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Trend Analysis of Tides Level and Projection Sea Level Rise on the West Coast of Peninsular Malaysia

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Abstract: Globally, sea levels are rising due to climate change caused by humans. Current and future sea level rise will have a variety of effects, particularly on coastal infrastructure. This study analysed the tidal level trend and projected sea level rise along the western coast of peninsular Malaysia using tide level records collected between 1986 and 2012. The seasonal Mann-Kendall test and linear trend were used to determine the tide level trend over time and to predict sea level rise for 2050 and 2100. Based on a confidence interval of 95%, the results of the analysis indicated a rising trend at all stations. Tau values for the Mann-Kendall test range between 0.16 and 0.33, while seasonal Mann-Kendall values range between 0.18 and 0.41. Based on the sea level projection analysis, the mean sea level will rise between 8.77 cm and 14.29 cm in 2050, and between 20.44 cm and 33.20 cm in 2100. In conclusion, the sea level trend at all stations on the west coasts of peninsular Malaysia exhibits an upward trend.

Keywords: Tidal level, sea-level rise, projection, west coast of peninsular Malaysia

1. Introduction

Tides are the rise and fall of sea levels caused by gravitational forces exerted by the moon and sun and the rotation of the Earth. The fluctuation of tide levels is influenced by many factors, such as climate change [1], which increases the global mean sea level. The contributions of ice-mass loss, land water storage, and ocean thermal expansion [2]-[4] may not be sufficient to determine global mean sea level changes.

Previous studies found a 2.4 ± 0.1 cm/year increase in sea level from 1993 to 2000 [5], and a 20 cm increase from 1880 to 2009, and 1972 to 2008 [6]. According to the IPCC [7], a trend of mean sea level rise occurred between 1700 and 2100, and the sea level is expected to rise from 0.65 m to 1 m by 2100. Furthermore, the IPCC [2] proposed a range of mean sea level based on scenarios between 44 m (RCP2.6) and 74 m (RCP8.5) for future estimation studies [8], [9]. Consequently, the analysis of predictions and forecasts of sea level rise becomes essential for tracking the temporal variation of sea level.

The Malay-Thai Peninsula's rate of sea-level rise was affected by global warming by 25 to 30 percent and suggested that the regional sea level may decline from 1.5 mm/year to 2 mm/year [10]. In contrast, a later study [11] found that the mean sea level in Malaysia declined at a slower rate than the minimum annual rate documented in the earlier study [10]. In addition, the paper states that the global tidal level has decreased at a rate of 2.4 ± 0.9 mm/year as a result of geological phase changes, such as the relative sea level along the Strait of Malacca over the past 5,000 years and more. Another study discovered that sea-level rise along Malaysia's east coast is roughly 3.27 ± 0.12 mm/year and 4.95 ± 0.15 mm/year along the west coast. According to the data, the average increasing rate around Malaysia is 4.22 ± 0.12mm/year, with a cumulative sea-level rise of 0.05 m from 1993 to 2015 [12].

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In a century, sea levels along the west coast of peninsular Malaysia are projected to rise by 10 cm (Pulau Langkawi) to 13 cm (Tanjung Piai) [13]. This report is also supported by the study [14], which reveals a range of increments between 16.87 cm (Pulau Langkawi) and 26.53 cm (Kukup). In addition, the study predicted that peninsular Malaysia's sea level will rise by 10.79 cm in 2050 and 23.94 cm in 2100 [15]. These results indicate that impacts and adaptation requirements are significantly greater than suggested by global sea-level rise measurements.

The purpose of this paper is to determine a trend analysis of sea-level rise along the west coast of peninsular Malaysia using long-term tidal level observations from 1985 to 2012. This study also predicted sea-level rise for 2050 and 2100 using the Mann-Kendall test and the linear trend method. Understanding the sea-level rise trend pattern is critical for managing sustainable coastal development.

2. Data and Methods

2.1 Tides Gauge Station and Data

Since 1984, the Department of Survey and Mapping Malaysia (JUPEM) has established a total of 21 tide gauge stations, 12 of which are located on peninsular Malaysia and 9 in East Malaysia. This study only selected tide gauge stations located on peninsular Malaysia's western coast (Fig. 1). The stations are Kukup (KUK), Tanjung Keling (TGK), Pelabuhan Kelang (PTK), Lumut (LUM), Pulau Pinang (PEN), and Pulau Langkawi (LAN).

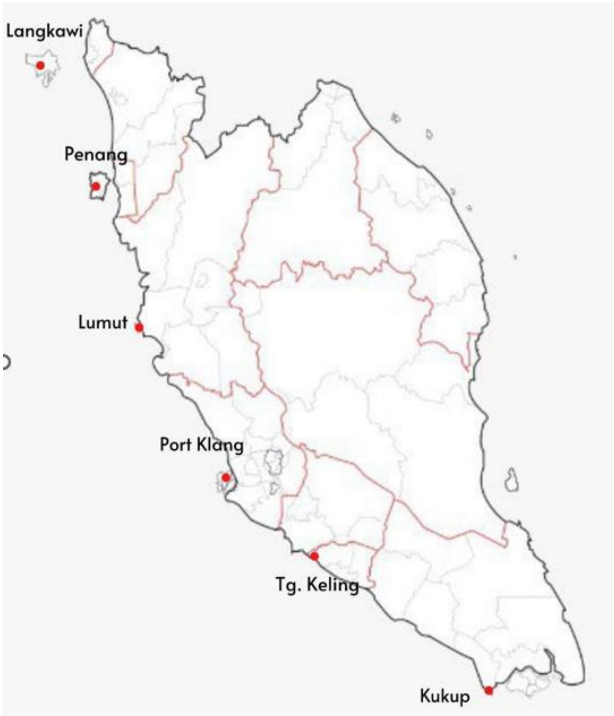

Fig. 1 - Location of tides gauge station at west coast of peninsular Malaysia

The Department of Survey and Mapping Malaysia (JUPEM) provided the hourly observed tide level records between 1984 and 2012. The information for six tide gauge stations utilised in this study is presented in Table 1. In data analysis, missing data is a common problem for a variety of reasons. The missing monthly data can be estimated by averaging hourly data records from prior and later time periods. The proportion of missing data is less than 1%. Furthermore, the smoothing process is used to remove 'noise' from the time-series graph.

Table 1 - Information of six tides gauge stations

Station ID (Code)	1677 (10)	1593 (9)	1591 (7)	1594 (5)	1595 (3)	1676 (2)
Station Name	Kukup (KUK)	Tanjung Keling (TGK)	Pelabuhan Kelang (PTK)	Lumut (LUM)	Pulau Pinang (PEN)	Pulau Langkawi (LAN)
Data Established	November 1985	November 1985	December 1983	November 1984	November 1984	November 1985
Periods (Years)	27	27	29	28	28	27
Missing data (%)	0.02	0.02	0.01	0.02	0.02	0.01

2.2 Mann Kendall

Mann-Kendall is a non-parametric trend test that considers the series' seasonality. The Mann Kendall Trend Test (also known as the M-K test) is used to look for consistently increasing or decreasing trends (monotonic) in Y values over time [16], [17]. Kendall's tau is a measure of association between two samples that is calculated using the samples' ranks. Monthly data with a seasonality of 12 months provides the trend of the same month of a different year, such as the January trend of all years. The Mann-Kendall tests are based on calculating Kendall's tau (-1 to 1) measure of association between two samples, which is based on the samples' ranks [18]-[20]. The trend is statistically significant when the p-value is less than 0.05. XLSTAT software was used to perform the analysis.

2.3 Linear Trend Estimation

Trend estimation is a statistical technique used to aid in data interpretation. When a series of measurements of a process is treated as a time series, trend estimation can be used to make and justify statements about data trends and relate measurements to the times at which they occurred. Linear trend estimation is the statistically distinct expression of data as a linear function of time to determine increase or decrease trends [17].

2.4 Trend Analysis and Projection of Sea Level Rise

Many studies have used statistical methods such as Mann-Kendall, moving average, linear regression, and others to investigate patterns and trends in time series data [21]- [24]. Trend analysis is used to forecast future scenarios by describing a long-term change in tide gauge analysis data. The data pattern was determined by analysing annual and monthly average tidal levels. The trend of sea level variation was determined using the 12-month moving average and the Seasonal Mann-Kendall methods. For moving average method, the average tidal level of a particular month is the average of the prior 12 months' tidal level and moving forward by one month for the next month. The trend of sea surface fluctuation is determined by fitting a linear equation to each tide station's monthly average tidal level plot. The projected rate of sea-level rise between 2050 and 2100 is based on a linear trend and a Mann-Kendall analysis. According to the length of the observed records, the possible forecasting error is 6.5% [25].

3. Result and Discussion

3.1 Descriptive Analysis of Tide Level Records

A descriptive analysis was carried out to describe the properties of a data set by generating summaries regarding data samples. It is frequently portrayed as a summary of the data that explains the contents of the data [25]. Table 2 is a tabulation of the annual and monthly data that resulted from a descriptive analysis of tide gauge data for six different stations.

According to Table 2, the maximum-minimum ranges for the yearly data are in the range of 15 cm to 20 cm, and the monthly data range from 38 cm to 93 cm. Based on the descriptive analysis for the coefficient of variation, Cv, the lowest variation coefficients for annual and monthly data are 0.010 and 0.018, respectively. This indicates that the probability distribution for the KUK station has a low dispersion around the mean value. In contrast to the annual value, the variation coefficient for each month is more uniformly distributed, with values ranging from 0.018 to 0.048. The annual skewness values show that the asymmetry of data distribution is positively skewed at all stations except for KUK and LAN, where it ranges from -0.049 to -0.313. This is because KUK and LAN have a negative skewness value. For six different stations, the asymmetry of the monthly data is either positively or negatively skewed, depending on the direction of the distortion.

Table 2 - Descriptive analysis of six tide level stations' data, including range and mean, coefficient of variation, C_v, and skewness (Pearson), Sk_p

	Annual					Month				
Station	**Max (cm)**	**Min (cm)**	**Mean (cm)**	**C_v**	**Sk_p**	**Max (cm)**	**Min (cm)**	**Mean (cm)**	**C_v**	**Sk_p**
KUK	408.18	393.24	401.49	0.010	0.036	423.03	384.76	401.35	0.018	0.560
TGK	293.55	276.62	285.95	0.014	-0.049	308.16	267.06	285.98	0.026	0.082
PTK	373.30	354.08	364.54	0.013	-0.313	389.28	339.90	364.70	0.026	-0.290
LUM	228.50	210.75	220.56	0.019	-0.262	283.88	191.21	220.46	0.047	0.499
PEN	278.40	258.17	269.45	0.017	-0.134	295.30	238.91	269.27	0.038	-0.518
LAN	232.09	212.11	222.70	0.020	0.007	248.34	191.62	222.43	0.048	-0.590

3.2 Average Annual and Monthly Tide Levels

According to the average annual tidal level at six tidal level stations shown in Fig. 2, the annual tidal level at all stations varies between 15 cm and 20 cm over the period, with the PEN station showing the highest maximum and minimum values (20.23 cm). The El-Nino phenomenon, which occurred between the second half of 1997 and the middle of 1998, was the primary reason for a significant drop in 1997 across all stations. El-Nino took place between the second half of 1997 and the middle of 1998.

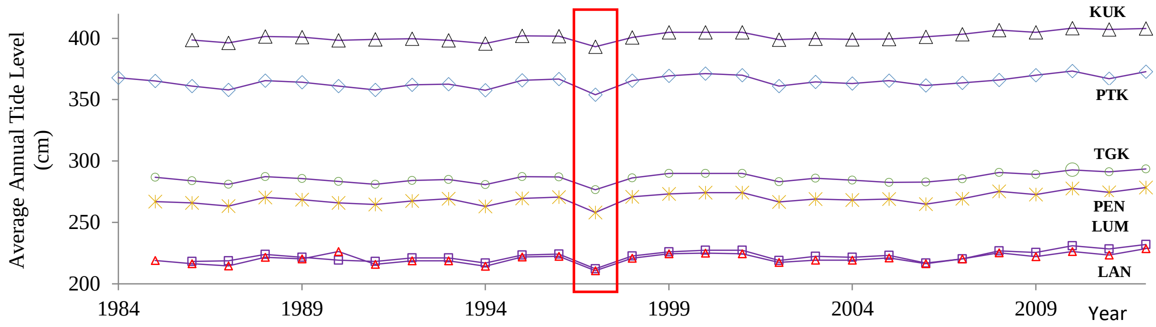

Fig. 2 - Average annual tidal level at six tidal level stations

The monthly variations and trends of the tide level that are depicted in Fig. 3 are nearly the same at all the stations along the west coast of peninsular Malaysia. In addition to El-Nino events (in the red box), the Boxing Day tsunami (late 2004) also influenced the pattern of tidal level, with high results between September and November and low measurements between January and March. In addition, the change in trend line between a moving average of one month and one year for each station is less than 20 cm, except for the LUM station (in December 1990), where it is approximately 50 cm.

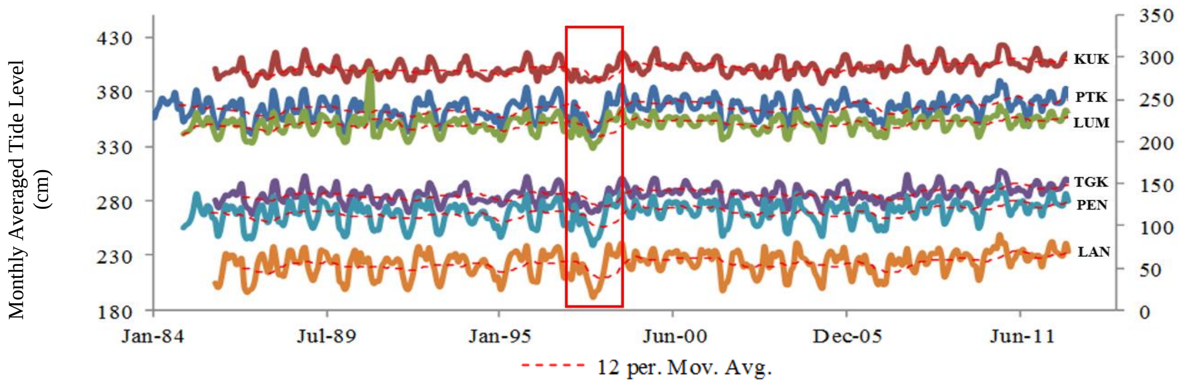

Fig. 3 - Monthly averages of tidal level for six tide gauge stations, with LUM station plotted using secondary axis

Table 3 summarises the results of trend analysis based on the Mann-Kendall test and monthly averaged data, which indicate that monotonic trends exist at all stations. The Mann-Kendall tau values range from 0.16 to 0.33, while seasonal Mann-Kendall tau values range from 0.18 to 0.41. At the intercept values shown in Table 3, Mann-Kendall analysis shows an upward trend for all stations. The seasonal Mann-Kendall test reveals a greater upward trend than the Manning Kendall test, except for the TGK and PTK stations.

Table 3 - Mann-Kendall trend analysis for tide gauge stations (significant level = 5%)

Station	TGK	KUK	PTK	LUM	PEN	LAN
Intercept	280.77	400.88	360.00	209.00	255.00	204.72
			Mann-Kendall			
Kendall's tau	0.253	0.329	0.174	0.157	0.203	0.180
Sen's slope	0.021	0.031	0.022	0.019	0.026	0.024
			Seasonal Mann-Kendall			
Kendall's tau	0.250	0.408	0.150	0.177	0.264	0.222

3.3 Sea-Level Rise Projection

The term "sea level rise" refers to the gradual elevation of water levels in the world's oceans as a direct result of human-caused global warming. Fig. 4 shows a linear line projection based on the monthly-averaged tidal level for 2050 and 2100, respectively. The notation y represents the tidal level in centimetres, and x represents the time in years. The linear trend equations derived from graph Fig. 4(a) are $y = 0.0228x + 360.10$ (at PTK station), $y = 0.0290x + 264.32$ (at PEN station), and $y = 0.0294x + 217.59$ (at LAN station). Furthermore, the linear trend equations obtained from graph Fig. 4(b) for KUK, TGK, and LUM stations are $y = 0.032x + 395.53$, $y = 0.0225x + 282.31$, and $y = 0.0198x + 217.08$, respectively. The gradient of the linear equation ranges between 0.0198 (at TGK station) and 0.032 (at KUK station).

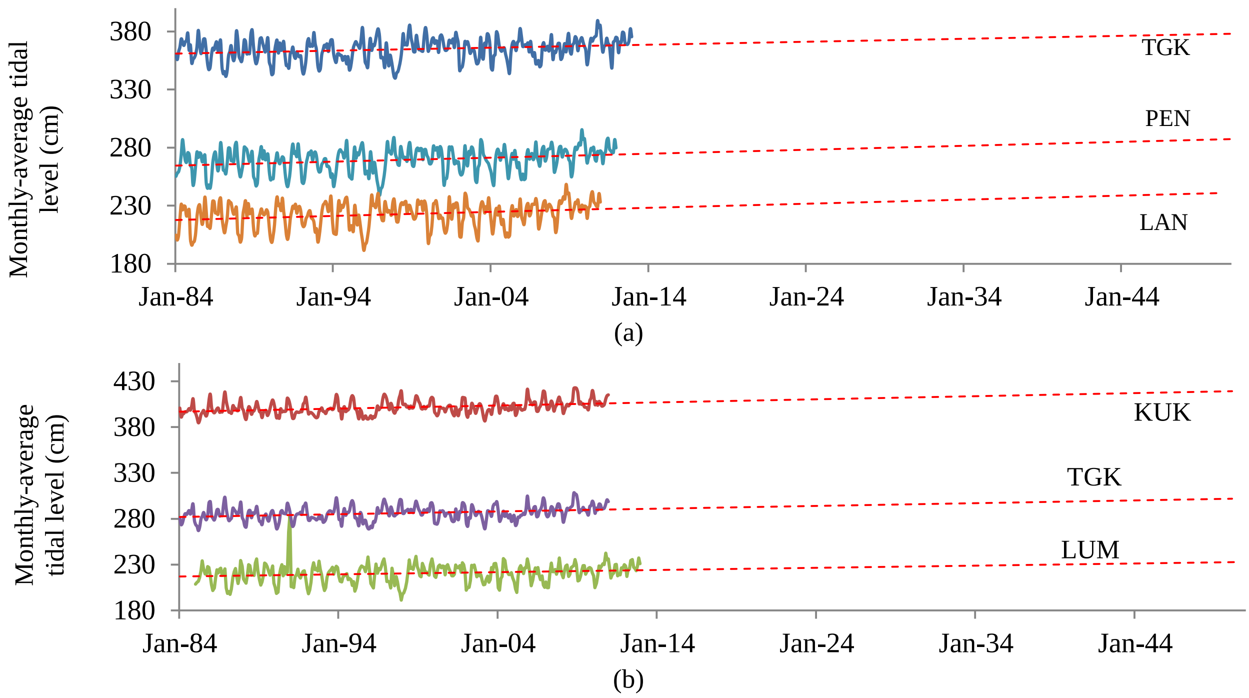

Fig. 4 - (a) Sea level rise projection using the linear method for Pelabuhan Kelang (PTK), Penang (PEN), and Langkawi (LAN), and; (b) Sea level rise projections using the linear method for Kukup (KUK), Tanjung Keling (TGK), and Lumut (LUM)

Table 4 shows the estimated rate of sea level rise in centimetres per year based on linear trend and Mann-Kendall analysis. The Mann-Kendall method indicates a lesser rate of sea-level rise than the linear trend analysis, which is less than 5 percent. Meanwhile, Jeofry & Rozainah [14] found that the linear trend analysis increased the rate of sea level rise faster than the seasonality method. Furthermore, the average rate of sea level rise is between 0.233 (LUM station) and 0.378 cm/year (KUK station). The rate of sea-level rise in cm/year at north-west stations is higher than that found in Jeofry & Rozainah [14].

Table 4 - The annual rate of sea level rise for the current study (linear trend and Mann-Kendall analysis) and the previous study

Tidal Station	Linear Trend (cm/year)	Mann-Kendall, (cm/year)	Previous Study [14], (cm/year)*
TGK	0.270	0.252	-
KUK	0.384	0.372	0.291
LUM	0.238	0.228	-
PTK	0.274	0.264	0.284
PEN	0.348	0.312	0.249
LAN	0.353	0.288	0.185

*Based on data from 1992 to 2009.

Table 5 shows the predicted increase in sea-level rise and the estimated sea level in 2050 and 2100. The average increment of sea-level rise is estimated using the linear trend and Mann-Kendall methods. The average of sea level rise increments shows that the LUM station recorded the lowest value in 2050 and 2100, with 8.77 cm and 20.44 cm, respectively. Furthermore, the KUK station recorded the largest increases in sea level rise increment, with 14.29 cm and 33.20 cm in 2050 and 2100, respectively. Meanwhile, Radzi & Ismail [27] and Jeofry & Rozainah [14] projected the increment of mean sea level for KUK station in 2050 to be 7.25 cm and 11.95 cm, respectively. For 2100, the increment of mean sea level based on results Radzi & Ismail [27] and Jeofry & Rozainah [14] is 14.90 cm and 26.53 cm, respectively. These previous results show lesser value than the current study for 2050 and 2100.

Table 5 - Rate and prediction of sea level rise in 2050 and 2100

Tidal Station	Increment of Sea Level Rise (cm)						Estimated Sea Level (cm)**	
	Linear Trend		Mann-Kendall		Average			
	2050	2100	2050	2100	2050	2100	2050	2100
TGK	10.26	23.76	9.49	22.09	9.88	22.93	296.70	309.75
KUK	14.59	33.79	13.98	32.61	14.29	33.20	414.56	433.47
LUM	8.95	20.89	8.59	19.99	8.77	20.44	234.40	250.42
PTK	10.31	23.99	9.95	23.15	10.13	23.57	229.58	241.25
PEN	13.11	30.51	11.75	27.35	12.43	28.93	374.79	388.23
LAN	13.29	30.93	10.85	25.25	12.07	28.09	281.62	298.12

**Compared to observed annual-averaged tidal level data in 2012.

4. Conclusion

As conclusion, all monitoring stations have an increasing trend in sea level, where the pattern of the trend line demonstrates fluctuations with seasonal periods. These fluctuations are validated by the Mann-Kendall analysis as well as by previous studies. For the year 2050, the rise in sea level is projected to be between 8.77 cm and 14.29 cm, while for the year 2100, the rise is projected to be between 20.44 cm and 33.20 cm. It shows that the rate of sea-level rise at the KUK station has been increasing much faster than the rate of sea-level rise at all stations. Both the trend analysis and the future projections show that the height of the water in the Malacca Strait will rise between 2050 and 2100.

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