COMPARATIVE STUDY OF COASTAL CHANGE ALONG THE ANDAMAN SEA COAST AND THE GULF OF THAILAND COAST

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Abstract

The study areas cover the coastline of Songkhla, Nakhon Si Thammarat, and Surat Thani provinces in the Gulf of Thailand and Satun, Trang, and Krabi provinces in the Andaman Sea. The coastal change study employs the GIS, remote sensing technique, and field investigation. The geomorphological map was created using the supervised classification method in ENVI (The Environment for Visualizing Images) program and field investigation. The geomorphological study results indicate that old tidal flat, intertidal flat, subtidal flat, old and young lagoons, marsh, and old and young sandy beach characterize the Gulf of Thailand coast. The Andaman Sea coast is represented by rocky coast, intertidal flat, and young sandy beach. The comparison of the coastal change shows that the coastal erosion of the Gulf of Thailand is more severe than the Andaman Sea coast. Most of the Gulf of Thailand coast is now used for aquaculture, whereas shrimp ponds sensitive to erosion have replaced the former mangrove coast. Along the Andaman Sea coast, erosion is protected by the remaining mangrove swamp, and it occurs only in the local area during seasonal storms.

Keywords: **Coastal Change, Geomorphology, Field Geology, Remote Sensing**

Introduction

The Department of Mineral Resources has conducted a preliminary study of the coastal changes in Thailand since 2002. It indicates that, around the Gulf of Thailand, 10.64% of the total 1,700 kilometers in length has been severely erodedThe Department of Mineral Resources has conducted a preliminary study of the coastal changes in Thailand since 2002. It indicates that, around the Gulf of Thailand, 10.64% of the total 1,700 kilometers in length has been severely eroded (more than 5 meters per year) and 17.74 % under moderate erosion (between 1-5 meters per year). Along the 937 kilometers long Andaman Sea coast, about 2.45% has been under severe erosion and 9.65% under moderate erosion. Consequently, it is necessary to study coastal change to understand better the causes of change in the provinces of Songkhla, Nakhon Si Thammarat, and Surat Thani

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on the coast of the Gulf of Thailand and the provinces of Satun, Trang, and Krabi on the coast of the Andaman Sea.

The present study involves the interpretation and analysis of satellite imageries. It will be benefited from the access and use of advanced remote sensing equipment and techniques. Field investigations include the study of coastal landforms, coastline location, and Quaternary stratigraphy and mapping the geomorphology of the study area.

Research Significance

Global warming has drawn strong public attention worldwide because it induces climate and sea-level changes. It consequently directly impacts the coastal zone of every country, including Thailand. Thailand comprises an extensive coastline 2002). These coastal totaling about 2,637 kilometers in length (DMR, zones are endowed with rich natural resources essential for the country's economic development. At present, the coasts of Thailand have been severely changed. In this study, the coastal change is detected using GIS techniques and remote sensing, which are useful for studying wide-area and at different times.

Study Area

The study area is located in the southern part of Thailand. It is located on the Gulf of Thailand and the Andaman Sea coast and lies in the provinces of Songkhla, Surat Thani, Nakhon Si Thammarat, Satun, Krabi, and Trang (Figure 1).

The southern region of Thailand is the Paleozoic-Mesozoic folded belt of the Thai-Malay Peninsula. It consists of two principles mountain ranges, the Phuket and the Nakhon Si Thammarat ranges, trending N-S direction with contrasting shoreline features along the Andaman Sea and the Gulf of Thailand.

The Andaman seaboard is the shoreline of submergence due to a recent tilting movement of the peninsular and forms a narrow coastal plain. This coast is indented with many drowned estuaries.

The Gulf of Thailand, the shoreline of emergence, is smooth with wider coastal terraces and plains. In places, they are composed of a series of alternating, parallel ridges and depressions, which become less marked inland where they grade to the adjacent terrace landscape.

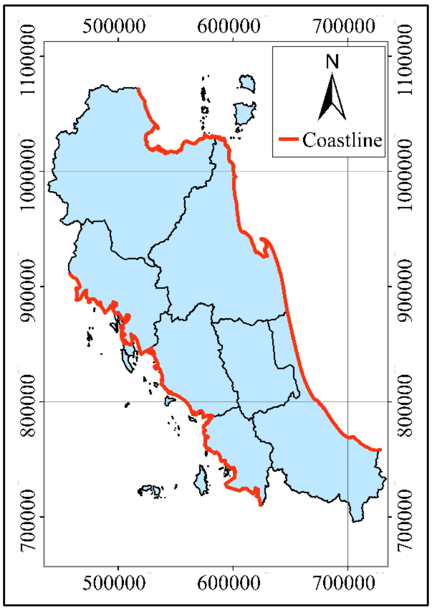

Figure 1. Study area along the Thailand coastline

Methodology

Various methods for coastal change investigation from satellite imagery have been developed. Integrated remote sensing and GIS is one of the most important data for the coastal change study. It is normally used to detect and map the coastline, land use/land cover, topography, geomorphology, and geological conditions.

All available and required data, both from relevant publications and derived from remote sensing and field investigation, were collected, mapped, and reformatted if required and stored in GIS as a database

The data acquired and used for the coastal change study can be divided into two groups; remote sensing data and non-remote sensing data.

Remote sensing data is beneficial in detecting and mapping the coastline, land use/land cover, topography, geomorphology, and geological conditions. In this study, data of Landsat 7 and Landsat 8 could be acquired and used for the Gulf of Thailand and the Andaman Sea coastal change study. Table 1 shows an overview of the satellite data used for this study.

Non - Remote sensing data comprise a topographic map, land use/land cover map, geological map, and all maps from available data sources and fieldworks related to the study area and other relevant publications, reports, and documents collected concerning organizations.

Teble 1. Study area along the Thailand coastline

RS-system	Path/Row	Acquisition date
Landsat 8	128/54	2022/08/12
Landsat 8	128/55	2022/08/12
Landsat 8	129/54	2022/0/312
Landsat 8	129/55	2022/03/12
Landsat 7	128/54	2000/07/22
Landsat 7	128/55	2000/07/22
Landsat 7	129/54	2000/12/04
Landsat 7	129/55	2000/12/04

This study used the Normalized Difference Water Index (NDWI) to delineate open water areas. The index is defined as;

$$NDWI = \frac{\rho_{GREEN} - \rho_{NIR}}{\rho_{GREEN} + \rho_{NIR}}$$

where ρ is the reflectance at a given spectral band (NIR, red and green).

NDWI uses reflected near-infrared (NIR) radiation and visible green light (Green) to enhance such features while eliminating the presence of soil and terrestrial vegetation features.

Image classification techniques are used to identify and classify pixels in the data digitally. This process assigns each pixel in an image to a particular class or subject based on statistical characteristics of the pixels' brightness values. There are several approaches to digital classification. In addition, the decision tree classification, this is technique for classified land and water in coastal area.

In this study, fieldwork is essential to remote sensing data interpretation. It is a critical requirement for providing accurate and reliable interpretation results.

Coastal change analysis is mainly concerned with the variation of coastline and geomorphology. As data from various sources become more readily available, exploring a strategy for integrating multispatial data for coastal mapping and change analysis is highly desirable. The integration analysis of spatial data from different sources is an area that has become increasingly important in the development of geomatics, especially its remote sensing and GIS components.

The GIS database is used to produce a coastal change map. GIS designing geographic information is dividing it into a series of data themes - layers - that can be integrated based on geographic location. Therefore, the database design of GIS should begin with identifying the data themes to be used and then determining the content and representations of each thematic layer. Each GIS database can be represented as feature classes (sets of points, lines, and polygons), imagery and raster. The product of the coastal change is Geomorphology Map and Coastline Map. The verification method integrates remote sensing techniques, GIS databases, and field investigations.

Geomorphological mapping is essential in understanding coastal change. It is based upon the integration of remotely sensed data and field investigation. Geomorphology focuses on the description/classification of landforms, characterization of processes, and the relationship between landforms and processes, while remote sensing can provide information on the location/distribution of landforms.

The coastline map serves as a primary data source for understanding coastal change. This map was created by automatically analyzing satellite remote sensing imagery and examining selected locations in the field. Accurate coverage of the coastline is significant for the study of coastal change.

Results

In this study, the ENVI program's remote sensing techniques and the ArcGIS software's GIS techniques are used to create the spatial database for the spatial analysis of coastal change. The study's coastal change datasets were derived from remote sensing data, available maps, and field surveys. The results of the shoreline analysis are the Normalized Difference Water Index (NDWI) maps. They show the difference between land and water. Then the decision tree classification is applied to the type of coastline. Comparing coastlines at different times shows the area of erosion and deposition. In addition, the classification of geomorphology is used to explain the coast change.

Image classification techniques are used to identify and classify pixels in the data digitally. Supervised classification is much more accurate for mapping classes. Maximum likelihood classification is a statistical decision criterion that helps classify overlapping signatures; pixels are assigned to the class with the highest probability. It is believed that the maximum likelihood classifier provides more accurate results. The result of land use/land cover represented the coastal geomorphology. This data processing is used for the geomorphologic map.

Geomorphology is the science of landforms, focusing on their origin, evolution, shape, and distribution across the physical landscape. Therefore, understanding geomorphology and its processes is essential to understanding physical geography. Coastal geomorphology, by definition, is the study of the morphological development and evolution of the coast as it acts under the influence of winds, waves, currents, and sea-level changes.

The coastal geomorphology of Thailand is characterized by sandy beach, dunes, coastal wetlands (tidal flats and marshes), rocky coasts, and cliffs. Long and windy mainland beach characterize the Gulf of Thailand's coast. Features like elevated beach with dunes, lagoons, tidal flats, and marshes have developed. The elevation of the coastal areas ranges from 0 to 4 meters above mean sea level, with smaller waves. Pocket beach dominate the Andaman Sea coastline, extensive and well-preserved tidal flat vegetated with mangrove forests, cliffs, and numerous islands.

These coastal landscapes indicate the invasion of the Holocene Sea, which peaked about 6,000 years ago BP. However, there is evidence of Late Pleistocene marine sediments found locally beneath the Holocene sediments on the Gulf of Thailand coast. The age of the rocks in the coastal zone ranges from Precambrian to Tertiary and includes all major rock types. Rocks on the east and west coasts of the peninsula are mostly the same units, except on the upper Gulf of Thailand coast, where unconsolidated Quaternary sediments predominate.

The Coastal Geomorphology

The coastal geomorphology of the Gulf of Thailand and the Andaman Sea coast is represented by rocky coast, old tidal flat, intertidal flat, subtidal flat, old and young lagoons, marsh, and old and young sandy beach.

1. Rocky Coast

Rocky coast is defined here as a spatial zone between the landward boundary of marine influence and the seaward boundary of terrestrial influence, consisting of a rocky substrate that is maintained along the coastline in the form of a cliff with varying profiles. This definition includes steep coastal embayment, pocket beaches between rocky outcrops, fan delta systems, and other non-rocky features such as barrier spits below estuaries and river mouths.

2. Tidal Flat

A tidal flat is a large, nearly horizontal area of land covered with water at high tide and exposed to the air at low tide. Tidal flats consist of fine-grained sediment, mostly mud, silt, and sand. Tidal flat areas along the studied coastal lines in this study are divided into three parts as;

(2.1) Old tidal flat located above high water at springs and flooded only under extreme conditions.

(2.2) Intertidal flat, located between high and low tide at springs, is periodically flooded during spring and neap tide cycles.

(2.3) Sub-tidal flat, below low water at springs, and rarely exposed to the air.

3. Lagoons

A lagoon is a shallow body of seawater from the open ocean by a barrier island or reef.

According to Sinsakul (2001) study, the lagoons in the studied coastal lines are divided into two types: the old lagoon and the young lagoon.

(3.1) Old lagoons are generally about 6,000 to 10,000 years old and formed where the sea inundated valley mouths or lowlands during the later stages of global Holocene marine transgression. Lagoons enclosed by Pleistocene barriers were drained during the low tide phase of the last glacial, leaving subaerial basins that were inundated when the sea rose again. Sediments are almost sand-interbedded clay; today, this area is a paddy field or sedge cover.

(3.2) Young lagoons are generally after sea level fall about 5,000 years old. Sediments are sands from old sandy beach erosion. This area is a swamp, and the water level depends on tidal.

4. Marsh

Marsh is a type of coastal wetland. It continuously assesses old tidal flats, delta, and lagoon. Marshes are most common in lagoons, estuaries, and on the sheltered side of shingle or sand spits. The currents there carry the fine particles to the calm side of the spit, and the sediment accumulates.

5. Sandy Beach

A sandy beach is a beach consisting primarily of sand. According to Sinsakul (2002) study, sandy beach along the studied coastal lines are divided into old sandy beach and young sandy beach.

(5.1) Old sandy beach was generated from transgressive sediment 6,000 years ago, with an elevation of 4-5 meters above mean sea level and far from the present coastline. Now this area is the settlement area.

(5.2) Young sandy beach is located along the coastline, about 0.5-2 meters above mean sea level.

Gulf of Thailand Sea Coast

Results from this study indicate that the Gulf of Thailand coast is represented by old tidal flat, intertidal flat, subtidal flat, old and young lagoons, marsh, and old and young sandy beach, as shown in Figure 2.

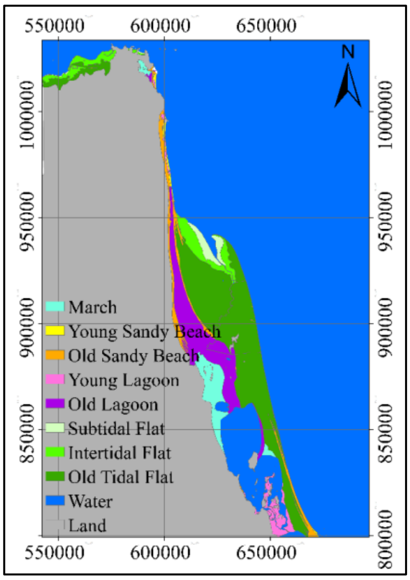

Figure 2. Coastal geomorphologic map of the Gulf of Thailand

Andaman Sea Coast

The results of the geomorphological study of this study indicate that the Andaman Sea coast is characterized by rocky coast, intertidal flat, and old and young sandy beach, as shown in Figure 3.

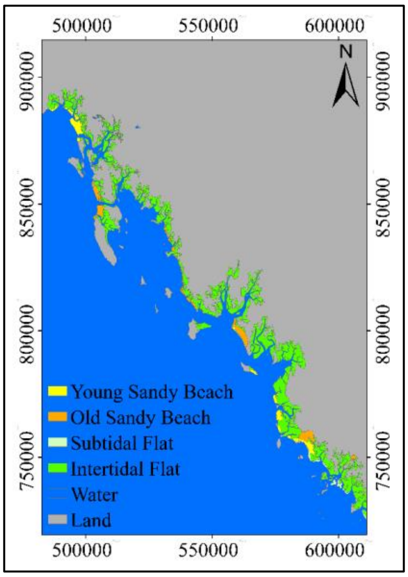

Figure 3. Coastal geomorphologic map of the Andaman Sea

Coastline Change Detection

Remote sensing data processing image transformations involve combining data from multiple spectral bands. Arithmetic operations (e.g., subtraction, addition, multiplication, division) are performed to combine the original bands and transform them into 'new' images that better represent or emphasize certain features of the scene. These operations, including various spectral or band ratio methods, are used more efficiently than multichannel images. In this study, image transformation techniques are used to classify land and water and identify the coastline.

A spectral water index is a single number derived from an arithmetic operation (e.g., ratio, difference, and normalized difference) of two or more spectral bands. An appropriate threshold value for the index is then established to distinguish water bodies from other land cover features based on spectral characteristics.

The Normalized Difference Water Index (NDWI) is used to separate water and non-water characteristics. Several definitions of NDWI combine different pairs of bands, usually and originally including green and near-infrared (NIR). The NDWI would result from the light color of the water body. The classification of land and water bodies using the NDWI method is shown in Figure 4.

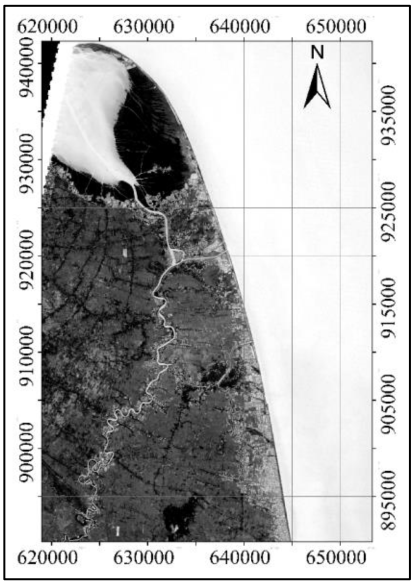

Figure 4. Map of Normalized Difference Water Index (NDWI)

The classification of land and water bodies uses the decision tree classification method. The coastal change can be distinguished by overlaying the coastline maps of a different times. The coastline change distance is calculated using an ArcGIS tool that compares the old and the present coastlines. The coastal change between the two periods is represented by coastal erosion, and coastal deposition is shown in Figure 5 to Figure 8.

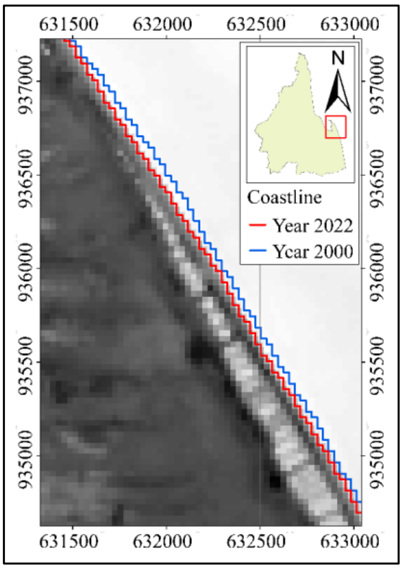

Figure 5. **Map of coastal change in Nakhon Si Thammarat province (Pak Panang district)**

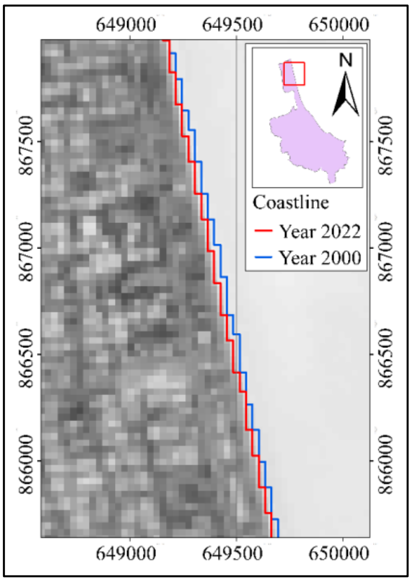

Figure 6. **Map of coastal change in Songkhla province (Ranod district)**

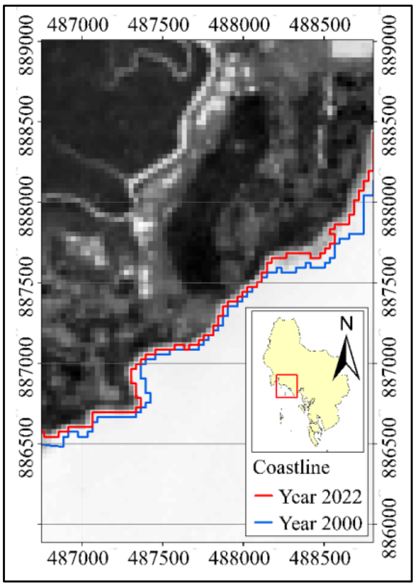

Figure 7. **Map of coastal change in Krabi province (Muang district)**

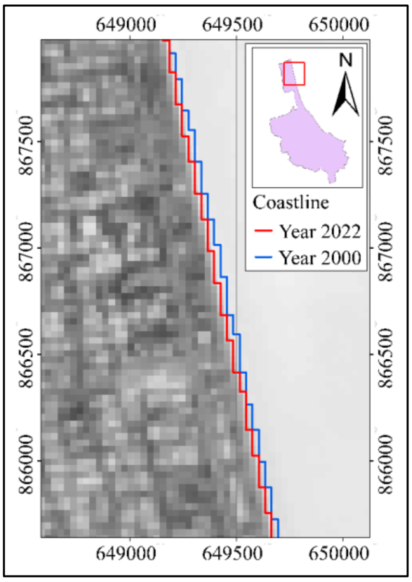

Figure 8. **Map of coastal change in Trang province (Sikao district)**

The coastal change on Thailand's coast is divided into 4 classes (Sinsakul *et al.*, 2003) as follows: 1). Severe erosion coast indicates coastal erosion of more than 5 meters per year. 2). Moderate erosion coast indicates coastal erosion of about 1-5 meters per year. 3). Depositional coast is the process of material moved up the beach by the swash at an angle controlled by the prevailing wind. The rate of deposit is about 1-5 meters per year. 4). Stable coast is a balance between sediment supply, subsidence, and coastal processes. The rate of coastal change is about ± 1 meter per year.

1. Gulf of Thailand Sea Coast

The study areas of the Surat Thani coast cover Ban Phot. The Nakhon Si Thammarat coast comprises the areas of Ban Fai Tha, Ban Ro, Ban Thang Khuen, Ban Tha Sung Bon, Ban Laem Talumphuk, Ban Chai Thale, Ban Ao Bon, Ban Na Saton, and Ban Na San. The Songkhla coast comprises the areas of Ban Map Bua and Ban Tha Bon.

Surat Thani province comprises an extensive coastline totaling about 135 kilometers in length. The result of the study shows a few coastal changes because the area is mainly tidal flat and mangrove swamp. That coastal change is slower than sandy beach. This province's coastal change is found mainly in the Donsak area. The coastline of the Ban Phot area, located in the Don Sak district of Surat Thani province, is about 9 kilometers long. Ban Phot area is changing from the coastal mangrove area to the shrimp ponds. The shrimp ponds are destroyed, and the local road is lacking by coastal erosion. The building of the seawall in the Ban Phot area in 2000, the area has been protected.

Nakhon Si Thammarat province has a coastline of about 190 kilometers. The coastal change in this area is severe because it is along monsoon and typhoon paths and is a relatively low area covered by mainly unconsolidated sediments. The coastal erosion is severe and affects more than 60 kilometers long. The main coastal erosion area covers the Sichon, Tha Sala, Pak Panang, and Hua Sai districts.

The coastline of the Ban Fai Tha area, located in the Sichon district of Nakhon Si Thammarat province, is about 6 kilometers in length. The coastline was formerly eroded, especially by the monsoon. But since building the breakwaters and jetties in Pak Nam Sichon in 1999, the area has been deposited by sediments. However, the erosion of the northern part of the area is increasing as the sediments have been transported and deposited in the southern part.

The coastline of the Ban Ro and Ban Thang Khuen area, located in the Tha Sala district of Nakhon Si Thammarat province, is about 7 kilometers in length. The coastal erosion is mainly in the sandy beach.

The coastline of the Ban Tha Sung Bon area, located in the center of the Tha Sala district of Nakhon Si Thammarat province, is about 7.5 kilometers in length. This area is a narrow sandy beach covered with many shrimp ponds. Sediments have deposited it since the building of the jetties, breakwaters, and groins in Ban Tha Sung Bon and Hat Dan Phasi in 1997. The northern part is eroded in the monsoon season. The sediment deposition blocks the channel in the Ban Nai Thung.

The coastline of the Ban Laem Talumphuk area, located in the Pak Panang district of Nakhon Si Thammarat province, is about 11.42 kilometers in length. The area is about 1 meter above mean sea level and comprises a spit and sandy beach. It consists of unconsolidated sediments. The land use has been changed from the coastal mangrove to the shrimp ponds, which are now destroyed by coastal erosion.

The coastline of the Ban Chai Thale area, located in the Pak Panang district of Nakhon Si Thammarat province, is about 9 kilometers in length. Ban Chai Thale comprises many shrimp ponds distributed on the narrow sandy beach.

The coastline of the Ban Ao Bon area, located in the Pak Panang district of Nakhon Si Thammarat province, is about 8 kilometers in length. The coastline of the Ban Ao Bon area consists of many shrimp ponds distributed on the narrow sandy beach. The main road is sensitive to destruction by coastal erosion.

The coastline of the Ban Na Saton area, located in the Hua Sai district of Nakhon Si Thammarat province, is about 7 kilometers in length. The main road is on the narrow sandy beach, which lies north-southerly. There are many shrimp ponds distributed along the coast. The building of the seawall and 23 breakwaters in 2004 for coastal protection of the area has increased sediment deposition. However, the erosion of the northern part of the area has also increased as no breakwater existed.

The coastline of the Ban Na San area, located in the Hua Sai district, Nakhon Si Thammarat province, is about 7 kilometers in length. The Ban Na San area is located south of the Ban Na Saton area and shows similar conditions. In the monsoon season, the pier and seawall of Ban Na San were destroyed by waves and wind. The sediments have been deposited in the southern part of the breakwaters

Songkhla province comprises an extensive coastline totaling about 150 kilometers in length. Significant coastal erosion has occurred in the northern part of the Ronot district.

The coastline of the Ban Map Bua area, located in the Ranod district, Songkhla province, is about 7.3 kilometers in length. Ban Map Bua area has many shrimp ponds distributed along the narrow sandy beach. The village is outside the beach, which is sensitive to coastal erosion. The seawall building in the Ban Map Bua pier area has been protected. However, the tilting tree and tree roots loosen due to coastal erosion.

The coastline of the Ban Tha Bon area, located in the Ranod district, Songkhla province, is about 7.5 kilometers in length. Ban Tha Bon consists of many shrimp ponds on the narrow sandy beach. The village is sensitive to erosion because it's outside the beach.

2. Andaman Sea Coast

The study area of the Krabi is Ban Laem Pho. The Trang coast comprises the areas of Hat Ratcha Mongkhon and Ban Pak Meng. The Satun coast includes the areas of Ban Thung Sabo and Ban Ravi, and Ban Pak La Ngu.

Krabi province comprises an extensive coastline totaling about 160 kilometers in length. This coast is mainly an intertidal flat and mangrove swamp. The sandy beach is narrow and sensitive to coastal erosion.

The coastline of the Ban Laem Pho area, located in the Muang district of Krabi province, is about 8 kilometers in length. The study area is located from Ao Nam Mao to Ban Laem Pho. The coastal erosion is mainly in Laem Pho Shell Cemetery, which is important for traveling.

The coast of Trang province is about 150 kilometers in length. This coast is an intertidal flat, mangrove swamp, and narrow sandy beach. Significant coastal erosion has occurred in the Sikao district.

The coastline of the Hat Ratcha Mongkhon area, located in the Sikao district, Trang province, is about 7.7 kilometers in length. Hat Ratcha Mongkhon is in the Rajamangala University of Technology Srivijaya of the Trang campus. The erosion uproots the big pines.

The coastline of the Ban Pak Meng area, located in the Sikao district, Trang province, is about 9 kilometers in length. The coastal erosion mainly occurred in the Hat Pak Meng of the Hat Chao Mai National Park. The area is a sandy beach with fallen trees left by coastal erosion. In 1995, the seawall was built to protect the area from coastal erosion, but some seawalls were destroyed.

The coast of Satun province is about 168 kilometers in length. It's covering Thung Wa, La Ngu, Tha Phae, and Muang Satun districts. This coastal is almost intertidal flat and mangrove area and young sandy beach. The main coastal erosion area covers the La Ngu district.

The coastline of the Ban Thung Sabo and Ban Ravi areas located in the Thung Wa district of Satun province is about 7 kilometers in length. Ban Thung Sabo and Ban Ravi areas are narrow sandy beach sensitive to coastal erosion. However, the building of the riprap seawall in this area has been protected. The coastline of the Ban Pak La Ngu area, located in the La Ngu district of Satun province, is about 9 kilometers in length. Ban Pak La Ngu is a narrow sandy beach sensitive to coastal erosion. It has been protected since the building of the riprap seawall.

The area of the coastal change of the Pak Panang, Ranod, Muang Krabi, and Sikao districts from Figure 5 to Figure 8 are shown in Table 2.

Teble 2. Study area along the Thailand coastline

Location	Area (m^2)
Pak Panang	125,354
Ranod	65,469
Muang Krabi	128,599
Sikao	69,374

Conclusions

The geomorphology of the Gulf of Thailand comprises mainly an old tidal flat, an intertidal flat, and a narrow sandy beach. The area is currently used for aquaculture, where the former mangrove coast has been replaced by shrimp ponds sensitive to erosion. The shrimp ponds, the trees, and the houses are eventually destroyed. Since the building of the seawalls, breakwaters, groins, and jetties in the Gulf of Thailand in 2000, the area of the building sites has been deposited by sediments. However, erosion has been increasing in areas where no building existed. The Andaman Sea coast is covered by rocky coast, intertidal flats, and short sandy beach. The coastal erosion is reduced by the protection of the remaining mangrove swamp, and it has occurred only in the local area during seasonal storms.

The comparison of coastal change between the Gulf of Thailand and the Andaman Sea shows that coastal erosion is more severe in the Gulf of Thailand than in the Andaman Sea. The Gulf of Thailand is mainly covered by the clay of an old tidal flat and intertidal flat which is more sensitive to erosion, but the Andaman Sea is covered mainly by the more resistant rock.

However, at present there are various agencies and villagers have come up with ways to prevent coastal erosion, such as protection strategies, which consist of stone breakwaters, bamboo revetments, and the heightening of dikes. For long-term and efficient solutions, the government in each coastal area has the authority to take care of coastal erosion in the area, and the strategies for coastal erosion protection in each area are planned independently. The protective structures to be effective, they should be designed. Therefore, the solution to this problem demands collective decisions by the national government in dealing with these issues.

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