Spatial-based Analysis for High-risk Erosion Area along the Coast of Thailand

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Abstract

This spatial-based analysis for high-risk erosion areas along the coast of Thailand aims to investigate and monitor coastal erosion, create a coastal zone change map for the entire country at scale 1:100,000 and provincial maps (including risk analyses) at scales 1:50,000 and 1:25,000, and implement a coastal geo-database for long-term coastal zone management. Key activities included the following: 1) shoreline and land use analysis using medium- and high-resolution satellite images taken during 1999–2010; 2) collection of field data such as DGPS/GPS data, land use survey, and oceanographic data; and 3) implementation of a coastal geo-database and distribution data via the Internet. Coastal zone observations in 2009–2010 revealed that the coast of Thailand eroded by 18.06 km^2 and accreted by 2.60 km^2. The most heavily eroded areas were in Pattani, Trad, and Nakornsrithamarat provinces, with losses of coastal land of 2.65 km^2, 2.24 km^2, and 1.80 km^2 , respectively. The largest areas of accretion were in Prachuapkhirikhan, Chumporn, and Pattani provinces, with increases in coastal land of 0.55 km^2, 0.48 km^2, and 0.25 km^2, respectively. In addition, a comparison among 23 provinces found the highest erosion rates in Samutprakarn, Samutsakorn, and Bangkok provinces, with land loss rates of 15.92 m/yr, 9.94 m/yr, and 8.48 m/yr, respectively, and the highest accretion rates in Samutprakarn, Bangkok, and Nakornsrithamarat provinces, with land accretion rates of 22.56 m/yr, 14.26 m/yr, and 12.88 m/yr, respectively. The distribution of coastal information was disseminated via GISTDA Coastal Map (GCOS), which users can access at http://ocean.gistda.or.th.

Keywords: Spatial-based analysis/ High-risk erosion area/ Coast of Thailand

1.Introduction

Thailand has a highly active coastline, with a length of more than 2,600 km within the Gulf of Thailand and the Andaman Sea. The coastal area includes 23 of Thailand's provinces, and there is a need for an enhanced understanding of the extreme impact from losses in coastal areas. In particular, the coast of Thailand has been facing a severe erosion problem over the past 10 years, especially along the Gulf of Thailand. This has meant an enormous loss of coastal land, coastal resources, coastal economy, and personal real estate, in addition to societal impacts.The main causes of coastal zone loss include both natural and anthropogenic activities. A World Bank environmental assessment found that coastal erosion is an environmental problem. Along the coastline of Thailand, many areas are exposed to erosion at a rate of more than 1–5 m per year. Overall, the rate of land loss is 2 km2 per year, or a total economic damageof up to Baht 6,000 million.

Previous studies have had diverse aims and goals that were dependent on location, and the obtained solutions were dependent on the policies and missions of each research group. There was also a lack of a holistic approach to problems with data integration and a lack of information for a clear overview of the status of the issue based on updated information. Researchers recognize the importance of using Geographic Information System (GIS) and Remote Sensing (RS) techniques, which encompass spatio-temporal information technology that is useful and extremely powerful for the measurement of long-term continuous data and for analysis, synthesis, and planning and decision making [2].

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The aims of this study are as follows: 1) to investigate and monitor the coastal erosion situation along the coast of Thailand; 2) to make a coastal zone change map for the entire country at scale 1:100,000 and to produce provincial maps, including risk analyses, at scales 1:50,000 and 1:25,000 along the coast of Thailand; and 3) to implement a coastal geo-database for long-term coastal zone management. Integrating these different parts will be extremely useful in effectively determining policies, national action plans, and solutions to the problems of coastal erosion in Thailand. The end result will be the development of sustainable coastal erosion management in Thailand.

2. Methodology

2.1 Study area

The study area is located in 23 provinces along the coast of Thailand (Fig. 1).

Figure 1: The study area along the coast of Thailand

2.2 Research data

1) Satellite images along the coast of Thailand: medium-resolution satellite images from THAICHOTE taken during 2009–2010 and LANDSAT taken during 1999–2010

2) Topographic maps along the coast of Thailand at scale 1:50,000, from the Department of Defense

3) Tide information from 1999–2010 from the Hydrographic Department of the Navy

4) Field data consisting of shoreline data, land use survey, weather data and oceanographic data

5) Field equipments: DGPS/GPS

6) Processing Software: ArcGIS, eCognition developer, Digital Shoreline model, PostgreSQL/PostGIS

2.3 Methodology

There were three main processing steps, as follows: 1) shoreline and land use analysis using medium-resolution satellite images taken during 1999–2010; 2) collection of field data such as DGPS/GPS data, land use survey, weather data, and oceanographic data; and 3) implementation of a coastal geo-database and distribution of data via the Internet (Fig. 2).

2.3.1 Digital Image Processing

A selection of satellite images taken during 1999–2010 were used for spatial analysis. Geometric Correction in ArcGIS was introduced to modify the satellite images in order to provide spatial accuracy by referring to the topographic map at scale 1: 50,000 from the Department of Defense. Ground Control Points (GCP) were spread across the images. All GCPs were determined by the map projection coordinates Transmercator 47 and WGS 1984. Images were processed so that the digital coordinate number for a GCP close to the original data was estimated by bilinear interpolation of the image data.

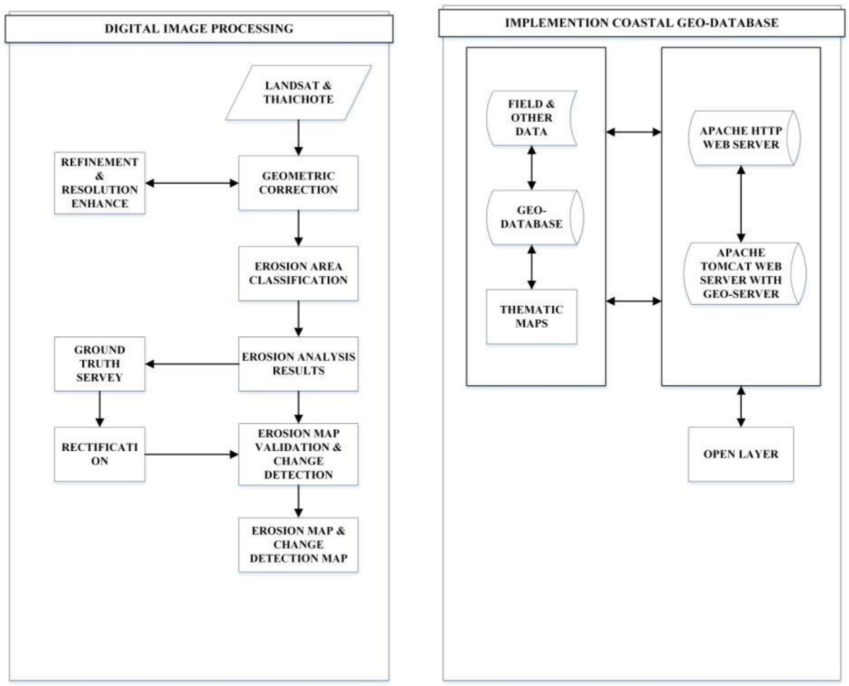

Figure 2: The study proceeded in three main steps: 1) satellite image analysis, 2) ground truth survey, and 3) coastal geo-database production

Data fusion relied upon THAICHOTE at resolutions of 15 m and 2 m in order to obtain pan-sharpened imagery and associated data for shoreline identification. An object-based analysis in eCognition Developer was used for this shoreline identification. The final step in data fusion involved checking the accuracy of the image analysis using data from the field survey (shoreline, beach profile) as a reference and programming the data collection period similar to the acquisition time of the satellite image in order to reduce differences between high tide and low tide during the day.

2.3.2 Shoreline change rate

An historic dataset of shoreline time series from LANDSAT-5 TM, taken during 1999–2010, was used to analyze shoreline change. This model represented a dynamically segmented linear model of a four-dimensional (4D) system involving x, y, z, and t (time). The output contains the distance measurements, which were used to compute rate-of-change statistics along each transect.

A baseline was created from shoreline buffering using intervals of 100 m for each transect. The calculation of shoreline change was achieved using a statistical technique to estimate the distance of shoreline movement and rate of change. Rates of change in shoreline positions were then employed to summarize historical shoreline movements and to predict future shoreline positions based on perceived historical trends. The method most commonly used, especially by coastal land planners and managers, to predict future shoreline change is extrapolation of a constant rate-of-change value [4] ; this involves both End Point Rate (EPR) and Linear Regression (LRR). These statistics are described by Thieler et al. and Himmelstoss [3,6], as explained below.

The EPR is calculated by dividing the distance of shoreline movement by the time elapsed between the earliest and latest measurements, as in equation 1. The major advantage of the EPR is its ease of computation and minimal requirement for shoreline data. (Thi Nguyen et al., 2008). The LRR statistics can be determined by fitting a least squares regression line to all shoreline points for a particular transect. The rate is the slope of the line. The advantages of LRR are that all shoreline data are used and the method is purely computational. It is based on accepted statistical concepts and it is easy to employ [5]. The future shoreline position can be estimate using the resulting slope of line and Y-intercept (Fig.3).

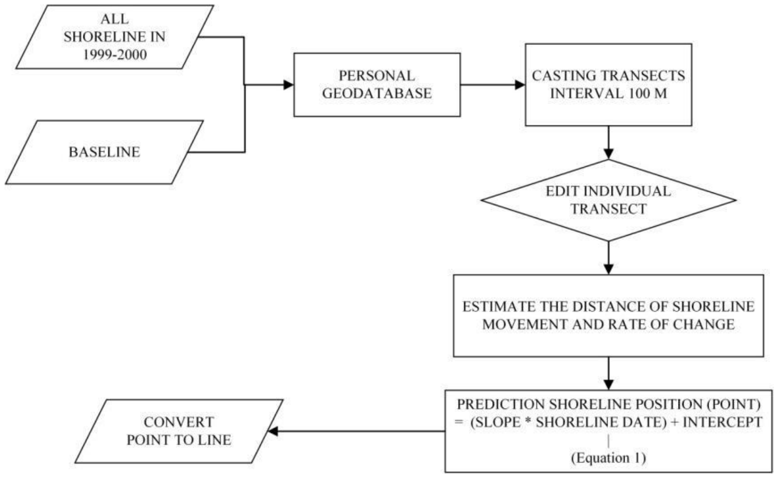

Figure 3: The shoreline change prediction procedure

2.3.3 Field data collection

Using data from the survey area as a reference, data collection was planned for a time close to the time when satellite imagery was acquired. In other words, correcting for the differences between high tide and low tide during the day. The data collected from the field contained slope and cross section information about the beach and beach characteristics.

2.3.4 Implementation of a coastal geo-database and distribution of data via the Internet

The time series dataset for shorelines during 1999–2010 was placed into a geo-database. Spatial and attribute data were also added to the database. Erosion and accretion areas were analyzed from the time series of shorelines with spatial analysis tools. The data in the geo-database were stored in two parts: ArcCatalog and PostgreSQL/PostGIS.

Feature Dataset in *ArcCatalog* using georeferences in UTM (Universal Transverse Mercator), the Grid Zone 47N and 48N Datum WGS-1984 included:

-Shoreline dataset at medium scale (Shoreline_LS5_UTM)

-Shoreline dataset at province medium scale (Shoreline_LS5_Province_UTM)

-Shoreline dataset at low scale (Shoreline_SP_THAICHOTE _UTM)

-Shoreline dataset at province low scale (Shoreline_SP_THAICHOTE _Province_UTM)

- Erosion and accretion area dataset at medium scale(Erosion_Accretion_LS5_UTM)

- Erosion and accretion area dataset at low scale (Erosion_Accretion_TH_UTM)

Feature Dataset in *PostgreSQL/PostGIS* was used for communication with the online mapping service (Web Map Service: WMS), which is stored in the server database, by storing geographic reference system Geographic coordinate system, Datum WGS-1984.

Published data were made available through the development of server-side software tools using open source suites, HTML, PHP, and JavaScript. These tools helped to support the design of the user interface to provide information through the website. The client side was Internet Explorer, which is readily available in Microsoft Windows.

3. Result and disscussion

3.1 The changing coastal areas along the coast of Thailand Researchers selected THAICHOTE images to review the changes in the coastline of Thailand using images taken during 2009–2010 and covering the entirety of 23 coastal provinces. In summary, the observed coastal zone change revealed that the coast of Thailand has eroded by 18.06 km^2 (11,291.52 rai) and accreted 2.60 km^2 (1,624.35 rai). The most heavily eroded areas are in Pattani, Trad, and Nakornsrithamarat provinces, with losses of coastal land of 2.65 km^2 (1,656.65 rai), 2.24 km^2 (1,399.40 rai), and 1.80 km^2 (1,124.89 rai), respectively. The areas with the largest accretion are in Prachuapkhirikhan, Chumporn, and Pattani provinces, with rates of increase in coastal land of 0.55 km^2 (342.57 rai), 0.48 km^2 (302.45 rai), and 0.25 km^2 (158.72 rai), respectively (Fig. 4, left).

In addition, we used LANDSAT 1999–2010 imagery to compare erosion and accretion rates between the 23 provinces. We found the highest erosion rates in Samutprakan, Samutsakorn, and Bangkok provinces, with land loss rates of 15.92 m/yr, 9.94 m/yr, and 8.48 m/yr, respectively, and the greatest accretion rates in Samutprakarn, Bangkok, and Nakornsrithamarat provinces, with rates of increase in coastal land of 22.56 m/yr, 14.26 m/yr, and 12.88 m/yr, respectively (Fig. 4, right).

3.2 Trend of shoreline change

The trend of shoreline change in the Gulf of Thailand and Andaman Sea indicated an average erosion rate of 5.33 m/yr and average accretion rate 6.67 m/yr.

Erosion rates of 3.15 m/yr, 8.69 m/yr, 3.52 m/yr, 3.92 m/yr, and 5.29 m/yr and accretion rates of 4.88 m/yr, 10.04 m/yr, 5.59 m/yr, 6.18 m/yr, and 5.36 m/yr were determined in five specific areas: the east coastal area, the inner Gulf of Thailand, the upper part of the coastal area (upper south), the lower part of the west coast area (lower south), and the Andaman coast area, respectively (Fig. 5).

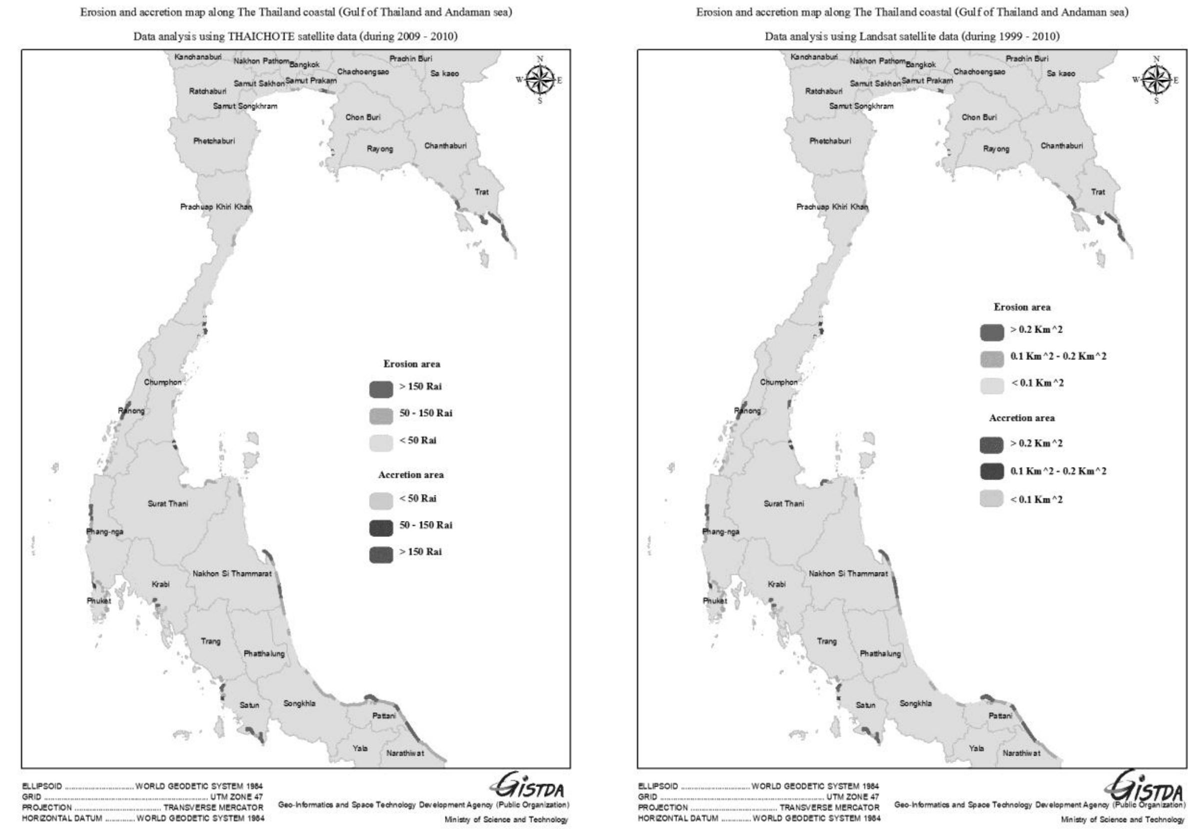

Figure 4: Erosion and accretion areas analyzed using THAICHOTE during 2009–2010 (left) and using LANDSAT during 1999–2010 (right)

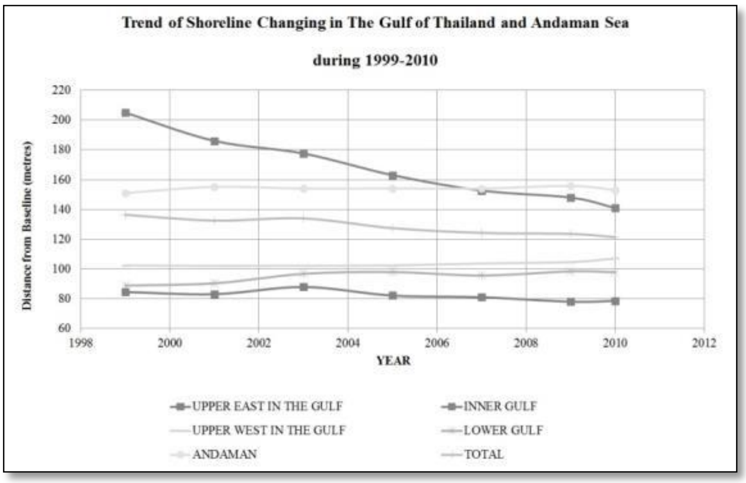

Figure 5: Trend of shoreline change in the Gulf of Thailand and Andaman Sea analyzed from LANDSAT images taken in 1999–2010

3.3 Critical risk erosion areas

Analysis of five specific critical erosion risk areas used LANDSAT 1999–2010 imagery to calculate erosion rate and THAICHOTE 2009–2010 imagery to determine erosion area. The results are described below.

3.3.1 The east coast area consisted of Rayong, Chantaburi, Trad, and Chonburi provinces, which had erosion rates of 2.94 m/yr, 5.07 m/yr, 1.37 m/yr, and 3.23 m/yr, respectively, and accretion rates of 6.15 m/yr, 4.03 m/yr, 5.14 m/yr, and 4.19 m/yr, respectively. Trad and Chantaburi provinces had the largest erosion areas of 2.24 km^2 (1,399.40 rai) and 0.52 km^2 (352.42 rai), respectively (Fig.6).

3.3.2 The inner Gulf of Thailand area consisted of Chacheangsao, Samutprakarn, Bangkok, Samutsakorn, Samutsongkram, and Petchaburi provinces, which had erosion rates of 7.95 m/yr, 15.92 m/yr, 8.48 m/yr, 9.94 m/yr, 6.49 m/yr, and 3.64 m/yr, respectively, and accretion rates of 1.87 m/yr, 22.56 m/yr, 14.26 m/yr, 8.90 m/yr, 9.21 m/yr, and 3.42 m/yr, respectively. Chacheangsao and Samutprakarn provinces had the largest erosion areas of 0.11 km^2 (69.72 rai) and 0.49 km^2 (307.51 rai), respectively (Fig.7).

3.3.3 The upper part of the coastal area (upper south) consisted of Prachaubkirikhan, Chumporn, and Suratthani provinces, which had erosion rates of 2.15 m/yr, 2.01 m/yr, and 6.40 m/yr and accretion rates of 2.64 m/yr, 3.41 m/yr, and 10.73 m/yr, respectively. Prachaubkirikhan and Chumporn provinces had the largest erosion areas of 0.91 km^2 (567.06 rai) and 0.59 km^2 (371.64 rai), respectively (Fig.8).

3.3.4 The lower part of the west coastal area (lower south) consisted of Nakhonsi-thammarat, Songkhla, Pattani, and Narathiwat provinces, which had erosion rates of 5.41 m/yr, 2.22 m/yr, 4.66 m/yr, and 3.37 m/yr and accretion rates of 12.88 m/yr, 3.23 m/yr, 5.44 m/yr, and 3.18 m/yr, respectively. Pattani and Nakhonsi-thammarat provinces had the largest erosion areas of 2.65 km^2 (1,656.65 rai) and 1.80 km^2 (1,124.89 rai), respectively (Fig.9) .

3.3.5 The Andaman coast area consisted of Ranong, Pang-nga, Phuket, Krabi, Trang, and Satun provinces, which had erosion rates of 6.80 m/yr, 5.14 m/yr, 4.36 m/yr, 3.13 m/yr, 6.40 m/yr, and 5.89 m/yr and accretion rates of 7.63 m/yr, 3.75 m/yr, 4.98 m/yr, 4.08 m/yr, 5.00 m/yr, and 6.70 m/yr, respectively. Satun and Ranong provinces had the largest erosion areas of 1.49 km^2 (931.74 rai) and 1.21 km^2 (755.82 rai), respectively (Fig.10).

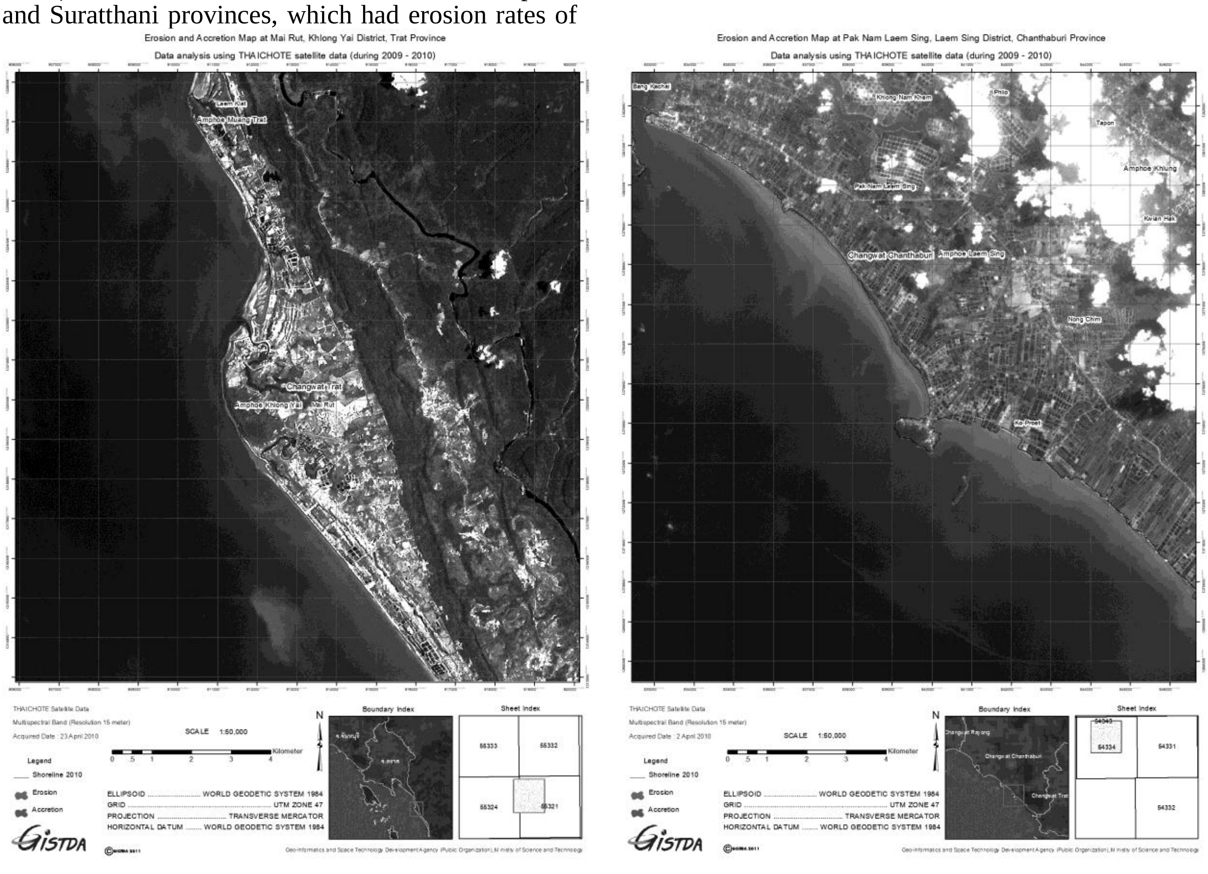

Figure 6: Erosion and accretion map at Trad Province (left) and Chantaburi Province (right) analyzed using THAICHOTE 2009–2010

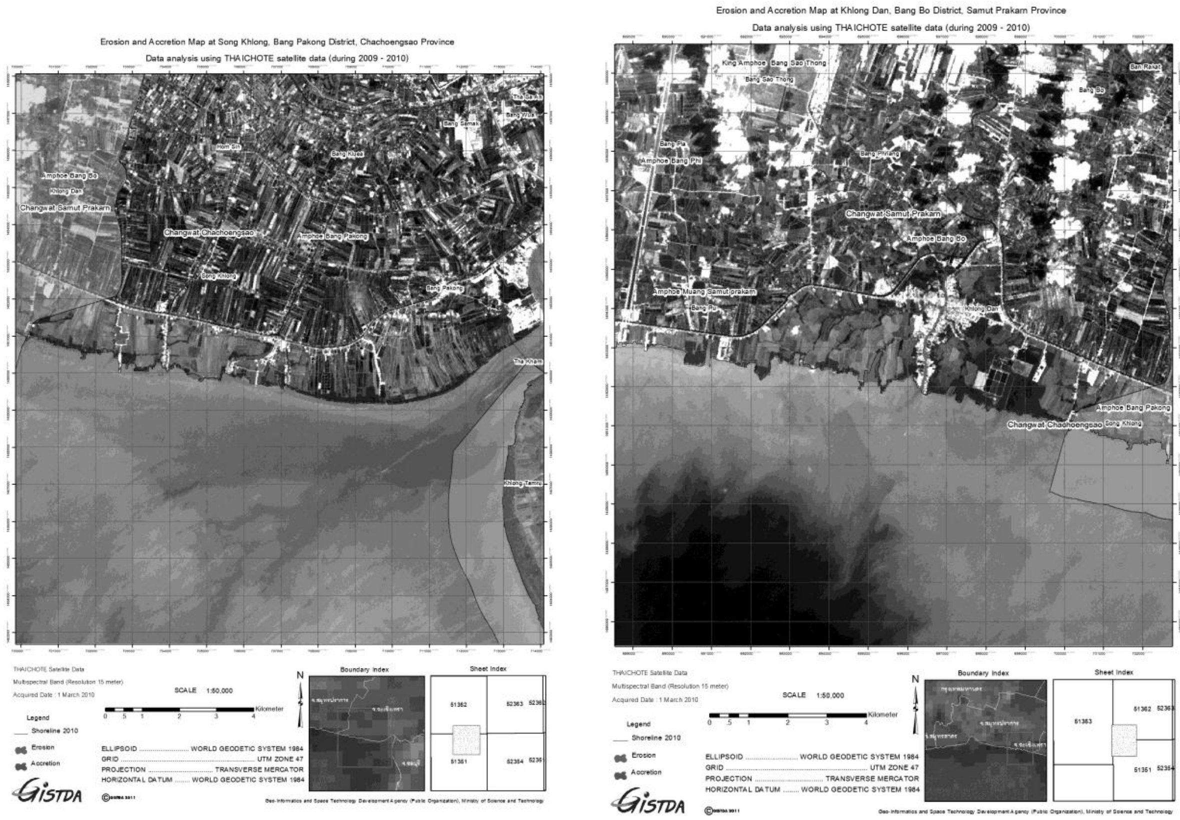

Figure 7: Erosion and accretion map at Chacheangsao Province (left) and Samutprakarn Province (right) analyzed using THAICHOTE 2009–2010

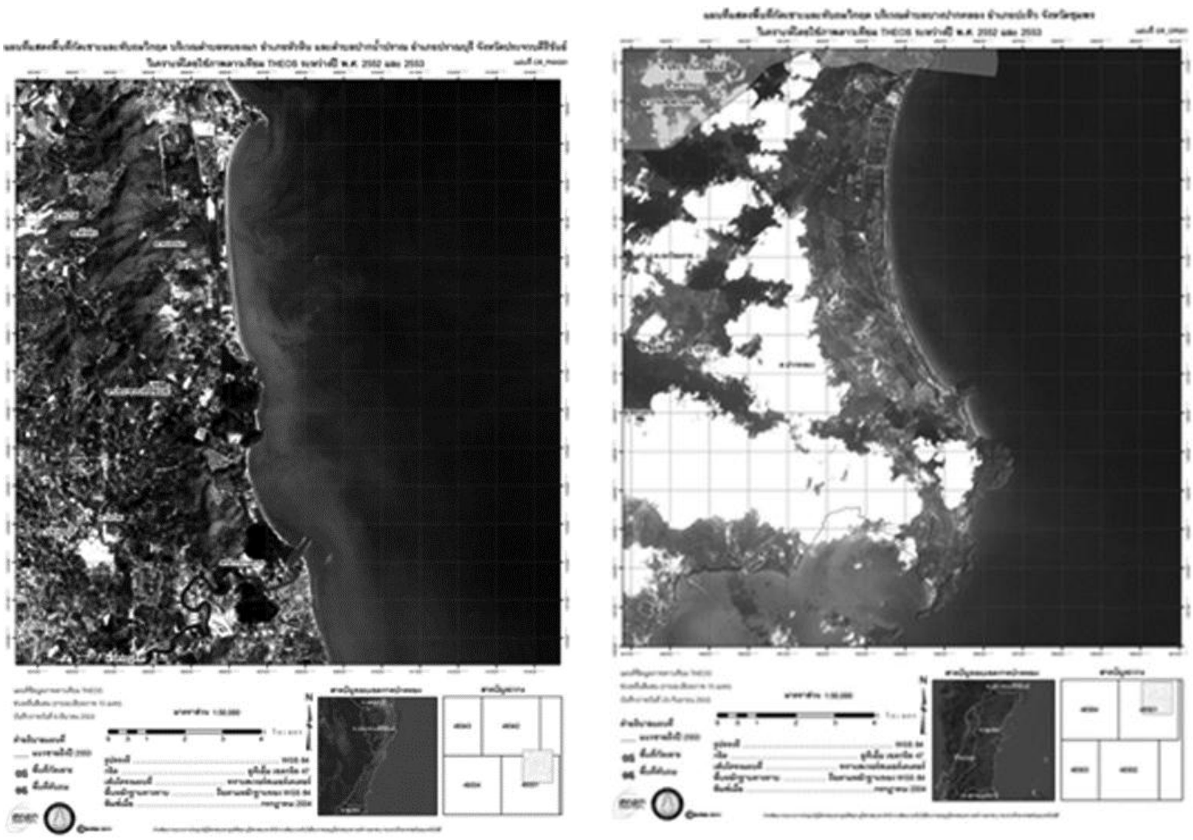

Figure 8: Erosion and accretion map at Prachaubkirikhan Province (left) and Chumporn Province (right) analyzed using THAICHOTE 2009–2010

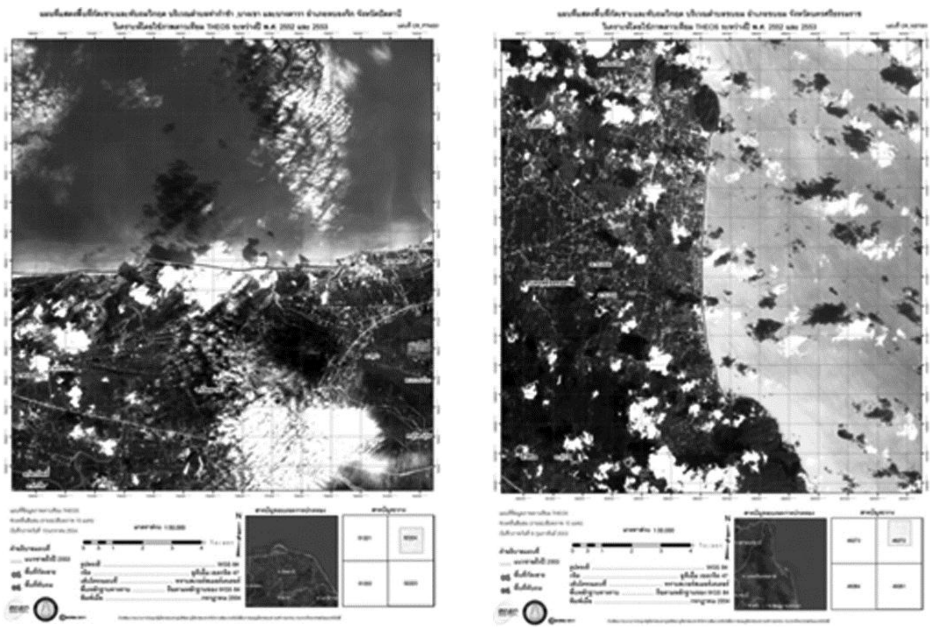

Figure 9: Erosion and accretion map at Pattani Province (left) and Nakhonsithammarat Province (right) analyzed using THAICHOTE 2009–2010

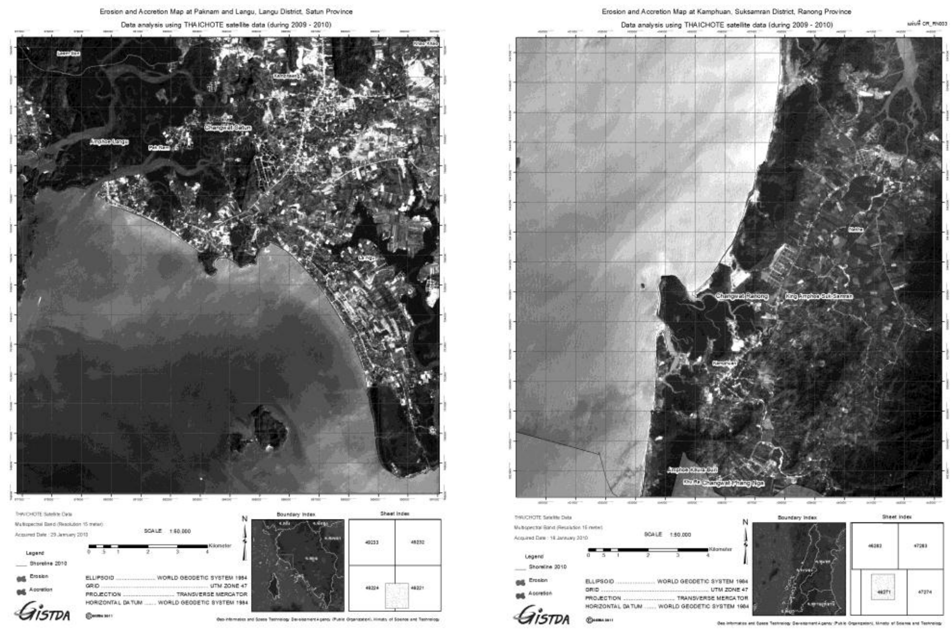

Figure 10: Erosion and accretion map at Satun Province (left) and Ranong Province (right) analyzed using THAICHOTE 2009–2010

3.4 GISTDA Coastal Model (GCOS)

A system of online mapping services (Web Map Service: WMS) was developed, which can be displayed as shown in Fig. 11. This online map has a search engine and the ability to display statistical information (Geo-statistic).

The system consists of four parts, the display map, control map, charting, and display statistics. Details are as follows.

1. *Display map* shows the shoreline, erosion and accretion area, erosion and accretion rate, and pictures from the field survey. These layers are superimposed. The properties of a layer must be in the form of POSTGIS, which could be a shape file or geo-tiff (aerial photographs).

2. *Control map* is a standard GIS Mapping tool that controls the map in terms of zoom out, zoom in, and moving the image.

3. *Chart* includes the results of the statistical analysis of data with bar graphs and line graphs, such as the display of coastal erosion in the study area over a given time and space to analyze the changing area.

4. *Statistic map* is statistical maps showing the frequency of each subject and automatically determines the range and frequency for each color.

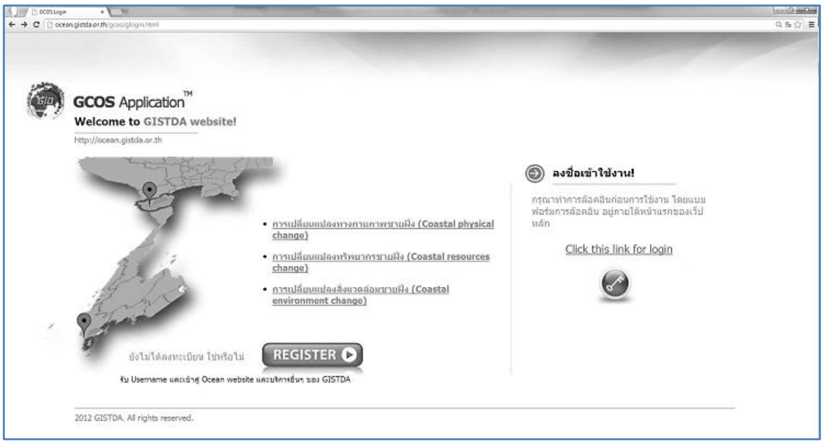

Figure 11: GISTDA website for the Thai coastal area (http://ocean.gistda.or.th/)

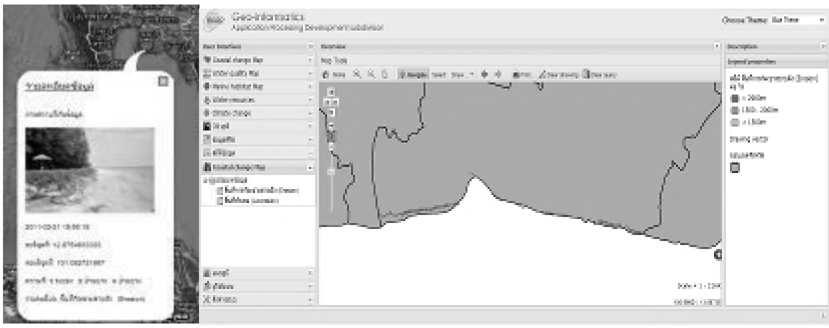

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Figure 12: GISTDA Coastal Model (GCOS)

Conclusion

Coastal areas in Thailand, currently covering 23 provinces, have been adopted for land uses including agriculture, forest and mangrove, residential, industrial, tourism, and ports, among others. The characteristics of land use change due to the development or expansion of existing infrastructure has resulted in imbalances in the coastal area. Furthermore, the influence of tides, waves, and seasonally changing winds results in some coastal areas experiencing large coastal land losses.

Investigation of coastal zone change in Thailand using LANDSAT images taken during 1999–2010 analyzed erosion and accretion rates at a 100-m interval along the coast. Twenty-three provinces were included in the study, which found the highest erosion rates in Samutprakan, Samutsakorn, and Bangkok provinces, with land loss rates of 15.92 m/yr, 9.94 m/yr, and 8.48 m/yr, respectively, and the highest accretion rates in Samutprakarn, Bangkok, and Nakornsrithamarat provinces, with land expansion rates of 22.56 m/yr, 14.26 m/yr, and 12.88 m/yr, respectively.

The limitations of LANDSAT images, which provide a resolution of 30 m per pixel level, make them appropriate for studying the overall picture. For more detailed study, such as that in the critical areas, THAICHOTE images (pan-sharpened) taken during 2009–2010, with a resolution of 2 m per pixel, were used. Findings from the study show that the most eroded areas were, in order, the 1) lower west side of the Gulf of Thailand, 2) upper east side of the Gulf of Thailand, 3) Andaman Sea side, 4) upper west side of the Gulf of Thailand, and 5) inner side of the Gulf of Thailand, with average areas of 0.11 km^2 (68.84 rai), 0.10 km^2 (60.87 rai), 0.09 km^2 (53.11 rai), 0.05 km^2 (28.73 rai), and 0.04 km^2 (25.05 rai), respectively. The greatest accreted areas were 1) upper West side of the Gulf of Thailand, 2) the Andaman Sea side, 3) inner side of the Gulf of Thailand, 4) lower West side of the Gulf of Thailand and 5) upper East side of the

Gulf of Thailand with average area of 0.03 km^2 (21.47 rai), 0.02 km^2 (10.50 rai), 0.01 km^2 (8.11 rai), 0.01 km^2 (7.12 rai), and 0.01 km^2 (6.36 rai) respectively.

The analysis of changing land in the coastal areas of Thailand found that change in both land use and type poses a risk of change in many sensitive areas, such as mangroves, mudflats, beaches, and lakes; such areas have typically been used to support activities such as aquaculture, housing, industry, tourism, transport, and energy.

Analysis of coastal land use during 2009–2010 using THAICHOTE images showed that, in 2010, the coastal land was used primarily for agricultural land; this land use type covered 12,597.44 km^2 (7,873,391.34 rai), increasing from 12,401.81 km^2 (7,751,124.76 rai) in 2009. The next most abundant land use types were urban and buildings, bare land (not exploited for human use), aquaculture, and salt flat. In contrast, the mangrove, forest, and water areas were reduced. These results demonstrate that land use activities, rather than natural factors, were the dominant cause of the tremendous increase in coastal erosion along the Thai coast.

Table 1. Coastal land use classification in Thailand from THAICHOTE 2010

Land use	Area		
	Km²	rai	percent
Agriculture	12,597.44	7,873,391.34	36.19
Urban and Built-up area	4,931.55	3,082,229.55	14.17
Bare Land	3,803.38	2,377,109.38	10.93
Aquaculture and Salt Flat	3,537.43	2,210,893.86	10.16
Mangrove	2,819.81	1,762,394.51	8.10
Cloud	2,706.534	1,691,580.52	7.78
Forest	1,981.51	1,238,443.33	5.69
Water	1,363.37	852,111.9	3.92
Shadow	1,069.44	668,384.79	3.07

Another very important factor arising from human activities were natural factors such as the severity of the wind waves and circulation of the monsoons affecting positive change in the coastal areas.

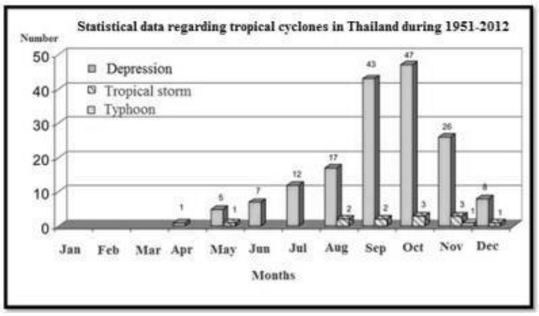
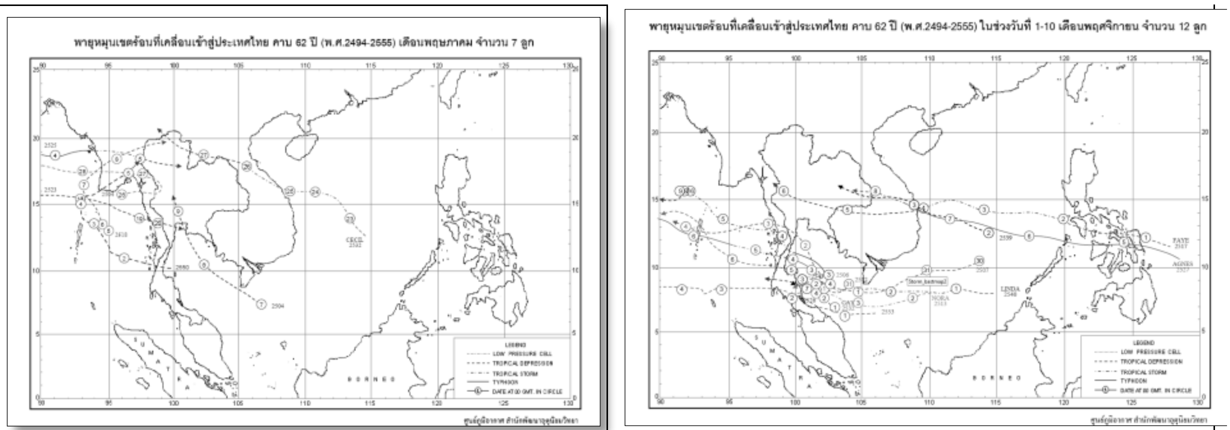


Figure 13: Statistical data regarding tropical cyclones in Thailand during 1951–2012 [1]



Passages of tropical cyclones into Thailand each May during 1952–2012, including 7 cyclones	Passages of tropical cyclones into Thailand each November during 1952–2012, including 12 cyclones

Figure 14: Passages of tropical cyclones into Thailand during the southwest (left) and northeast (right) monsoons

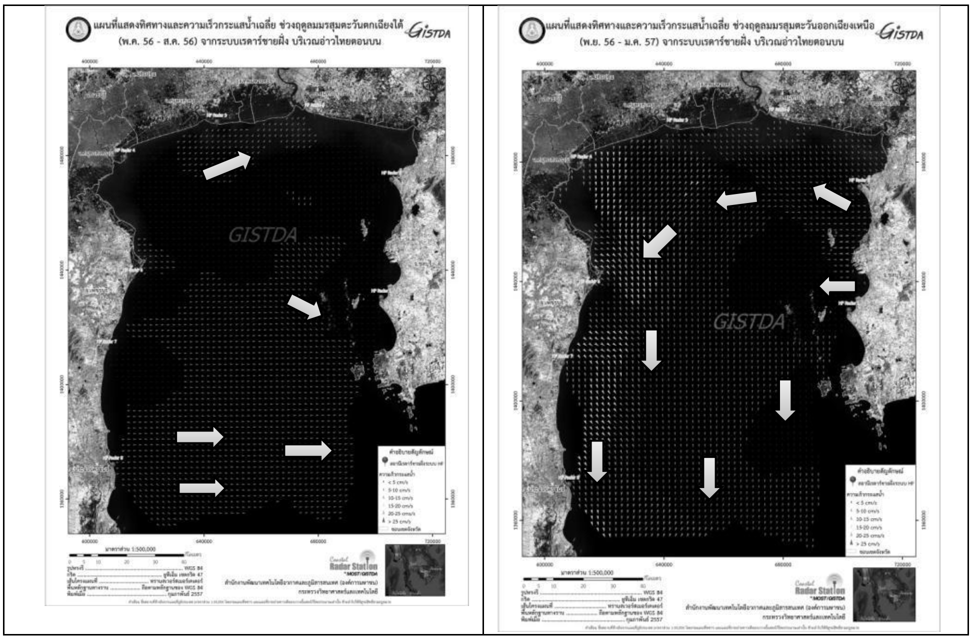


Figure 15: Seasonal circulation pattern in the upper Gulf of Thailand during the southwest (left) and northeast (right) monsoons

It can be seen that the efficiency and sustainability of coastal zone management is dependent upon the integration of technical data, advance information, and data continuity. Therefore, the preparation of a spatial database that is continuously updated every year can serve as a basis for making decisions. This is also more efficient than using point data collected at any one time. It is hoped that this research will provide guidelines for the agencies involved in the management of coastal areas to support data gathering for the development of efficient management plans for such coastal areas in future.

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