ASSESSMENT OF SEA LEVEL RISE IMPACT ON PENINSULAR MALAYSIA GEODETIC VERTICAL DATUM

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ABSTRACT:

Sea level is the height of the ocean surface in relation to a benchmark or vertical control point. The rising of sea level has become a crucial topic, which frequently discussed among professionals, government, non-government, and researchers upon their devastating impacts on daily human life and human survival. Nevertheless, there is a great deal of ambiguity around the rates, ranges, and time frame of sea levels rise. It is importance to study the variation of present-day sea level rise to understand its impact, particularly on our National Geodetic Vertical Datum (NGVD). This study focuses on quantifying the rate and magnitude of sea level rise over Peninsular Malaysia using in-situ tide gauge and multi-mission satellite altimeter. The time period for tide gauge data used is 35 years (1984 - 2018) consisting 12 tide gauges in Peninsular Malaysia. Meanwhile, the period of satellite altimetry data is 26 years (1993 - 2018). This study uses robust fit regression (Iterative Re-weighted Least-Squares) for both tide gauge and satellite altimetry data to calculate the rate of sea level rise. The outcomes of this study show that the rate of sea level rise at Pelabuhan Kelang tide gauge station is the lowest among 12 other tide gauges with a rate of 2.36 ± 0.35 mm/year and slightly affected by sea level rise. Besides, the rate of sea level rise in Peninsular Malaysia is on an upward trend with an average of 3.20 ± 0.27 mm/year from tide gauge data and 4.14 ± 0.32 mm/year from satellite altimetry data. The sea level rise study provides insights to the rate and magnitude of sea level rise at tide gauge stations, particularly at Pelabuhan Kelang station for further study. Last but not least, this study would also benefit authorities in preparing mitigation plans to secure and improve our Peninsular Malaysia Geodetic Vertical Datum (PMGVD) for various applications.

1. INTRODUCTION

1.1 Research Background

One of the major sources of the rising water levels caused by man-made is the greenhouse gas traps in the atmosphere, which led to the increase of global temperatures. In addition to the melting glaciers and ice caps, climate change also causing an increase in ocean temperatures and sea levels (Mengel et al., 2016). Due to the sea level rise being one of the greatest consequences of global warming, most of the world's population and natural systems will be severely affected (Nicholls et al., 2007). A number of professional organisations are constantly working together to deal with this issue.

According to Church et al. (2010), tides gauges located at the coasts and islands across the world show an annual rise of 1.7 mm in global sea levels over the twentieth century. As mentioned in the Fourth Assessment Report (AR4) by the Intergovernmental Panel on Climate Change (IPCC), from 1980-2000 to 2090-2100, the sea level is also expected to rise approximately 18-59 cm. (IPCC, 2007). Based on the previous study by Din et al. (2016), the difference between 10 years (1984-1993) and 32 years (1984-2015) of tidal data at Pelabuhan Kelang shows a sea level rise of 27 mm. In the following years, Din et al. (2017) found that the sea level of Malaysian waters gradually increases by 2 to 6.5 mm per year. Many other studies indicate that the sea level is increasing alarmingly. This sea level might have a long-term influence on mean sea level (MSL) changes, thus affecting our National Geodetic Vertical Datum (NGVD).

As a result of the interplay between global climate and regional tectonics, the average height of the oceans fluctuates over time. The height of the ocean surface relative to a vertical control point is known as "sea level". Due to the dispersion of ocean water and terrain movement, local MSL can differ significantly from global MSL changes. Department of Survey and Mapping Malaysia (DSMM) uses 12 tide gauges to accurately measure local MSL. This effort resulted in adopting the Pelabuhan Kelang tide gauge as the starting point of Peninsular Malaysia Geodetic Vertical Datum (PMGVD). The PMGVD value at Pelabuhan Kelang station is 3.624 m above zero tide gauge. This value was computed based on the tidal observations from 1984 to 1993 and it is used as a reference (Mohammed, 2003; Sulaiman, 2016). This study intends to determine the rate and magnitude of sea level rise over Peninsular Malaysia by utilising the tide gauges and multi-mission satellite altimeters. The period of tidal data for 12 tide gauge stations in Peninsular

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Malaysia is over 35 years (1984 - 2018). The distribution of the tide gauge stations is shown in Figure 1. Meanwhile, the satellite altimetry data used in this study are over 26 years (1993 - 2018). Both data are then analysed and assessed relative to the influences of sea level rise on PMGVD. A comparison has been conducted between the MSL of 10 years (1984–1993) and 35 years (1984–2018) derived from tidal data collected at Pelabuhan Kelang as PMGVD may be affected by the long-term rising sea level.

Din et al. (2019) have stated that the conventional tide gauges have issues on forecasting sea level variations due to the uneven geographical distribution of tide gauge stations and the absence of continuous deep ocean data. According to Feng et al. (2013), the supplement of satellite altimetry (absolute sea level) is necessary to study the sea level and not only depend on tide gauges, which might be affected by the vertical land motion. Using tide gauge stations to monitor long-term sea levels has limitations as it is poorly maintained and has low-quality data. (Hannah, 2010). Absolute sea level can be computed using satellite altimeters, particularly along the coast of Peninsular Malaysia.

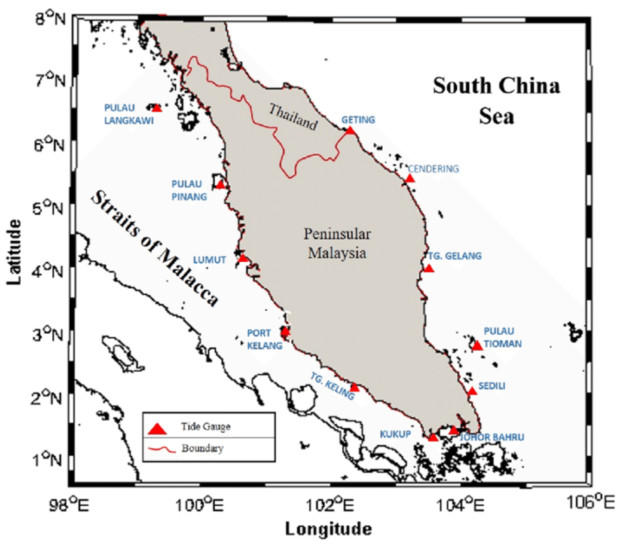

Figure 1. The location of tide gauge stations in Peninsular Malaysia (Din et al., 2016)

This research uses monthly tidal data from 12 tide gauge stations in Malaysia to quantify the rate of sea level rise. The number of stations selected is based on the study area, Peninsular Malaysia, and the data span from its establishment until 2018 have been retrieved from DSMM via the Permanent Service for Mean Sea Level (PSMSL) website. Satellite altimetry data are used to quantify the rate of sea level rise to attain a credible result. In addition, robust fit regression technique is adopted to quantify the rate of sea level rise via MATLAB programming language. Finally, the rate of sea level rise derived from tide gauge and satellite altimetry are used to analyse and evaluate the PMGVD.

2. DATA AND METHODS

2.1 Identification of Research Area

The research area covers the coastal areas of Peninsular Malaysia. It consists of 12 tide gauge stations, as shown in Figure 1. The tidal data are acquired from the PSMSL website. The tide gauge stations used during this research are listed in Table 1. The period of data used for each tide gauge station is 35 years, from 1984 to 2018. The data availability for each tide gauge depends on the PSMSL data. Generally, the available data for Peninsular Malaysia tide gauge stations range up to 2018, except for Johor Bharu station, which stopped operating in 2014. For satellite altimetry data, the data are acquired in the specific range of the latitude 1°N to 8°N and longitude 99°E to 106°E, covering the Malacca Straits and the southern part of the South China Sea. The period of data for satellite altimetry is shown in Table 2.

Table 1. The list of tide gauge stations used in this study

No	Tide Gauge Station	Latitude	Longitude	Period of Data
1	Johor Bahru	1°27'42"N	103°47'30"E	1984-2014
2	Tanjung Gelang	3°58'30"N	103°25'48"E	1984-2018
3	Pelabuhan Kelang	3° 3'0"N	101°21'30"E	1984-2018
4	Cendering	5°15'54"N	103°11'12"E	1984-2018
5	Tanjung Keling	2°12'54"N	102° 9'12"E	1984-2018
6	Lumut	4°14'24"N	100°36'48"E	1985-2018
7	Pulau Pinang	5°25'18"N	100°20'48"E	1984-2018
8	Pulau Langkawi	6°25'51"N	99°45'51"E	1985-2018
9	Kukup	1°19'31"N	103°26'34"E	1985-2018
10	Pulau Tioman	2°48'26"N	104° 8'24"E	1985-2018
11	Tanjung Sedili	1°55'54"N	104° 6'54"E	1984-2018
12	Geting	6°13'35"N	102° 6'24"E	1984-2018

Table 2. Time frame of TOPEX-class and ERS-class data used in the study

Satellite Mission	Data Span
TOPEX/Poseidon	January 1993 - August 2002 (Cycle 011 - 364)
Jason-1	January 2002 – January 2009 (Cycle 001 - 260)
Jason-2	July 2008 – October 2016 (Cycle 000 - 303)
Jason-3	February 2016 - December 2018 (Cycle 000 - 180)
ERS-1	January 1993 - Jun 1996 (Cycle 091-156)
ERS-2	April 1995 - July 2011 (Cycle 001 - 169)
EnviSat	May 2002 - April 2012 (Cycle 006 - 113)
Cryosat-2	July 2010 – December 2015 (Cycle 004 - 074)
Sentinel-3A	March 2016 - December 2018 (Cycle 001 - 066)

2.2 Data Acquisition

2.2.1 Tide Gauge Data

The main source for tide gauge data is from the PSMSL, which is responsible for collecting tidal data for long-term sea-level changes monitoring. The tidal data are retrieved via PSMSL website (https://psmsl.org/data/obtaining/). The PSMSL works closely with the related authorities in different countries, such as DSMM in Malaysia, to store and manage tide gauge data around the world. The acquired data are recorded monthly, suitable for the purpose of this study.

2.2.2 Satellite Altimetry Data

The satellite altimetry data used in this study consist of TOPEX/Poseidon, Jason-1, Jason-2, and Jason-3 (hereinafter TOPEX-class). Besides, ERS-class are also included in this study, namely ERS-1, ERS-2, ENVISAT, CYROSAT-2, and SENTINEL-3A. The data used in this study are retrieved from Radar Altimeter Database System (RADS). The timespans of satellite altimetry data are shown in Table 2.

2.3 Data Processing

2.3.1 Tidal Data Processing

The downloaded tide gauge records are in the form of monthly average data, where the measurements are referenced to the Revised Local Reference (RLR). Tidal data are processed and filtered using Microsoft Excel. The acquired data have some missing data due to the station maintenance; hence, they must be adequately filtered. Unlike altimetric data, tidal data do not involve any complex processing. A simple data cleaning process to remove outliers is carried out using Microsoft Excel and/or TextPad. Then, the monthly sea levels are used to compute yearly MSL to obtain the sea level anomaly (SLA) at the Peninsular Malaysia tide gauge stations.

Subsequently, the rate of sea level is computed using robust fit regression analysis. Robust fit analysis determines solutions and identifies outliers. It involves an Iteratively Re-weighted Least-Squares (IRLS) technique that fits a linear trend to each station’s annual sea level time series. Depending on the trends, measurement weights are modified by refitting the trendline and iterate the process until the solution becomes convergent. The weights of the observations, denoted by wi, are readjusted by the bi-square weight function that has been selected to use. The link between this weight function and the normalised residuals, denoted by ui, may be expressed as (Holland and Welsch, 1977; Md Din et al., 2015):

$$w_i = \begin{cases} (1-(u_i)^2)^2, & |u_i| < 1 \\ 0, & |u_i| \geq 1 \end{cases} \quad (1)$$

where ,

$$u_i = \frac{r_i}{KS\sqrt{1-h_i}} \quad (2)$$

r_i : residuals,
h_i : leverage,
S : Mean absolute deviation divided by a factor 0.6745 to make it an unbiased estimator of standard deviation,
K : A tuning constant, which default value of 4.685 provides for 95% asymptotic efficiency as the ordinary least squares assuming Gaussian distribution.

2.3.2 Multi-mission Satellite Altimetry Data Processing

The satellite altimetry data acquired from the satellite mission are referred to as sea surface height (SSH). From this SSH, the SLA can be derived using the mean sea surface (MSS) of DTU15. Figure 2 shows the overview of RADS altimetry processing. Each satellite altimeter mission needs to be corrected by applying specific models in the processing to minimise the bias, as shown in Table 3. The correction parameters involve in deriving sea level are listed in Table 3.

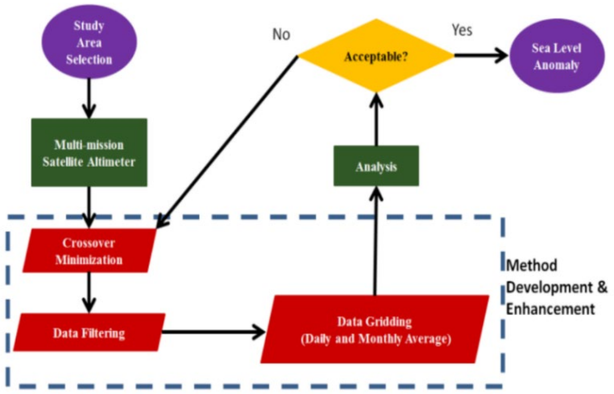

Figure 2. Overview of altimetry data processing flow in RADS (Din et al., 2019)

After applying corrections, the data are processed by performing the crossover minimisation. This crossover minimisation aims to adjust the different satellite missions to a consistent standard surface due to the orbital errors, satellite orbit frame inconsistencies, and SSH (Hamden et al., 2021). Schrama (1989) has stated that dual crossover minimisation must be conducted since TOPEX-class satellites are more accurate than ERS-class satellites. Thus, this crossover minimisation must be conducted with fixed TOPEX-class satellite orbits and altered ERS-class satellite orbits. (Trisirisatayawong et al., 2011).

This study only considers the crossover minimisation analysis between the ERS-class and TOPEX-class satellites. To evaluate the smoothness of orbital error fitting function (one cycle per orbital revolution), the study area must be smaller than the crossover minimisation region. Trisirisatayawong et al. (2011) mentioned in their study that individual crossovers are limited to 18 days to avoid omitting true oceanic signals and sea level trends.

Distance-weighted gridding is used to obtain relevant grid points between tracks with minimal data loss. The weighing function selects relevant and unimportant points. The points near the centre are vital, while points further from the centre are negligible. Fw (r) is a Gaussian weighting function, which can be expressed as (Singh et al., 2004):

$$Fw(r) = e^{-\frac{r^2}{\sigma^2}} \quad (3)$$

where,
σ (sigma) : a parameter governing the smoothness of the filtered result,
r : the distance between the data point and the grid point.

Daily SLA data from multi-mission satellite altimeter are then filtered and gridded to 0.25° by 0.25° bins. By adopting a set of

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sigmas 2.0, altimetric data processing has improved the accuracy and precision of SLA data, particularly for sea level trend computation. The gridding process considers both temporal and spatial weighting of SLA using a square mesh with a 0.25° (spatial) block size and an 18-day cut-off (temporal). This decision is made based on the ERS-class track spacing and repeat period (35 days) and leads to focusing on altimetric data in the area of mesh points (gridding point), while occasionally allowing the data gap.

Table 3. Geophysical corrections of TOPEX-class and ERS-class

Correction/Model	Editing (m) Min	Editing (m) Max	Description
Orbit/Gravity field			All satellites: EIGEN GL04C ERS: DGM-E04/D-PAF
Dry Troposphere	-2.4	-2.1	All satellites: Atmospheric pressure grids (ECMWF)
Wet Troposphere	-0.6	0.0	All satellites: Radiometer measurement
Ionosphere	-0.4	0.04	All satellites: Smoothed dual-frequency, ERS: NIC09
Dynamic atmospheric	-1.0	1.0	All satellites: MOG2D
Ocean tide	-5.0	5.0	All satellites: GOT4.10
Load tide	-0.1	0.1	All satellites: GOT4.10
Solid earth tide	-1.0	1.0	Applied (Elastic response to tidal potential)
Pole tide	-0.1	0.1	Applied (Tide produced by Polar Wobble)
Sea state bias	-1.0	1.0	All Satellites: CLS non parametric ERS: BM3/BM4 parametric
Reference	-1.0	1.0	DTU15 mean sea surface
Engineering flag			Applied
Reference surface			TOPEX, Jason-1, Jason-2, Jason-3

The daily solutions for SLA are then combined to calculate the monthly average solutions. This method makes the monthly altimeter and tide gauge solutions similar. This is because the satellite altimeter only flies over the tide gauge three times a month (TOPEX-class) and only once a month (worst case) (ERS-class). The methodology of this study (daily to monthly altimeter solution) increases the connection between altimetry and tidal data (monthly data) (Din et al., 2015).

2.4 Data Analysis

The processing results from robust fit regression to compute the sea level rise rate are evaluated between tide gauge and satellite altimetry. The processing results are analysed based on the rate of sea level rise for 35 years from tide gauge and 26 years from satellite altimetry. Furthermore, this sea level rise rate is then used to evaluate their impacts on PMGVD.

3. RESULTS AND ANALYSIS

3.1 Rate and Magnitude of Sea Level from Tide Gauge

3.1.1 Sea Level Rate derived from Tidal Data

The rates of sea level rise for tidal stations in Peninsular Malaysia show a consistent upward trend for most tide gauges stations, as shown in Figures 3 to Figure 6. Facing the Malacca Strait in Peninsular Malaysia, Kukup station experience the highest rate of sea level rise with 4.43 ± 0.26 mm/year, as shown in Figure 3. Din et al. (2016) has also stated that the sea level rise acceleration for the Kukup tide gauge station was the highest among other tide gauge stations.

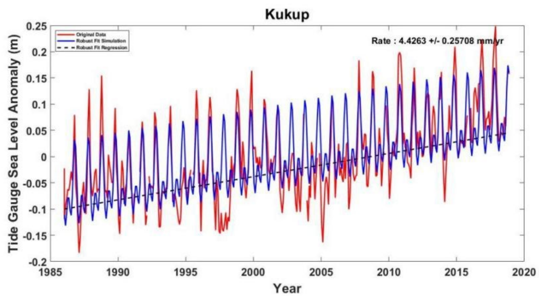

Figure 3. Sea level trend derived using tidal data at Kukup tide gauge station from 1986 to 2018

Concurrently, the Pelabuhan Kelang tide gauge station experiences sea level rate of 2.36 ± 0.35 mm/year, which is the lowest rate on the west coast, as shown in Figure 4. Referring to the rates in Malacca Strait, they are range from 2.36 ± 0.35 mm/year to 4.43 ± 0.26 mm/year, with an average of 3.17 ± 0.30 mm/year using robust fit regression.

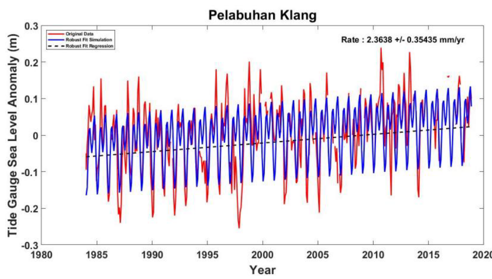

Figure 4. Sea level trend derived using tidal data at Pelabuhan Kelang tide gauge station from 1986 to 2018

The rate of sea level rise in the east coast (South China Sea) of Peninsular Malaysia, particularly at Geting tide gauge station, yields a rate of 3.73 ± 0.32 mm/year, which is the highest in the east coast, as shown in Figure 5.

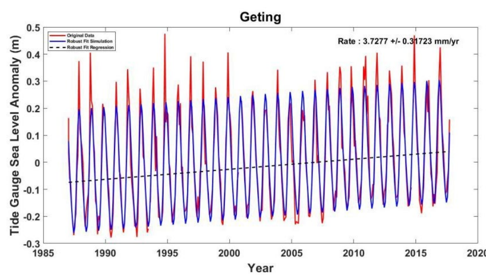

Figure 5. Sea level trend derived using tidal data at Geting tide gauge station from 1986 to 2018

Meanwhile, the lowest sea level rate in the east coast is observed at Tanjung Sedili, with the rate value of 2.53 ± 0.23 mm/year (Figure 6). The range of sea level rates for the South China Sea variate from 2.53 ± 0.23 mm/year to 3.73 ± 0.32 mm/year, with a mean of 3.23 ± 0.24 mm/year.

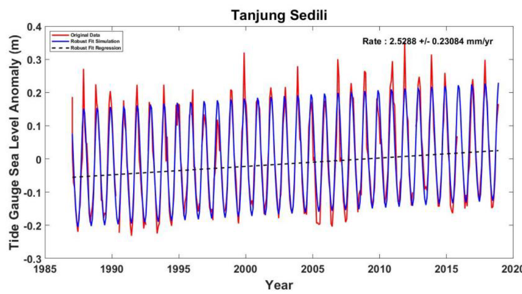

Figure 6. Sea level trend derived using tidal data at Tanjung Sedili station from 1985 to 2018

The highest sea level rate for the 12 tide gauge stations is recorded at Kukup station, with the rate value of 4.43 ± 0.26 mm/year. On the other hand, the Pelabuhan Kelang station experiences sea level rate of 2.36 ± 0.35 mm/year, which is the lowest rate among 12 tide gauge stations. Since both Kukup and Pelabuhan Kelang stations are located in Malacca Strait, there might be a disturbance in annual cycle with many higher harmonics due to the semi-closed zone; hence, preventing short-term circulation dynamics from averaging out (Din et al., 2012; Kamaruddin et al., 2017). The values of sea level rate in Malacca Strait and South China Sea are summarised in Table 4, whereas the overview of sea level rate in Peninsular Malaysia is shown in Figure 7. Using robust fit regression analysis, the sea level rate for the Peninsular Malaysia tide gauges yields an average of 3.20 ± 0.27 mm/year.

Table 4. Sea level rate (mm/yr) derived using robust fit regression analysis for tide gauge stations located in Peninsular Malaysia

Sea Level Rise Progression from Tide Gauge		
Location	**Period**	**Sea Level Rate (mm/yr)**
Malacca Strait		
Pulau Langkawi	1986-2018	3.40 ± 0.36
Pulau Pinang	1985-2018	3.48 ± 0.33
Lumut	1984-2018	2.90 ± 0.32
Pelabuhan Kelang	1984-2018	2.36 ± 0.35
Tanjung Keling	1984-2018	2.40 ± 0.27
Kukup	1986-2018	4.43 ± 0.26
Johor Bahru	1984-2014	3.28 ± 0.23
Average		**3.17 ± 0.30**
South China Sea		
Cendering	1984-2018	3.53 ± 0.24
Geting	1987-2018	3.73 ± 0.32
Pulau Tioman	1986-2018	3.08 ± 0.22
Tanjung Gelang	1984-2018	3.39 ± 0.19
Tanjung Sedili	1987-2018	2.53 ± 0.23
Average		**3.23 ± 0.24**
Total Average		**3.20 ± 0.27**

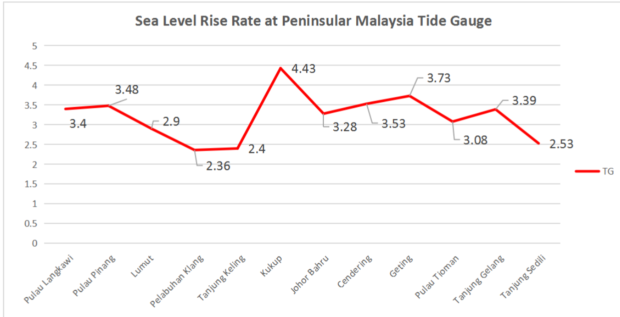

Figure 7. Sea level rate from tidal data at tide gauge stations located in Peninsular Malaysia. The unit is in mm/year

3.1.2 Sea Level Magnitude derived from Tidal Data

The magnitude of sea level is calculated based on the tidal data range from 1984 to 2018. From the calculated value, it shows that the smallest magnitude of 0.018 m is at Tanjung Keling station. On the other hand, the largest magnitude of 0.128 m is observed at Cendering station, as tabulated in Table 5. From the findings, a "very strong" El Nino in 2015/2016 is clearly depicted in the magnitude of the calculated sea-level. (ONI, 2016). In these estimates, the extent to which sea levels are predicted to rise along the coast of Peninsular Malaysia are varies. Table 5 lists the values of yearly MSL and sea level magnitude at 12 tide gauge stations located in Peninsular Malaysia

Table 5. Yearly MSL (m) and sea level magnitude (m) at tide gauge stations located in Peninsular Malaysia

Location	**Data Span**	**Yearly MSL (m)**	**Sea Level Magnitude (m)**
Cendering	1985-2018	2.187 - 2.220	0.033
Kukup	1986-2018	3.987 - 4.115	0.128
Pulau Langkawi	1986-2018	2.182 - 2.281	0.099
Geting	1987-2017	2.252 - 2.373	0.121
Johor Bahru	1984-2013	2.852 - 2.915	0.063
Pulau Pinang	1986-2018	2.658 - 2.747	0.089
Pulau Tioman	1986-2018	2.812 - 2.858	0.046
Tanjung Gelang	1984-2018	2.804 - 2.872	0.068
Tanjung Sedili	1987-2018	2.373 - 2.447	0.074
Lumut	1985-2018	2.206 - 2.252	0.046
Pelabuhan Kelang	1984-2018	3.678 - 3.707	0.029
Tanjung Keling	1985-2018	2.868 - 2.886	0.018
		Minimum (m)	**0.018**
		Maximum (m)	**0.128**
Total Average (m)		**0.068**	

3.2 Sea Level Rate from Satellite Altimeter

Using the satellite altimetry data, MSS height is calculated based on the mean of the data over an observation period. The values of SLA can be computed relative to the differences between MSS and sea surface height (SSH) as recorded by satellite. Then, by using the same method of robust fit regression, the rate of sea level from altimetric data is computed. The data span for satellite altimeter is 23 years (1993 - 2018). The data are interpolated to the specific positions to obtain the SLA at 12 tide gauge stations in Peninsular Malaysia. Eventually, this method leads to many residuals as stated by Anderson and Scharroo (2011), where the residual of SLA increases along the coast due to the shallow water.

Referring to Figure 8, the sea level rate at Johor Bahru tide gauge station is 5.60 ± 0.34 mm/year, meanwhile at Pulau Langkawi station records the lowest rate of 4.43 ± 0.43 mm/year (Figure 9). The range of sea level rate for this study using robust fit regression method is from 4.43 ± 0.43 mm/year to 5.60 ± 0.34 mm/year, with an average of 5.05 ± 0.42 mm/year in Malacca Strait.

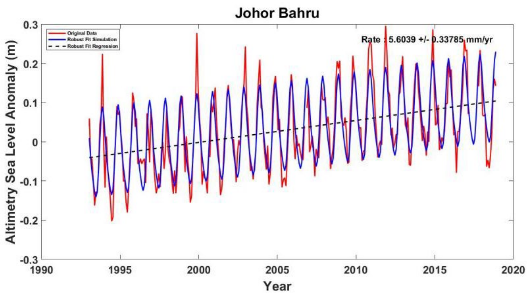

Figure 8. Sea level trend from satellite altimetry data at Johor Bahru station from 1993 to 2018

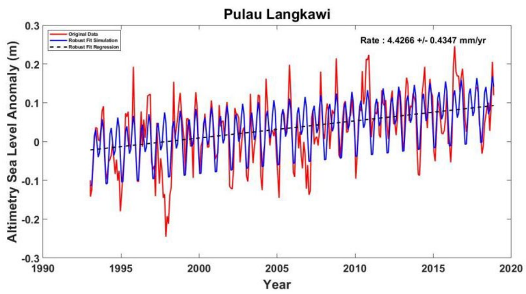

Figure 9. Sea level trend from satellite altimetry data at Pulau Langkawi station from 1993 to 2018

Furthermore, the highest sea level rate is recorded at Tanjung Sedili station with the value of 5.15 ± 0.30 (Figure 10). Concurrently, the area with the lowest rate on the east coast of Peninsular Malaysia is at Cendering station, which is at 3.45 ± 0.32 mm/year (Figure 11). Facing South China Sea, the values of sea level rate at tide gauge stations range from 3.45 mm/year to 5.15 mm/year with a standard deviation of 0.32 mm and mean of 4.14 ± 0.32 mm/year.

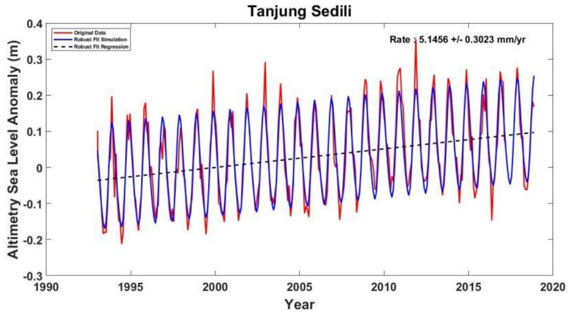

Figure 10. Sea level trend from satellite altimetry data at Tanjung Sedili station from 1993 to 2018

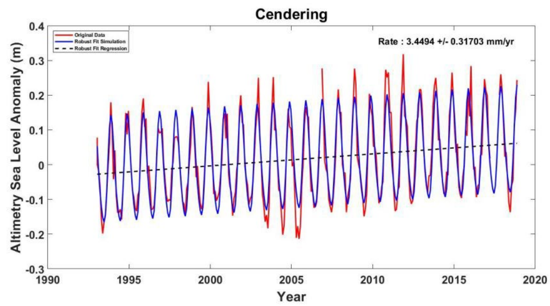

Figure 11. Sea level trend from satellite altimetry data at Cendering station from 1993 to 2018

The overview of the sea level rate derived from satellite altimetry at Peninsular Malaysia is shown in Figure 12. This study shows that the absolute sea level over the Malaysian seas is rising which has been mentioned in the study by Din et al. (2019).

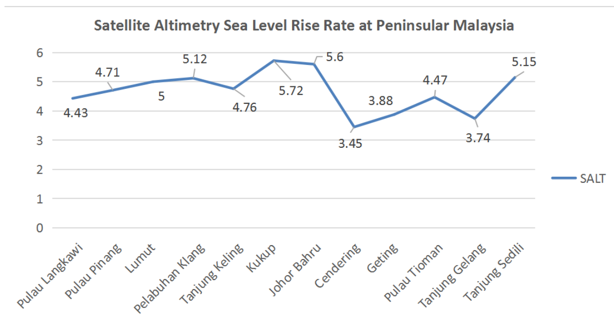

Figure 12. Sea level rate from altimetric data at tide gauge stations located in Peninsular Malaysia. The unit is in mm/year

3.3 Evaluation of Sea Level Rise on PMGVD

3.3.1 The Differences between Tidal Average of 35 Years (1984-2018) and Tidal Average of 10 Years (1984-1993)

Referring to the tidal data collected at Pelabuhan Kelang tide gauge station, the yearly MSL from 1984 until 2018 are calculated (Table 6). Then, the differences in MSL of tidal data collected over 10 years (1984-1993) and 35 years (1984-2018) are computed. The original value of PMGVD (MSL A) is 3.624 m, which is computed from the time span of 10 years. In comparison with the MSL B, the value of MSL calculated over 35 years is 3.658 m.

From the previous study conducted by Din et al. (2016), the magnitude of sea level at Pelabuhan Kelang tide gauge was 27 mm derived from a data span of 32-year relative to the

PMGVD. On the other hand, the sea level is shown to rise as it approaches land. The computed MSL B (3.658m) from the data period of 35 years (1984 - 2018) shows that the MSL is rising with a magnitude of 34 mm from MSL A to MSL B. Thus, it is shown that the sea level magnitude from MSL (1984 - 2015) and MSL (1984 - 2018) was 27 mm and 34 mm, respectively (Din et al., 2016). The difference between both of these sea level magnitudes is 7 mm. Thus, the magnitude demonstrates the impact of long-term MSL changes on PMGVD.

In this study, it is clear that sea level rise affects the geodetic vertical datum, which is crucial for land development and our national geoid model, MyGEOID, established by fitting to the MSL. The effect of this sea level rise varies depending on its location and oceanographic characteristics. This study shows that the Pelabuhan Kelang tide gauge experience the lowest sea level rate at 2.36 ± 0.35 mm/year. Due to the tides or water flows primarily entering from one side of the strait, the PMGVD is slightly affected by the rising sea level. These tides and water flows are influenced by the north-west to south-east geometrical shifts and tiny islands (Akdag, 1996). Eventually, the PMGVD must be continuously monitored to preserve its reliability.

Table 6. Yearly MSL at Pelabuhan Kelang (1984-2018)

Year	Mean(m)		Year	Mean(m)		Year	Mean(m)
1984	3.678		1997	3.540		2010	3.744
1985	3.651		1998	3.654		2011	3.673
1986	3.610		1999	3.691		2012	3.728
1987	3.579		2000	3.737		2013	3.743
1988	3.654		2001	3.698		2014	3.662
1989	3.643		2002	3.610		2015	3.680
1990	3.611		2003	3.644		2016	3.736
1991	3.584		2004	3.632		2017	3.730
1992	3.615		2005	3.653		2018	3.707
1993	3.625		2006	3.613			
1994	3.578		2007	3.635			
1995	3.657		2008	3.660			
1996	3.669		2009	3.707			
MSL A (1984 to 1993) = 3.624 m (PMGVD)							
MSL B (1984 to 2018) = 3.658 m							
Magnitude (MSL B - MSL A) = 0.034 m							

3.3.2 Mean Sea Level Simulation on PMGVD

The tidal gauge benchmark B0169 is set relative to the Pelabuhan Kelang (B0169) zero tide gauge, where the long-term MSL changes will affect the benchmark of geodetic vertical datum. Figure 13 shows a clear illustration of the magnitude of sea level between the MSL from 1984 to 1993 and the computed MSL from 1983 to 2018. The MSL value calculated by Din et al. (2016) from 1984 to 2015 is 3.651 m, whereas this study computes MSL over 35 years of data (1984-2018) with the value of 3.658 m. The difference in time between those calculated MSL is 3 years with a significant difference value of 7 mm. It is demonstrated that the magnitude of sea level has moved upwards while approaching the land areas.

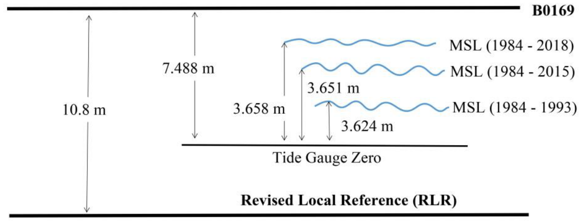

Figure 13. MSL height variation at benchmark located at Pelabuhan Kelang

4. CONCLUSION

The result of this study in quantifying the sea level rate using both tidal and satellite altimetry data shows an upward trend with an average value of 3.20 ± 0.27 mm/year for tidal data and 4.14 ± 0.32 mm/year for altimetric data. The sea level rate at Pelabuhan Kelang station is further analysed to evaluate the reliability and credibility of PMGVD. From the output, it is clearly indicating that Pelabuhan Kelang station experiences a rate of sea level at 2.36 ± 0.35 mm/year, which is the lowest among 12 tide gauge stations located in Peninsular Malaysia. Moreover, the difference between MSL A and B is 3.4 cm with 3-year different in data span. It has been proven that different period of MSL would give different value of MSL affecting PMGVD. To briefly summarise, this study provides new insights towards the sea level rise impact on PMGVD by quantifying the sea level rise variation and magnitude in the coastal area of Peninsular Malaysia, particularly at 12 tide gauge stations. In addition, this study would also help the authorities to preserve and improve the reliability of PMGVD for various purposes.

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