Research Article

Trend Analysis of Sea Level Change in the Gulf of Thailand

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ABSTRACT

This study aims to examine the trend of sea level change in the Gulf of Thailand. This study uses sea level data of the 18 tide gauge stations during January 1977 until August 2019 from Marine Department, the Ministry of Transport in Thailand. Time series analysis is employed including seasonal removal and trend detection. Trend detection is checked by using both parametric and non-parametric statistics test. Autoregressive model is used to ensure that errors are independent, therefore linear regression can be used to assess the linear trend. The results show that the rate of change in sea level varies from station to station and only 13 tide gauge stations show significant increasing in sea level. In addition, sea level change has linearly increased from 3.44 to 19.19 mm/year. The highest rate of sea level change appears in the eastern coast of the Gulf of Thailand since sea level change at Ao Udom, Chonburi province has linearly increasing of 19.19 mm/year.

Keywords: Gulf of Thailand, Sea level, Sea Level Change, Trend Analysis

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Introduction

Global climate change is the phenomenon that affects the sea level around the world. In the 21st century, the world's average sea level has risen to about 3 mm/year. However, the rising of sea level may vary in different from ocean basins to ocean basins. Repanić and Bašić [1] used least squares method to analyze permanent service for mean sea level (PSMSL) of nine tide gauge stations in Adriatic between of 57 years (1956-2006). The results show that 50-year period relative trends have been determined with standard deviations from 0.1 to 0.3 mm/year. Furthermore, Barbosa et al. [2] used nonparametric smoothing and robust lowess to estimate sea level trends for each tide gauge stations in the Northeast Atlantic, and the results showed a slight increasing trend. Therefore, the past and future sea level rise at specific locations may be more or less than the global average due to local factors including ground settling, upstream flood control, erosion, regional ocean currents, etc. Sea level change has a great impact to humanity and organisms in natural ecosystems, agriculture, fisheries, sanitation, economic and society. In addition, the effects of sea level rise include destructive erosion, flooding, agricultural soil contamination with salt, and lost habitat of animals and plants.

Moreover, sea level rise will impact all coastal area including shoreline recession, loss of coastal infrastructure, loss of natural resources and biodiversity. Normally, sea level change is affected by glacioeustasy, subsidence of land, manmade activity, ocean-atmosphere effects. In Thailand, land subsidence near the coast seems to play a major role in sea level change [3]. Although, Thailand lies between the Andaman Sea on the west and the Gulf of Thailand on the east, this study focuses on the rising sea level on the Gulf of Thailand because the capital city, Bangkok, is affected by the rising sea level as well as the southern and eastern coasts of Thailand. From the previous studies, sea level change of the Gulf of Thailand has increased about 5 mm/year over the past 25 years (1985-2009) and may has a great impact to coastal areas all over the country [3]. However, the rising of sea level does not only cause a serious coastal erosion problem but also natural resources, environment, coastal ecosystems, economic and Thai society. Moreover, it may cause loss of property of the people and government, travel business, coastal fishing and changing in local life. There are reported on the slightly change in the sea level as Vongvisessomjai [4] used U.K. meteorological office's coupled ocean-atmosphere general circulation model (CGCMs) to assess regional variation in sea level change using data which was recorded over 56 years at Ko Lak tide gauge station, Prachuap Khiri Khan province and Sattahip tide gauge station, Chonburi province. The result revealed that sea levels were falling slowly or not changing at the rate of -0.36 mm/yr or -3.6 cm/century at Sattahip and Ko Lak. Moreover, Sojisuporn et al. [3] used linear regression method to analyze the annual local mean sea level (MSL) at 13 tide gauge stations bordering the Gulf of Thailand between 1985-2009. In addition, Pongsiri et al. [5] used harmonic analysis and linear regression model for analyzing trend of sea level in the Gulf of Thailand. The results found that the increasing trends were observed for almost all tide gauge stations. Furthermore, Ritphring *et al.* [6] studied the projections of future beach loss due to sea level rise for sandy beaches along Thailand's coastlines based on RCP scenarios using the Bruun rule. The results indicated that the projected loss rate may reach a maximum of 71.8% where 23 beach zones will be completely lost. In addition, the paper stated that the sea level rise could cause significant shoreline recession along all of Thailand's coasts in the future [6].

Therefore, this study aims to assess the trend of sea level change in the Gulf of Thailand in 43 years time span (1977-2019) using time series analysis and linear trend for relevant agencies to use the analysis results for further study or develop an effective strategy for preventing shoreline recession along the Gulf of Thailand.

Materials and Methods

Data

This study uses monthly sea level data from the 18 tide gauge stations located along the Gulf of Thailand during January, 1977 until August, 2019 (43 Years) as shown in Figure 1. Sea level data were obtained from Marine Department, the Ministry of Transport in Thailand. Data for each tide gauge station is recorded in different period, the duration of recorded data at each tide gauge station is described in Table 1.

Figure 1 Location of 18 tide gauge stations in this study.

Table 1 Data availability for each station.

Station	Station Name	Period	Months
TC	Samutsakorn	Jul, 1977 – Dec, 2000	282
		Jan, 2002 – Aug, 2019	212
MK	Samutsongkram	Jan, 1987 - Aug, 2019	392
BL	Petchburi (Ban Laem)	Jan, 1997 - Aug, 2019	272
KV	Prachuap khiri khan (Klong wan)	May, 2006 - Jan, 2015	105

Station	Station Name	Period	Months
PB	Prachuap khiri khan (Phan Buri)	Jul, 1992 – Feb, 2006	164
BK	Chachoengsao (Bang Pakong)	Sep, 1981 - Aug, 2019	456
AU	Chonburi (Au Udom)	Sep, 2006 - Aug, 2019	156
RY	Rayong (Rayong)	Jan, 1997 - Aug, 2019	272
PS	Rayong (Prasae)	Jan, 1984 - Jan, 2015	373
TL	Chantraburi (Thachalab)	Jan, 1999 - Aug, 2019	248
LG	Trat (Laem Ngop)	Jan, 1984 - Aug, 2019	428
KY	Trat (Klong Yai)	Apr, 1993 - Dec, 2005	153
LS	Chomporn	Jan, 1997 - Dec, 2011	180
		Jan, 2013 - Aug, 2019	80
SA	Suratthani	Sep, 2006 - Jan, 2017	125
SC	Nakorn Sri Thamarat (Sichon)	Sep, 1992 - Aug, 2019	324
PN	Nakorn Sri Thamarat (Pak panung)	Jan, 1997 - Aug, 2019	272
PT	Pattani	Jan, 1999 - Aug, 2019	248
NR	Narathiwas (Bangnara)	Jan, 1991 - Aug, 2019	344

Data Cleaning

The monthly sea level data from each tide gauge stations were cleaned since missing values appear on Jan-Feb, 2019 in Thachalab data set. The missing values were imputed by using the seasonally decomposed missing value imputation by imputeTS function in R package [15]. In this study, data were also seasonally adjusted before detecting trend and assessing trend of sea level change.

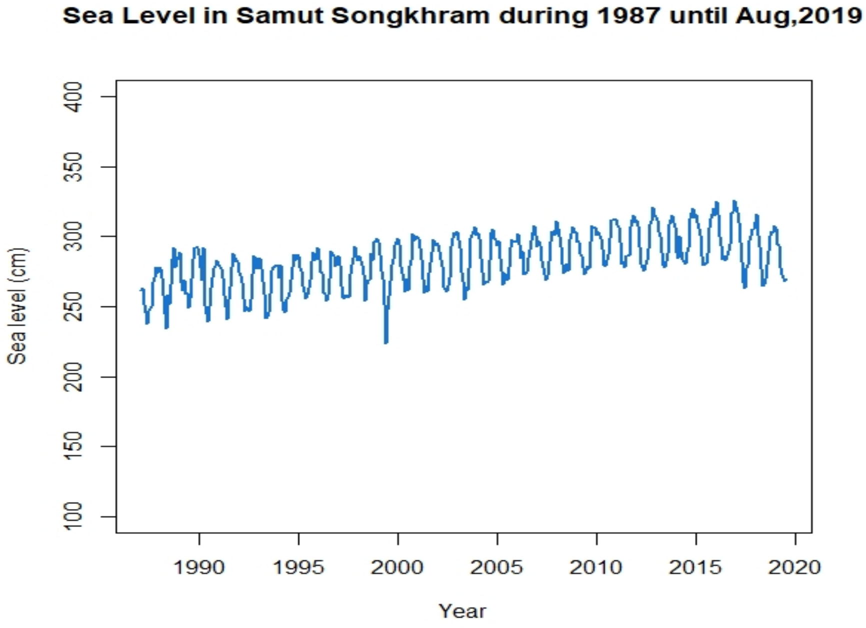


Figure 2 Sample of actual sea level change which contain a seasonal.

Figure 2 shows the actual sea level at Samut Songkram tide gauge stations during January 1987–August 2019 and it shows that monthly sea level data contains a seasonal. Therefore, seasonal variations were removed by subtracting the monthly average and then adding back the overall mean sea level [7].

Statistics test for trend detection methods

Generally, parametric and non-parametric statistical tests can be used for trend detection. The parametric statistical test includes linear regression [8-9], periodic functions [8] while non-parametric statistical test includes Run test, Mann-Kendall test [8-10], Seasonal Kendall [8] and Spearman's Rho [9]. In this study, the parametric statistics methods that we employed was linear regression method with concerning whether time series contain increasing trend or decreasing trend. For non-parametric trend detection, we employed Mann-Kendall test which was used to detect a monotonic trend in time series. The advantage of Mann-Kendall is that it can be used to detect trend whether the trend is linear or non-linear [10].

For the hypothesis testing about trend, the null hypothesis H_0 states that there is no trend whereas the alternative hypothesis H_1 states that there is trend. This hypothesis testing can be used for both parametric and non-parametric statistical tests.

Linear Regression test

The linear regression for trend detection considers the relationship between the variable Y on time variable X [11]. The regression coefficient b_1 was computed from the sample data and the statistic used for the hypothesis testing was t, and it is presented in equation 1.

$$t = \frac{b_1}{s/\sqrt{S_{xx}}} \tag{1}$$

Statistic t follows the Student’s t distribution with degrees of freedom n-2, where n is the sample size, s is the residual standard deviation, and S_{xx} is the sums of squares of the independent variable which is time variable. The null hypothesis, H_0: $\beta_1 = 0$ (There is no trend), is tested against the alternative hypothesis, $H_1: \beta_1 \neq 0$, at level of significance α, where β_1 is the parameter (population value of the regression coefficient). The null hypothesis H_0 is rejected when the absolute of the calculated t-value, which is computed by equation 1, is greater than or equal to the absolute value of the critical value $t_{\alpha/2}$.

Mann-Kendall test

The Mann-Kendall test (MK test) is widely used for trend detection. To perform a MK test, the difference between each pair of observed values y_i and y_j ,where $j>i$, of the variable Y is computed and assign the integer value of 1 if $y_i < y_j$, -1 if $y_i > y_j$, otherwise is 0. The statistic S is defined as [12]

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sign}(y_j - y_i) \tag{2}$$

where n is the number of observed values and sign function is given as

$$\text{sign}(y_j - y_i) = \begin{cases} 1 & \text{if } y_j - y_i > 0 \\ 0 & \text{if } y_j - y_i = 0 \\ -1 & \text{if } y_j - y_i < 0 \end{cases} \tag{3}$$

For n > 10, the sampling distribution of S follows the standard normal distribution [11] and its mean and variance can be obtained by the following formula

$$E(s) = 0 \tag{4}$$

$$\sigma^2(s) = n(n-1)(2n+5)/18 \tag{5}$$

The Z statistic of MK test [11] can be computed as

$$Z = \begin{cases} (S-1)/\sigma_s & \text{if } S>0 \\ 0 & \text{if } S=0 \\ (S+1)/\sigma_s & \text{if } S<0 \end{cases} \tag{6}$$

There is a correction for ties when $y_i = y_j$ [13]. In the MK test, the null hypothesis (H_0) that there is no trend is rejected when the absolute of *Z*-value, which is computed by equation 6, is greater than or equal to the absolute value of the critical value $Z_{\alpha/2}$.

Trend Analysis

In this study, trend of sea level change was assessed by linear trend using the least square method. The simple linear regression model was employed to fit these seasonally adjusted sea level (Figure 3). The model is shown in equation 7.

$$Y_{it} = b_{0i} + b_{1i} d_t \tag{7}$$

where Y_{it} denotes the seasonally adjusted sea level at station *i* for month *t*,

d_t denotes the time elapsed in months.

b_{oi} is the average sea level at station i over the given period

b_{1i} is the estimated rate of increase in sea level per month.

The model assumes that errors are independent and normally distributed. For the assumption of independent errors, a first and second order autoregressive model are suitable for removing uncertainty which is represented by the residuals around the trend line. Therefore, AR(1) and AR(2), were fitted to the residuals from a fitted model in equations 8-9 [14]. Then, the average monthly sea levels at each station are adjusted to remove autocorrelations by using equation 8 for AR(1) and equation 9 for AR(2).

$$Y_t' = Y_t - r_1 Y_{t-1} \tag{8}$$

$$Y_t^{'} = Y_t - r_1 Y_{t-1} - r_2 Y_{t-2} \qquad (9)$$

where coefficients r_1 and r_2 are the estimated parameters in the fitted 2-term autoregressive models and $Y_t^{'}$ are the adjusted sea level [7] and transform using $Y_t^{''} = \left(\frac{1}{1-r_1}\right) Y_t^{'}$ for AR(1) and $Y_t^{''} = \left(\frac{1}{1 - r_1 - r_2}\right) Y_t^{'}$ for AR(2).

Subsequently, we checked whether autocorrelations problem was resolved or not by using Durbin-Watson test and the results showed that autocorrelation did not exist. Moreover, normal distribution of the errors was checked by Kolmogorov-Smirnov test and the results showed that errors were normally distributed at significance level 0.05 except Bangnara station at Narathiwas province that error was normally distributed at significance level 0.01. Therefore, we constructed linear regression model and obtained the estimated increasing rate in sea level per month.

Results and Discussion

As explain in trend analysis section, the ACF and PACF plots in Figure 3 show that the autocorrelations of residuals are significant and positive up to lag 1 and 2 at Pattani tide gauge station. To account for these significant autocorrelations, an AR(2) model was fitted to the residuals from the simple linear regression model therefore the autocorrelations were removed by equation 9. For this station, the average values of the two parameters (in the fitted 2-term autoregressive models) are $r_1 = 0.426$ and $r_2 = 0.336$.

Subsequently, the autocorrelation for this station is tested by using Durbin-Watson test (DW = 2.076, p-value = 0.704). The results in Table 2 show that the autocorrelations were removed using AR(p) where p is either 1 or 2. In addition, we summarize the results of statistical testing for trend detection in Table 2. The results showed that there were five tide gauge stations including Klong wan, Klong Yai, Lang Suan, Suratthani, Pak Panung, which did not show significant trend. The results are similar to Pongsiri and et al. [5], except that Rayong had significant trend.

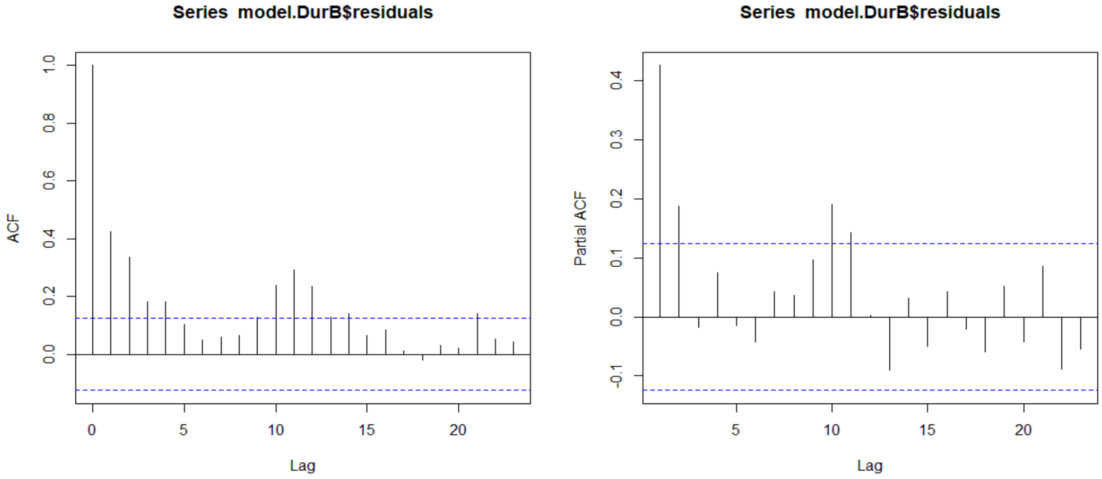


Figure 3 ACF and PACF plots for Pattani station.

Table 2 Trend detection results for each tide gauge station.

No.	Station	Period	Linear regression		Mann-Kendall		Trend detection	Model
			Z value	p-value	Z value	p-value		
1	TC	Jul, 1977 – Dec, 2000	11.51	(b)	10.363	(b)	Sig.	AR(1)
		Jan, 2002 – Aug, 2019	6.92	(b)	6.343	(b)	Sig.	AR(1)
2	MK	Jan, 1987 - Aug, 2019	3.473	(b)	3.836	(b)	Sig.	AR(2)
3	BL	Jan, 1997 - Aug, 2019	6.836	(b)	7.004	(b)	Sig.	AR(1)
4	KV	May, 2006 - Jan, 2015	0.030	(a)	-0.270	(a)	Non-Sig.	-
5	PB	Jul, 1992 – Feb, 2006	2.558	(c)	2.175	(c)	Sig.	AR(2)
6	BK	Sep, 1981 - Aug, 2019	7.526	(b)	7.299	(b)	Sig.	AR(1)
7	AU	Sep, 2006 - Aug, 2019	2.744	(b)	3.162	(b)	Sig.	AR(2)
8	RY	Jan, 1997 - Aug, 2019	3.135	(b)	2.874	(b)	Sig.	AR(1)
9	PS	Jan, 1984 - Jan, 2015	7.815	(b)	7.034	(b)	Sig.	AR(1)
10	TL	Jan, 1999 - Aug, 2019	3.021	(b)	3.294	(b)	Sig.	AR(1)
11	LG	Jan, 1984 - Aug, 2019	6.065	(b)	6.597	(b)	Sig.	AR(1)
12	KY	Apr, 1993 - Dec, 2005	-0.420	(a)	-0.327	(a)	Non-Sig.	-
13	LS	Jan, 1997 - Dec, 2011	0.206	(a)	-0.101	(a)	Non-Sig.	-
		Jan, 2013 - Aug, 2019	1.331	(a)	1.400	(a)	Non-Sig.	-
14	SA	Sep, 2006 - Jan, 2017	0.683	(a)	0.825	(a)	Non-Sig.	-
15	SC	Sep, 1992 - Aug, 2019	5.598	(b)	5.510	(b)	Sig.	AR(1)
16	PN	Jan, 1997 - Aug, 2019	-1.407	(a)	-1.341	(a)	Non-Sig.	-
17	PT	Jan, 1999 - Aug, 2019	1.978	(c)	2.017	(c)	Sig.	AR(2)
18	NR	Jan, 1991 - Aug, 2019	4.320	(b)	5.210	(b)	Sig.	AR(2)

Remark: (a) No significant, (b) Significant with p-value < 0.01, (c) Significant with p-value < 0.05

Table 3 shows that the rate of change in sea level (mm/year) had significant change in 13 tide gauge stations. The sea level change has linearly increased for all tide gauge station. In addition, the rate of change in sea level varied from station to station. Sea level change has linearly increased from 0.72 to 19.19 mm/year. However, the average rate of sea level change of the northern coast of the Gulf of Thailand is higher than another coast since sea level change of both stations, Samut Sakorn and Samut Songkram, have linearly increased for more than 10 mm/year. The highest average rate of sea level change appears in the eastern coast of the Gulf of Thailand since sea level change at Ao Udom, Chonburi province has linearly increasing of 19.19 mm/year while sea level change in the southern coast of the Gulf of Thailand is lower than another coast.

Table 3 Rate of change in sea level for each tide gauge station.

Station	Station Name	Period	Rate of change in sea level (mm/year)
TC	Samutsakorn	Jul, 1977 – Dec, 2000	16.27
		Jan, 2002 – Aug, 2019	7.88
MK	Samutsongkram	Jan, 1987 - Aug, 2019	10.44
BL	Petchburi (Ban Laem)	Jan, 1997 - Aug, 2019	7.05
PB	Prachuap khiri khan (Phan Buri)	Jul, 1992 – Feb, 2006	3.99
BK	Chachoengsao (Bang Pakong)	Sep, 1981 - Aug, 2019	5.07
AU	Chonburi (Au Udom)	Sep, 2006 - Aug, 2019	19.19
RY	Rayong (Rayong)	Jan, 1997 - Aug, 2019	3.44
PS	Rayong (Prasae)	Jan, 1984 - Jan, 2015	4.17
TL	Chantraburi (Thachalab)	Jan, 1999 - Aug, 2019	5.50
LG	Trat (Laem Ngop)	Jan, 1984 - Aug, 2019	3.66
SC	Nakorn Sri Thamarat (Sichon)	Sep, 1992 - Aug, 2019	5.74
PT	Pattani	Jan, 1999 - Aug, 2019	4.72
NR	Narathiwas (Bangnara)	Jan, 1991 - Aug, 2019	7.22

Figure 4 shows sea level trends for tide gauge station in the northern GOT. This figure shows that sea level change of Samut Sakorn and Samut Songkhram have linearly increased about 16.27 and 10.44 mm/year which is very high. Figure 5 shows sea level change of tide gauge station located in the western coast of GOT, which also has linearly increased. However, the change is less than the northern coast of GOT.

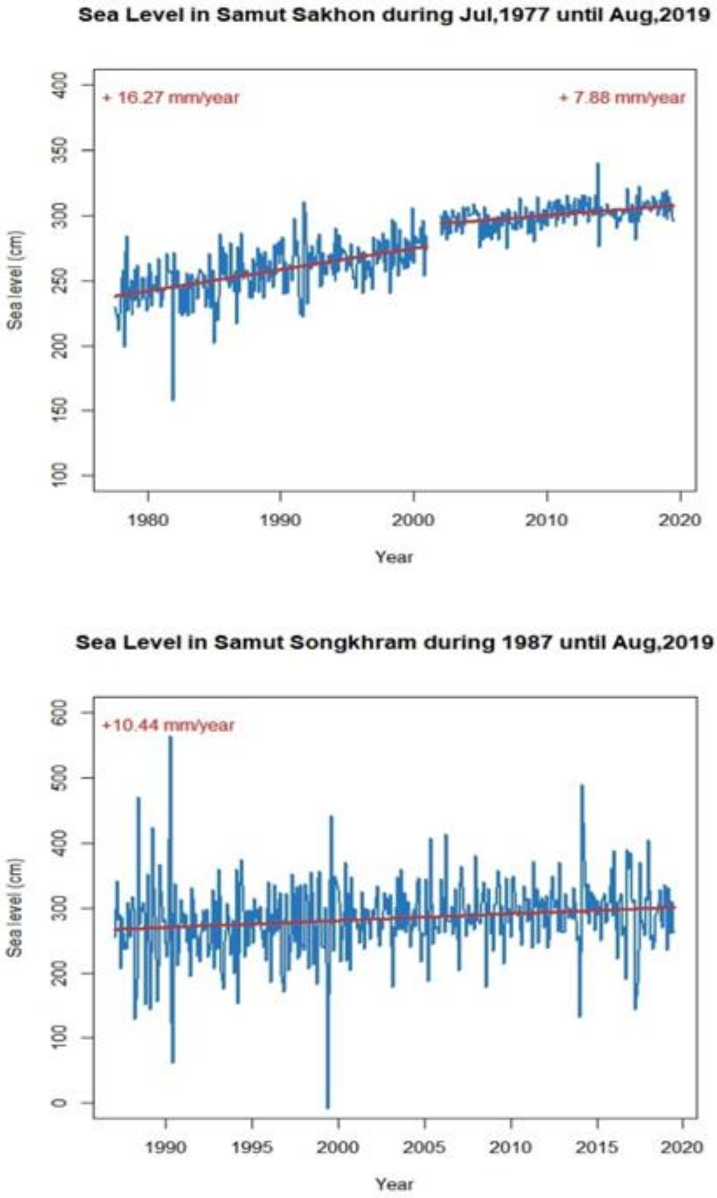
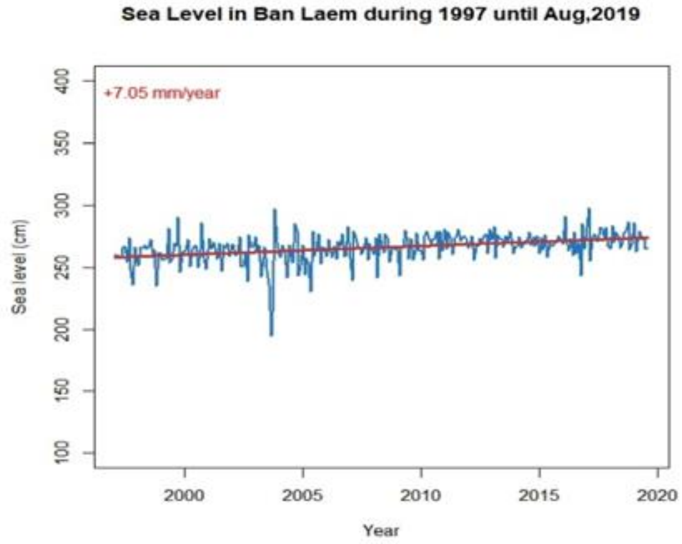
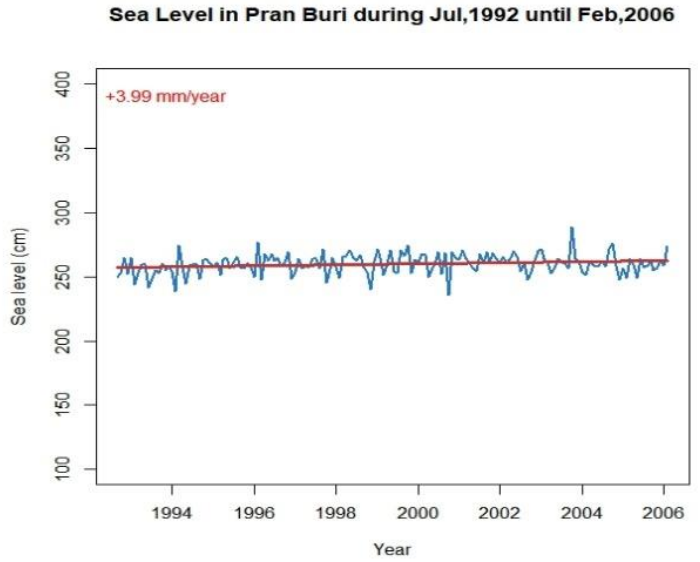


Figure 4 Sea level trends for tide gauge stations located in the northern coast of the Gulf of Thailand.



Sea Level in Ban Laem during 1997 until Aug,2019



Sea Level in Pran Buri during Jul,1992 until Feb,2006

Figure 5 Sea level trends for tide gauge stations located in the western coast of the Gulf of Thailand.

Figure 6 shows that sea level change at Ao Udom, chonburi also has highest linearly increased about 19.19 mm/year which is gradually change as sea level in the northern coast of GOT. However, sea level change in Rayong is slightly change. Figure 7 shows that at tide gauge stations located at southern coast of GOT, sea level change also has linearly increased about 4-7 mm/year.

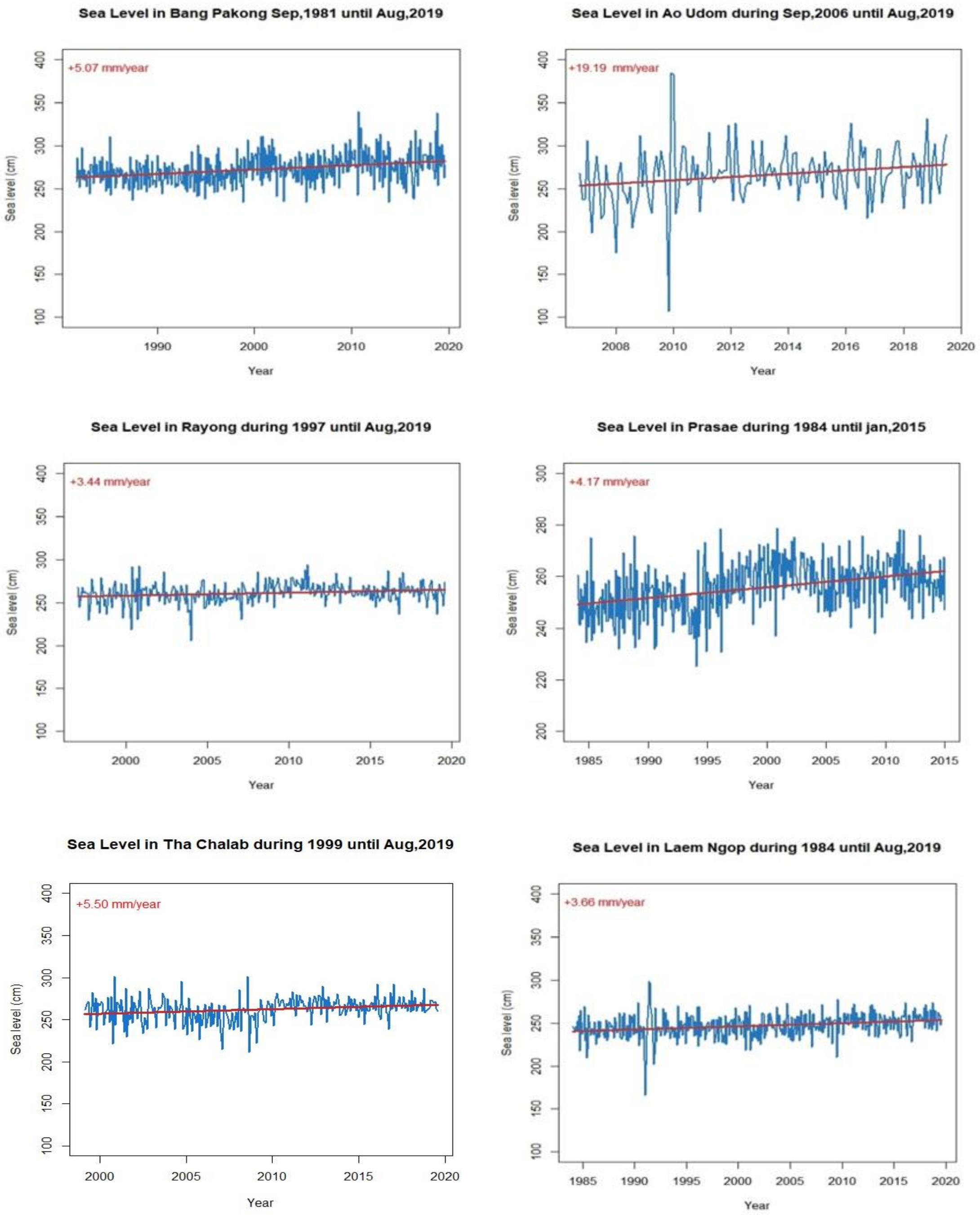


Figure 6 Sea level trends for tide gauge stations located in the eastern coast of the Gulf of Thailand.

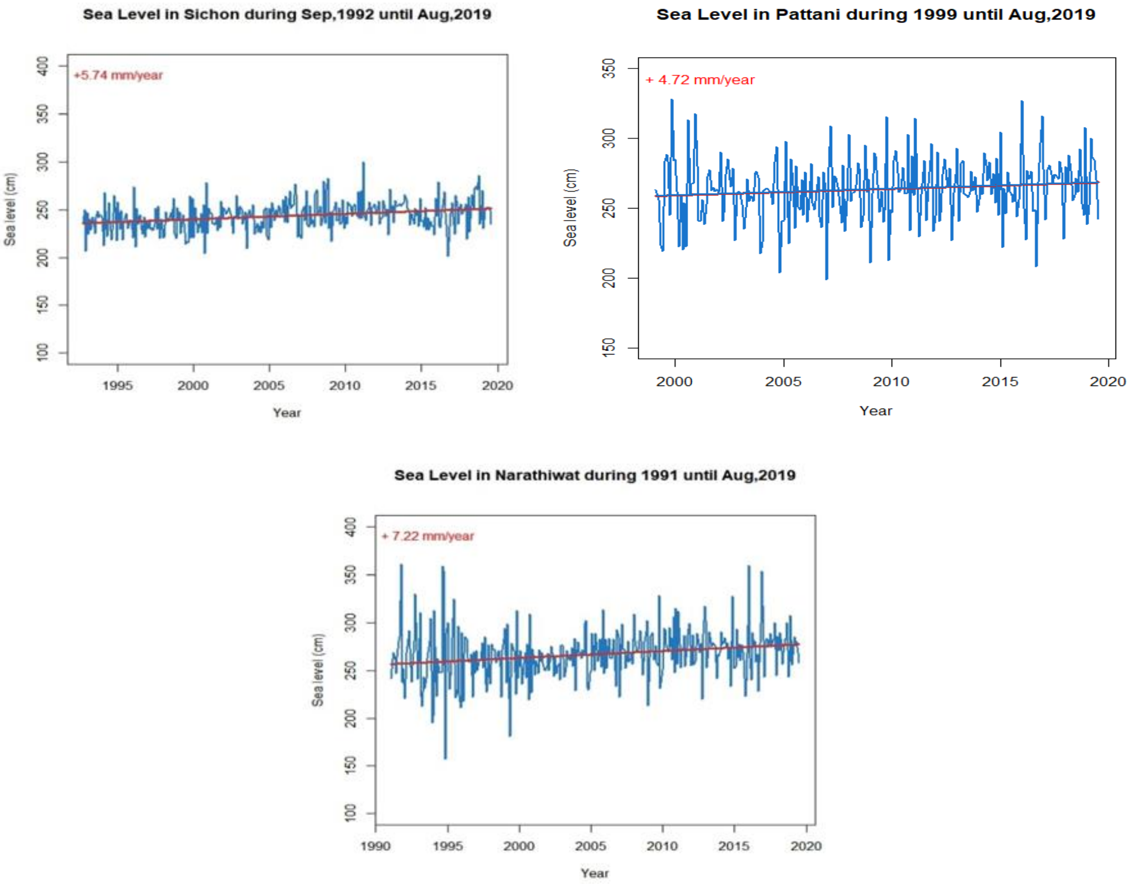


Figure 7 Sea level trends for tide gauge stations located in the southern coast of the Gulf of Thailand.

Conclusions

This study examines the trend of sea level change in the Gulf of Thailand using time series analysis. The parametric and non-parametric statistics are used for trend detection and linear regression is employed for trend analysis. The results show that the rate of sea level change in the Gulf of Thailand has increasing trends for 13 tide gauge stations. The average rate of sea level change of the northern coast of the Gulf of Thailand is higher than that of the other coasts. However, the change of sea level may depend on the rainfall, the temperature and soil subsidence, and these factors should be further studied.

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