall's tau measure of association between two samples, which is itself based on the ranks of the samples. The monthly data with seasonality of 12 months gives the trend of the same month of different year, e.g. the trend of January of all the years.

The rate of sea level rise for the year 2050 and 2100 are projected using linear trend and Mann-Kendall analysis.

3. Result and Discussion

3.1. Annual-Averaged Tidal Level

The annual-averaged tidal level computed from the hourly data for both stations from 1986 to 2012 (in Fig 3) show that Tanjung Keling and Kukup records range between 192.68 cm and 293.55 cm, and between 332.12 cm and 408.18 cm, respectively.

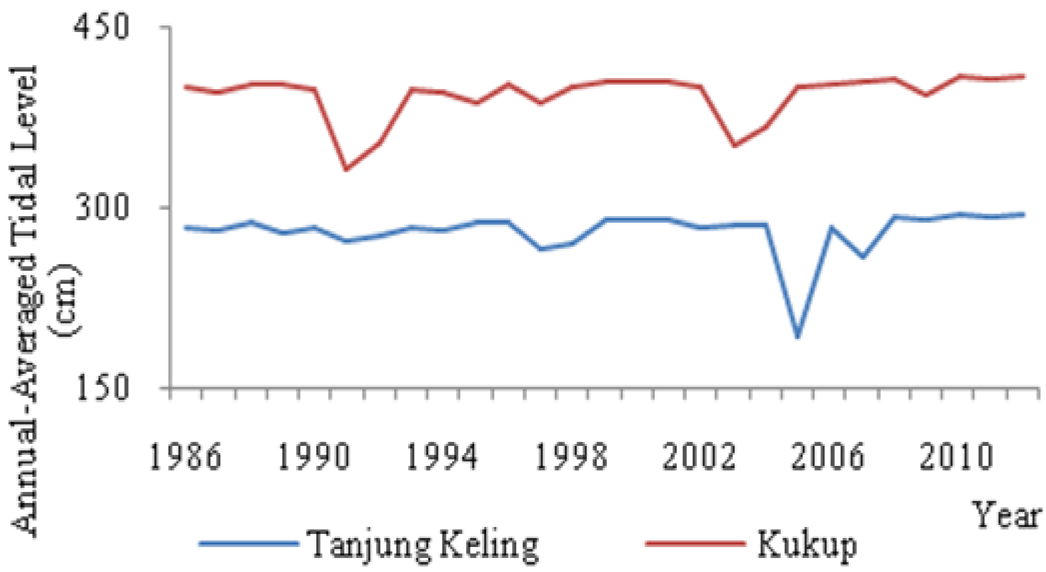

Fig-3. Annual-averaged observed data at Kukup and Tanjung Keling Station before data treatment

In general, Kukup station gauged higher level than Tanjung Keling station, where difference of annual-averaged tidal level lies between 104.47 cm and 122.31 cm in same year.

Tanjung Keling trend shows a sudden drop from 284.40 in 2004 to 192.68 in 2005, which is caused by missing data in station records. Data are not available for approximately 4 months (in April-May and October-December, 2005) in year 2005 and caused annual-averaged to be lower than the average of 279.45 cm. Meanwhile, Kukup trend shows 2 very noticeable drops, occurred in 1991 to 1992 and 2003 to 2004, within 26 hours to 2 months in one event. The drops caused by missing data are between 47 cm and 66 cm.

Data treatment on records data for Tanjung Keling and Kukup in annual-averaged is ranged between 279.94 cm and 293.69 cm, and between 392.28 cm and 408.27 cm, respectively.

3.2. Trend Analysis of Monthly-Averaged Tidal Level

The monthly-averaged tidal level in cm from year 1986 to 2012 is shown in Fig 4 (Tanjung Keling) and Fig 5 (Kukup), with the trend line of 12-month moving average. The monthly-averaged tidal level is between 270.63 cm and 302.85 cm, for Tanjung Keling station, while Kukup station recorded between 378.07 cm and 418.79 cm. Figures show in-consistency of pattern over the time as caused by El Nino event (between late 1997 to midst of 1998) and effect of the Boxing Day tsunami (late 2004). The tidal level seems to be higher between September and November, and recorded a low measurement between January to March. Generally, the sea level has been fluctuating over the time, and alteration of trend line between a month and 12-month moving average for both stations is less than 10 cm. There is a trend in seasonal period (12 months) as in Fig 4 and Fig 5. Meanwhile, Mann-Kendall analysis found an upward trend for Tanjung Keling and Kukup stations at intercept value of 280.77 cm and 400.879 cm, respectively as tabulated in Table 2. The analysis also shows an increase trend of about 10 times in seasonal period.

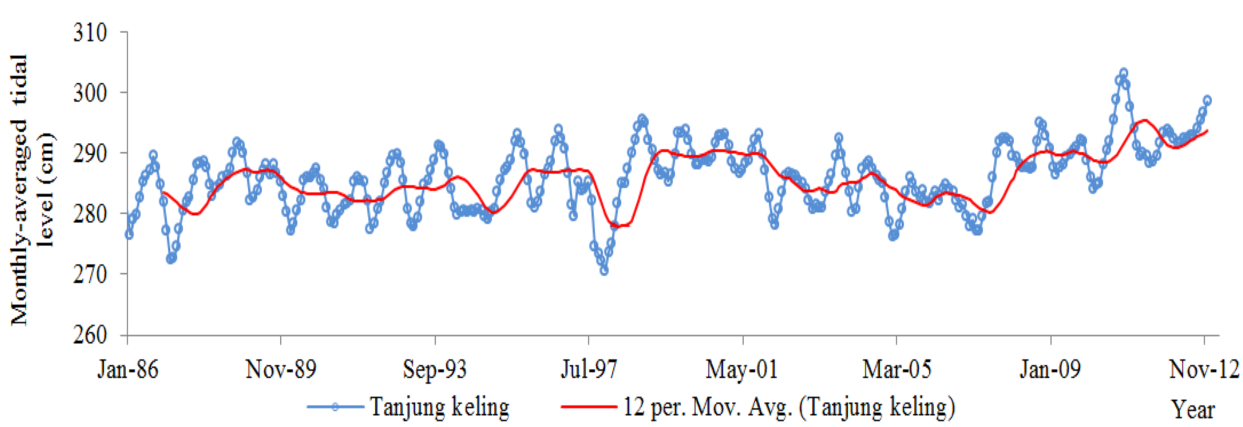

Fig-4. One- and 12-month moving average analysis of data plotted against year 1986 to 2012 for Tanjung Keling station

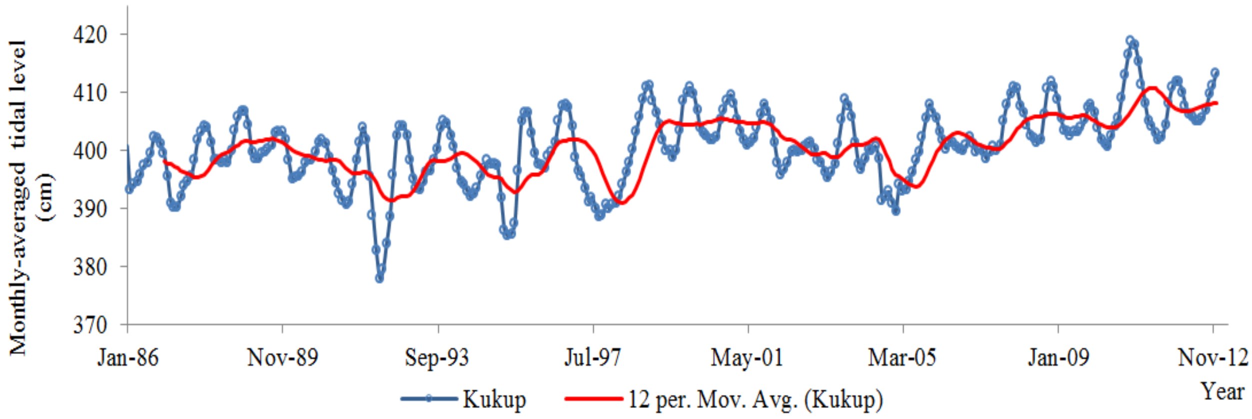

Fig-5. One- and 12-month moving average analysis of data plotted against year 1986 to 2012 for Kukup station

Table-2. Mann-Kendall analysis for Tanjung Keling and Kukup stations (Confidence interval = 95%, p-value < 0.0001)

Stations	Mann-Kendall		Seasonal Mann-Kendall (12 periods)	
	Kendall's tau	Sen's slope	Kendall's tau	Sen's slope
Tanjung Keling	0.253	0.021	0.250	0.221
Kukup	0.329	0.031	0.408	0.339

3.3. Prediction of Sea Level Rise

The linear trend gives $y = 0.0225x + 282.31$ ($R^2 = 0.1543$) and $y = 0.032x + 395.53$ ($R^2 = 0.2262$) for Tanjung Keling and Kukup, respectively using the monthly-averaged tidal level. The notation y is used to represent tidal level in cm and x represents the time in year. The rate of sea level rise in cm/month was estimated by linear trend (as shown in Fig 6) and Mann-Kendall analysis, and compared to the findings by Radzi and Ismail (2013), and Jeofry and Rozainah (2013) in Table 3.

Table-3. Rate of sea level rise per year for current study (linear trend and Mann-Kendall analysis) and previous studies

Tidal station	Linear trend (cm/yr)	Mann-Kendall (cm/yr)	Radzi and Ismail (2013)* (cm/yr)	Jeofry and Rozainah (2013)** (cm/yr)
Tanjung Keling	0.270	0.252	NA	NA
Kukup	0.384	0.372	0.148	0.291

*Based on historical data,1986-2005
** Based on historical data,1999-2009

Mann-Kendall analysis shows lower rate of sea level rise than linear trend analysis, less than 5% in average. Jeofry and Rozainah (2013) also found that the rate of sea level rise produced by linear trend analysis is 0.027 cm/yr higher than Deterministic Seasonality. The increase of sea level rise for 26 years is about 7 cm and 10 cm at Tanjung Keling and Kukup, respectively. Both methods estimates –5.3±0.9 cm (Tanjung Keling) and ±2.5 cm (Kukup) by comparing to annual-averaged tidal level Kukup in 2012, which are 293.69 cm and 408.27 cm, respectively. Prediction of increment of sea level rise and estimated sea level in 2050 and 2100 is tabulated in Table 4. The average increment of sea level rise is estimated to be between the two methods. Rate of sea level rise at Kukup increased rapidly compared to the rate at Tanjung Keling station.

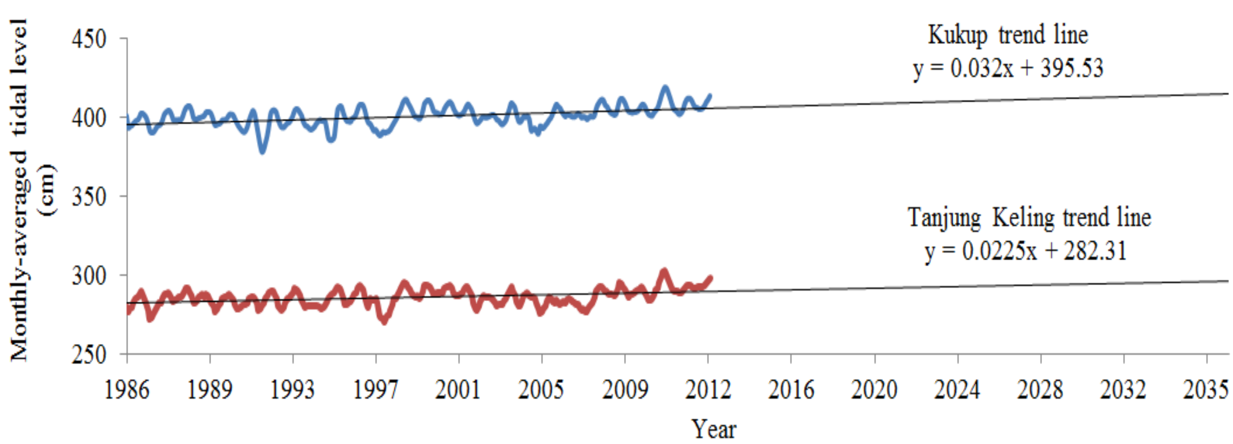

Fig-6. Tanjung Keling and Kukup forecasting graph for mean sea level rise

Table-4. Prediction of increment of sea level rise and sea level in 2050 and 2100

Tidal station	Increment of sea level rise (cm)				Estimated sea level (cm)*	
	Linear trend		Mann-Kendall analysis			
	2050	2100	2050	2100	2050	2100
Tanjung Keling	10.26	23.76	9.58	22.18	303.61	316.66
Kukup	14.59	33.79	14.14	32.74	422.67	441.92

*comparing to current annual-averaged tidal level data in 2012

A comparison of findings by various researchers on the future sea level rise at Kukup show that rate of sea level rise changes based on the length of data. Although, Radzi and Ismail (2013) used 20 years of data, the increment of sea level rise is the smallest than the others. They also predicted that the sea level will be at 408.41 cm in year 2050 (based on actual current tidal record in 2005), but it just 0.14 cm higher than current annual-averaged tidal level record in 2012. The rate of sea level rises seems to be increased rapidly over time and may be influenced by global warming and human activities along Strait of Malacca.

Table-5. A Comparison future sea level rise on current study and previous study at Kukup station

Current Study and previous study	**Increment of sea level rise (cm)**	
	2050	**2100**
Current study	14.4	33.65
Radzi and Ismail (2013)	7.25	14.90
Jeofry and Rozainah (2013)	11.25	26.93

4. Conclusıon

Kukup and Tanjung Keling stations have an upward trend of sea level rise based on 95% confidence interval. The pattern of trend line at Tanjung Keling and Kukup based on 12 months moving average shows changes with seasonal periods, and validated by Mann-Kendall analysis, and by previous studies. The trend analysis and the future projection also show that the Straits of Malacca will experience a rise in sea level in year 2050 and 2100 as pointed out in the IPCC reports.

5. Acknowledgements

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