Article

Impact of Sea Level Rise on Tourism Carrying Capacity in Thailand

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Abstract: Sea level rise due to climate change affects beaches, which are a source of high recreational value in the economy. The tourism carrying capacity (TCC) assessment is one of the tools to determine the management capacity of a beach. Pattaya beach represents the character of well-known beaches in Thailand, while Chalatat beach represents the character of beaches that are the focus of domestic tourism. To evaluate beach area this study detected the shoreline position using Google Earth images with tidal correction. The Bruun rule was used for shoreline projection. TCC was calculated by using the beach area, correction factors, and management capacity. The results find that the current effective carrying capacity is approximately 200,000 for Pattaya beach and 49,000 for Chalatat beach. Although the Chalatat beach areas are larger than Pattaya, the effective carrying capacity of Pattaya beach is larger than the effective carrying capacity of Chalatat beach for all situations because TCC is affected by beach areas, correction factors, and management capacity. Because beach areas experience the effects of sea-level rise, protection against future beach loss should be considered for coastal management.

1. Introduction

The beach is an important ecosystem that has many benefits, including recreation, fisheries, and a buffer near the ocean. Recreation opportunities on the beach affect economic growth in many coastal areas. In this study, Pattaya beach and Chalatat beach were chosen to be the study areas because they represent the character of well-known beaches for tourists who travel to Thailand and the character of recreational use for local people in those areas, respectively. Approximately 14 million tourists visit Pattaya annually, while 7 million tourists visit Songkhla (located at Chalatat beach), according to statistical data from the Ministry of Tourism and Sports. Due to climate change, the global sea level is rising and will increase during the early twenty-first century because of increasing temperatures [1]. The data from the tidal gauge near the study area reveals that the sea level has risen approximately 14.2 mm per year from 1992 to 2006 at Pattaya beach and 7.4 mm per year from 1987 to 2011 at Chalatat beach [2]. From a previous study, the national beach loss rate projections using the Bruun rule for 2081–2100 are 45.8% for the RCP2.6 scenario and 71.8% for RCP8.5. Also, 23 of 64 beach zones in Thailand will be completely lost [3]. To address these concerns, beach area loss from sea-level rise will be an essential issue for beach tourism. The Bruun rule is the widely applied method for projecting shoreline retreat from sea level rise [4].

Tourism carrying capacity (TCC) is a tool to measure and determine the development of the beach when combining it with other management tools [5]. TCC is defined as the physical and social

capacity of the environment related to tourist activity and beach development. Carrying capacity is "the maximum number of people that may visit a tourist destination at the same time, without destroying the physical, economic, socio-cultural environment and an unacceptable decrease in the quality of visitors' satisfaction" [6]. A TCC assessment consists of physical carrying capacity (PCC), real carrying capacity (RCC), and effective carrying capacity (ECC) [7]. Beach area loss from sea-level rise decreases the carrying capacity of the beach, especially in physical terms. Moreover, the different forms of management at each beach affects that beach's ECC.

Several studies have used the Bruun rule to examine the impacts of sea-level rise on shoreline retreat that affect TCC, such as at Catalan beaches where PCC will decrease in proportion to the sea level rise [8]. In Thailand, the TCC has been analysed at Jomtien beach (Southern part) in Chonburi province. The PCC can support the tourists but the inefficient management of Jomtien beach decreases the facility carrying capacity [9]. Furthermore, the study of TCC at Jomtien beach examined present-day scenarios, which do not account for the sea level rise from climate change in future scenarios.

The purpose of this study is to evaluate the change in the area of the locations under study expected to be caused by sea-level rise and the TCC of the beaches in future scenarios. The shoreline recession from sea level rise was analysed using the Bruun rule and the detection of shoreline position from satellite images using the tidal correction method. The shoreline retreat was used to calculate the changes in beach area. The areas required per-user data; the average visit time was obtained using a survey. The correction factor (a rainy day) was measured by the Thailand Meteorological Department. Then, data on beach management were collected by field observation of the two beaches. These findings should be considered in the planning of near-future coastal zone management to protect the tourism carrying capacity and beach areas from future sea level rise.

2. Study Areas and Data

2.1. Study Areas

In this study, Pattaya beach represents the characteristics of a well-known beach, while Chalatat beach represents the domestic tourism of the local area in Thailand (Figure 1). Thailand is affected by northeastern monsoons from the middle of October to the middle of February and southwestern monsoons that cause heavy rain and high waves.

Pattaya beach is located in Chonburi province on the eastern side of the Gulf of Thailand. Pattaya beach is 3 km long and divided into three areas: North Pattaya, Central Pattaya, and South Pattaya. There are many hotels and shops along the streets in front of the beach. The diverse activities at Pattaya beach include sunbathing, swimming, banana boats, jet skis, and parachuting. Moreover, snorkelling and scuba diving tours to Koh Lan are provided by tour services at Pattaya beach.

Chalatat beach is 4.8 km long and located in Songkhla province in the southern part of Thailand. It is crowded with people on the weekend and during special festivals in Thailand.
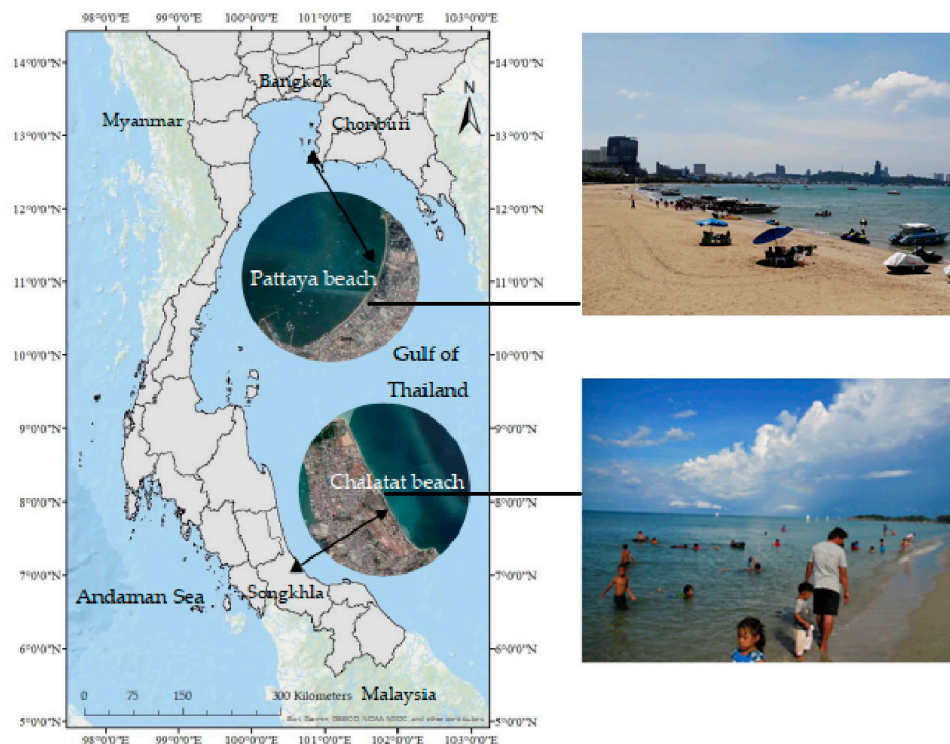
Figure 1. Study areas map.

2.2. Data

The data used in this study contains satellite images from Google Earth, sea level rise data, wave data, slope and sediment size, the average visit time and area required per user, and management capacity.

2.2.1. Satellite Images from Google Earth

In this study, satellite images from Google Earth were used to detect the shoreline positions for Pattaya and Chalatat beaches for the periods listed in Table 1.

Table 1. Time series of satellite images from Google Earth.

Study Areas	Past	Present
Pattaya beach	30 December 2017	16 February 2019
Chalatat beach	9 July 2017	6 August 2018

2.2.2. Sea Level Rise Data

This study used sea-level rise data from 21CMIP5 models, which are the ensemble-mean regional sea-level rise data (1-degree latitude-longitude resolution) for the RCP2.6, RCP4.5, RCP6.0, and RCP8.5 scenarios that relate to 1986–2005 [1]. The ensemble-mean sea level rise data ranges are 0.36–0.60 m for Pattaya beach and 0.38–0.62 m for Chalatat beach.

2.2.3. Wave Data

This study used 3-h significant wave data and 12-h exceeds significant wave height re-analysed data (1-degree latitude-longitude resolution) provided by The European Centre for Medium-Range Weather Forecasts (ECMWF; see www.ecmwf.int), averaged over the 30-year period (1980–2010). The significant wave height is 0.92 m for Pattaya beach and 0.77 m for Chalatat beach. The significant wave period is 7.15 s for Pattaya beach and 6.85 s for Chalatat beach.

2.2.4. Slope and Sediment Size

From field observations, the average foreshore beach slope (Figure 2, Table 2, Figure 3 and Table 3) is 9.34 degrees for Pattaya beach and 6.43 degrees for Chalatat beach. The average sediment grain size is 0.30 mm for Pattaya beach and 0.27 mm for Chalatat beach. Sediment size (D_{50}) was analysed using the sieve analysis American Society for Testing and Materials (ASTM) D422-63 (2007) standard test method. The foreshore beach slope was measured using beach profiling. The closure depths of Pattaya beach and Chalatat beach are 7.72 m and 7.60 m, respectively.

Table 2. Slope, sediment size of Pattaya beach.

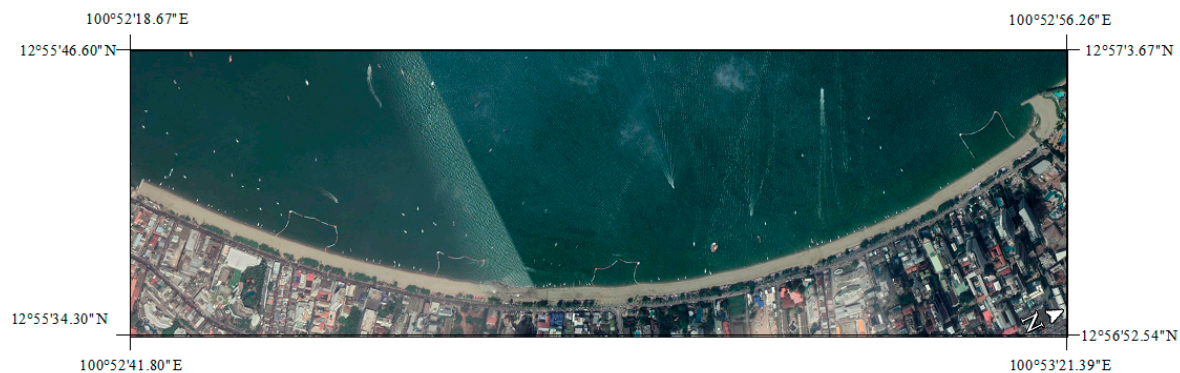| Section	Coordinates		Foreshore Beach Slope (Degree)	Sediment Size (mm)
	Latitude °N	Latitude °E		
a-a	12.945473	100.884282	5.9	0.30
b-b	12.941012	100.883742	10.0	0.29
c-c	12.936839	100.882171	9.6	0.33
d-d	12.933348	100.879980	9.8	0.30
e-e	12.929972	100.876831	11.4	0.30

Figure 2. Survey sections of Pattaya beach.

Table 3. Slope, sediment size of Chalatat beach.

| Section	Coordinates		Foreshore Beach Slope (Degree)	Sediment Size (mm)
	Latitude °N	Latitude °E		
a-a	7.182229	100.617478	0.8	0.27
b-b	7.182993	100.616394	9.5	0.27
c-c	7.183756	100.615355	14.5	0.27
d-d	7.186357	100.613644	9.8	0.27
e-e	7.188759	100.611942	9.2	0.27
f-f	7.190354	100.610879	5.9	0.27
g-g	7.191895	100.609843	6.5	0.27
h-h	7.193698	100.608989	8.4	0.27
i-i	7.198230	100.605882	2.5	0.27
j-j	7.202470	100.603497	4.7	0.27
k-k	7.203720	100.602813	3.8	0.27
l-l	7.206058	100.601536	4.9	0.27
m-m	7.209899	100.599467	3.2	0.27
n-n	7.212273	100.598171	6.4	0.27
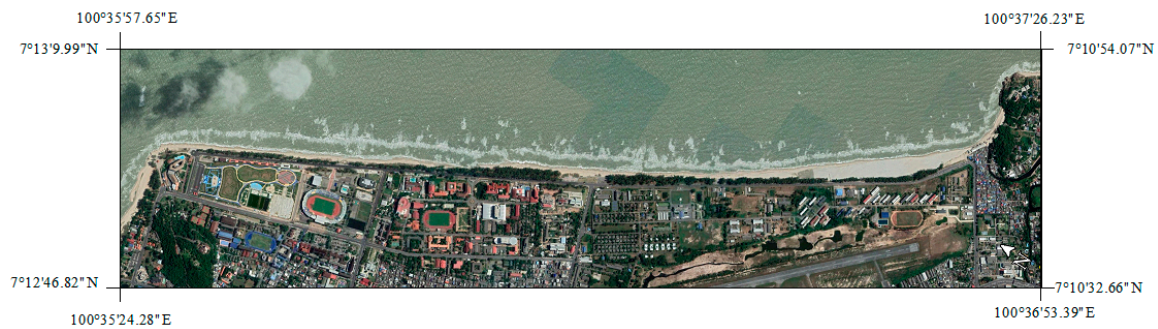
Figure 3. Survey sections of Chalatat beach.

2.2.5. Average Visit Time and Area Required per User

From the questionnaire survey, this study collected a sample size with a 99% confidence factor and 10% precision. The sample included 166 of the 40,221 tourists who visited Pattaya beach each day and 165 of the 20,919 tourists who visited Songkhla each day. Based on information gathered from beachgoers, the average visit time at both Pattaya and Chalatat beach was 3 h. Furthermore, the area required per user was 3 m^2 for Pattaya beach and 11 m^2 for Chalatat beach.

2.2.6. Management Capacity

The management capacity (Table 4) was determined by the facilities and infrastructure in the study areas, where 0 = absent, 1 = little, and 2 = adequate. The maximum possible score was 30.

Table 4. Management capacity.

Title	Score	
	Pattaya Beach	**Chalatat Beach**
Public bathroom	0	1
Bins	1	1
Parking	0	1
Security	2	1
Accommodation	2	2
Restaurant	2	2
Accessibility	2	1
Street lighting	2	1
Sunbath bed	2	0
Bay watch	2	2
Swimming	2	2
Snorkeling	0	0
Scuba	0	0
Kayak	2	0
Other sports	2	1
Summary score	21	15

3. Methods

The method used in this study is depicted in Figure 4. The first step was to detect the shoreline position using the tidal correction method. The next step was to determine the shoreline retreat using the Bruun rule. The last step was to analyse TCC.
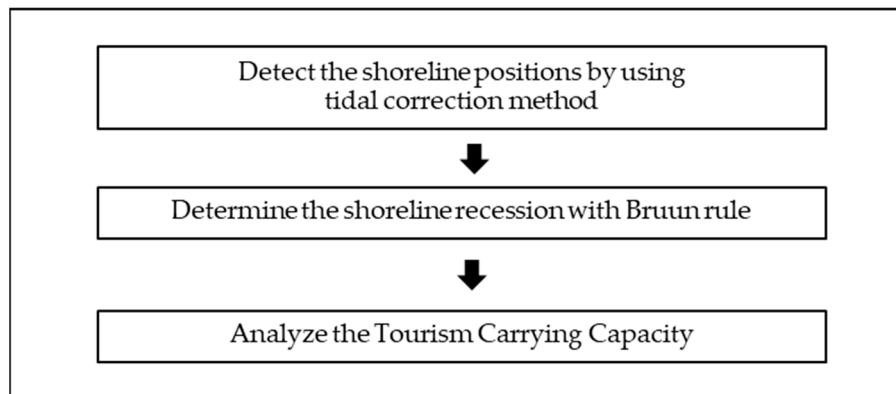
Figure 4. Flow chart.

3.1. Detection of the Shoreline Position Using the Tidal Correction Method

The tidal correction method was developed to obtain the shoreline position by detecting the mean sea level as the reference and correcting for the tidal effect [10]. To detect the shoreline position from Google Earth images using the tidal correction method, ground control points were taken in the images to rectify them. An image-processing method was used to analyse the pixels in the images, and the shoreline position was detected automatically with MATLAB software. In the tidal correction step, the capture time of the images was estimated by measuring the solar azimuth angle from the shadow object on the images. As depicted in Figure 5, θ is the foreshore slope of the beach. The shoreline position was corrected with a trigonometric function to become the shoreline position at mean sea level as follows:
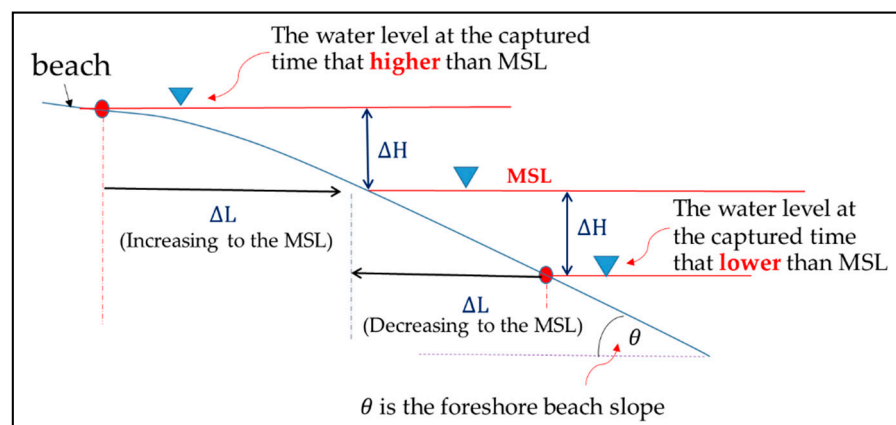
$$\Delta L = \frac{H}{\tan \theta} \tag{1}$$

Figure 5. Beach profile of tidal correction method. Adapted from [11].

3.2. Shoreline Retreat Base on the Bruun Rule

The Bruun rule [4] was developed by Bruun to estimate future shoreline retreat from the changes in sea level with a linear relationship based on equilibrium profile theory, as follows:

$$\frac{\Delta y}{y_*} = \frac{S}{h_* + B_h} \tag{2}$$

where Δy is the shoreline recession, y_* is the distance in the horizontal to the depth of closure, S is the sea level rise, h_* is the depth of closure, and B_h is the berm height.

To calculate the depth of closure [12], we used the significant wave height and significant wave period as follows:

$$h_* = 2.28H_{e,t} - 68.5\left(\frac{H_{e,t}^2}{gT_{e,t}^2}\right) \tag{3}$$

where $H_{e,t}$ is the significant wave height, which is exceeded 12 h per t years, g is the gravitational acceleration, and $T_{e,t}$ is the significant wave period with 12-h-per-t-year exceedance.

To determine the distance to the depth of the closure point, y_*, which depends on grain size [13] and the depth of closure, we used the following:

$$h_* = A y_*^{2/3} \tag{4}$$

where A is the scaling parameter based on the sediment size (d_{50}) and h_* is the depth of closure from Equation (3).

To calculate the berm height (B_h) with Equations (5) [14] and (6) [15], the significant wave data and wave period were required:

$$B_h = 0.125H_b^{5/8}\left(gT_s^2\right)^{3/8} \tag{5}$$

where B_h is berm height, H_b is breaking wave height, and T_s is mean significant wave period, and:

$$\frac{H_b}{H_s} = (\tan\alpha)^{0.2}\left(\frac{H_s}{L_s}\right)^{-0.25} \tag{6}$$

where H_s is mean significant wave height, $\tan\alpha$ is beach slope, and L_s is significant wave length. The shoreline retreat can be calculated by including all parameters in Equation (2).

3.3. TCC

As defined previously, TCC consists of PCC, RCC, and ECC.

In this study, PCC was calculated from the beach areas, area required per user (Equation (7)), and rotation factor (Equation (2)) [16], where A is beach areas, Au is area required per user, and Rf is the rotation factor (the daily open period divided by average visit time):

$$PCC = A/Au \times Rf \tag{7}$$

RCC was calculated using Equation (8), and the correction factors were calculated using Equation (9):

$$RCC = PCC \times (Cf1 \times Cf2 \times Cf3 \dots Cfn), \tag{8}$$

where Cf is the correction factors, and:

$$Cf = 1 - Lmx/Tmx, \tag{9}$$

where Lmx is the limiting magnitude of variable x and Tmx is the total magnitude of variable x. The correction factors were determined by considering the factors that limit tourism activities.

ECC is the maximum number of tourists that the area can sustain. ECC is calculated by combining the RCC with management capacity (indicates the present condition of tourism management) [17], as follows:

$$ECC = RCC \times Mc \tag{10}$$

where Mc is the management capacity.

4. Results

4.1. Beach Areas for Each Scenario

From the detection of shoreline position using the tidal correction method combined with the Bruun rule, the beach areas for past, present, and future scenarios are depicted in Figure 6 for Pattaya beach and Figure 7 for Chalatat beach. The results demonstrate that the present scenario in the study areas is the maximum beach area compared to the other scenarios, due to sea-level rise.
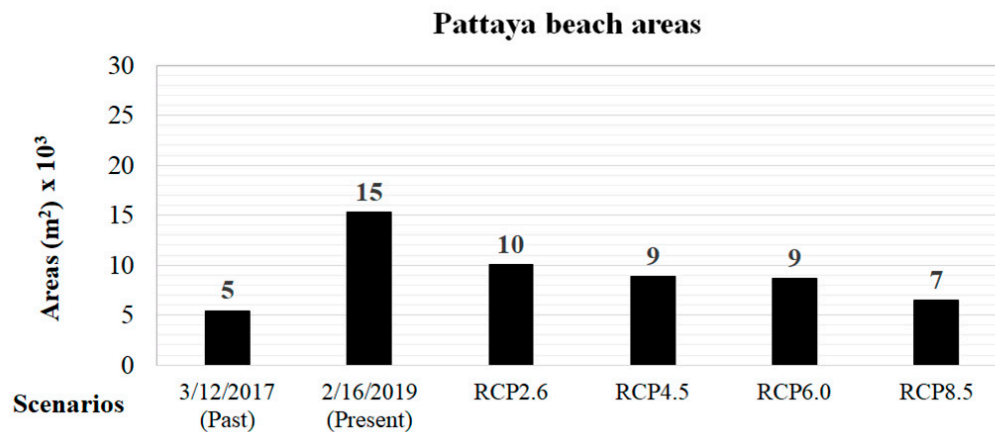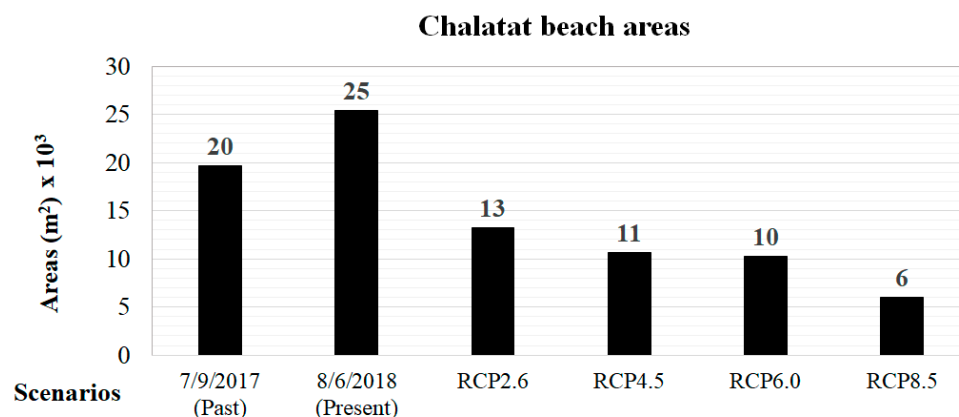

Figure 6. Pattaya beach area.

Figure 7. Chalatat beach area.

4.2. Tourism Carrying Capacity

The TCCs are depicted in Figure 8 for Pattaya beach and Figure 9 for Chalatat beach. The present scenario has the maximum TCC in both of the study areas. The results indicate that beach area, correction factors, and management affect the TCC. In terms of PCC, Pattaya beach areas are more significant than Chalatat beach areas, but the PCC at Pattaya beach is higher than Chalatat beach because of the larger area required per user at Chalatat beach. Thus, the PCC depends on the area required per user and the average visit time, which affect the physical characteristic of tourism beach capacity. The RCC at Pattaya beach is higher than at Chalatat beach because of the larger number of correction factors at Chalatat beach. The correction factors depend on the rainy days that are a factor of the climate zone of the study areas. Chalatat beach is located on the east coast in the southern part of Thailand, which has a longer rainy season than Pattaya beach, located in the eastern region. Moreover, Pattaya beach has a higher management capacity than Chalatat beach, resulting in a significantly higher ECC at Pattaya beach. In conclusion, ECC relies on the parameters of management capacity where Pattaya beach is a well-known beach for international tourists, but Chalatat beach is known as

a domestic tourism beach. Pattaya beach contributes great benefits to economic development in the tourism sector of Thailand. Consequently, Pattaya beach has more efficient management owing to government expenditure on the area.
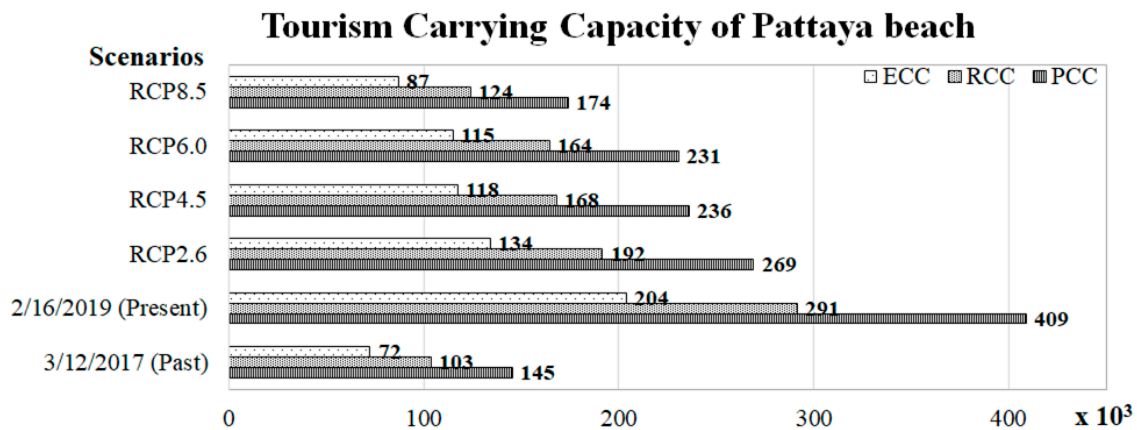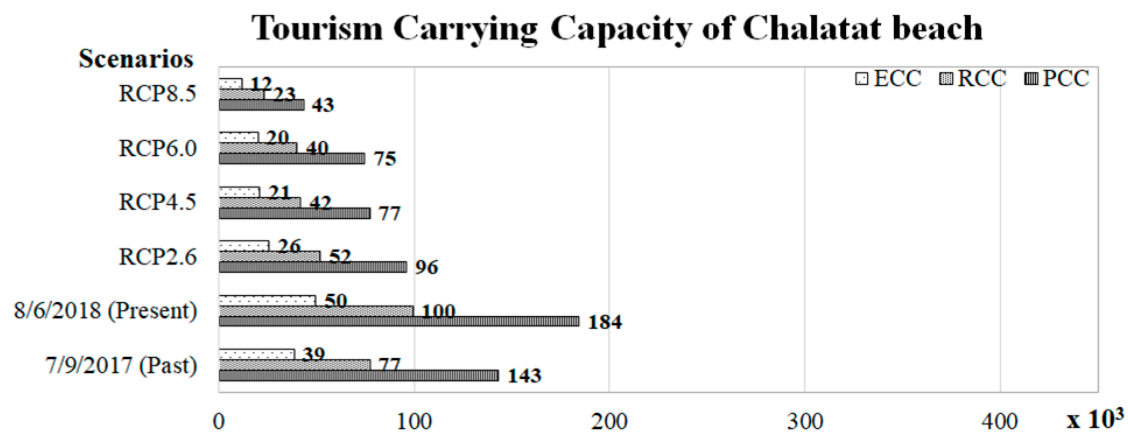
Tourism Carrying Capacity of Pattaya beach

Figure 8. Tourism carrying capacity (TCC) of Pattaya beach.

Tourism Carrying Capacity of Chalatat beach

Figure 9. TCC of Chalatat beach.

Moreover, the increase in TCC will explicitly affect the beach environment and ecosystem. The culture and lifestyle of local people in coastal communities are likely to adjust to the tourists. These are interesting topics to study further in the future.

5. Conclusions

This study presented the TCC of the Pattaya and Chalatat beaches due to sea-level rise under a range of different scenarios. Pattaya beach represented the character of the well-known beaches of Thailand while Chalatat beach represented the character of beaches that are the focus of domestic tourism. This study detected the shoreline position using Google Earth images with tidal correction to analyse beach areas and calculate the shoreline retreat with the Bruun rule. Then, the TCC was assessed using the beach area, correction factors, and management capacity. The results suggest that the ECC of Pattaya beach in the present is about 200,000, while it is 49,000 for Chalatat beach. Our analysis showed that the ECC of Pattaya beach will be more extensive than the ECC of Chalatat beach in all situations, even though there is more abundant beach area at Chalatat than at Pattaya. The factors contributing to the TCC are the beach areas, correction factors and management capacity. Sea-level rise directly affects the beach areas, so the possibility of future beach loss could be a concern. Also, the effective management of facilities and infrastructure around beach areas will affect the development of TCC. Nevertheless, the protection of tourism beaches should be considered in the future.

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